Climate Smart Agriculture (CSA) Training Guide

By

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Training Guide overview

Introduction

Agriculture, as the backbone of the Ethiopian economy, contributes roughly 40% of GDP, more than 75% of employment, and 80% of foreign exchange earnings (FAO 2021). Ethiopian agriculture is heavily reliant on natural rainfall, with irrigation used on only about 5% of total cultivated land (USAID 2021). As a result, the sector is highly vulnerable to climate change. Climate change endangers the country's agriculture development, natural resources, biodiversity conservation, and government poverty-reduction efforts. Climate change-related impacts such as food insecurity, malnutrition, poverty, biodiversity loss, and loss of livelihood are deeply intertwined and continue to be the country's primary development challenges. In 2021/2022, climate change has caused Ethiopia to suffer one of its worst droughts that has ravaged vast parts of the country. The drought has ravaged livestock and wildlife resources. Future prediction suggest that Ethiopia will continue to suffer from climate change related problems. Thus action is needed to address problem.

Since 1960, average temperatures in Ethiopia have risen by 1°C at a rate of 0.25°C per decade (WB 2022). Over the last three decades, overall precipitation has been decline with significant year-to-year volatility. Extreme events such as droughts and floods have also become more common, in addition to rainfall variability and rising temperatures, all of which have a negative impact on the agricultural sector. According to the IPCC's Fifth Assessment Report (IPCC 2014), in the country, the average annual temperature is expected to rise by 0.9 to 1.1°C by the 2030s, 1.7°C to 2.1°C by the 2050s, and 2.73 to 4°C by the 2080s (CRGE, 2011). Climate models predict that climate change-related hazards will reduce agricultural productivity by 50% by 2080 (Cline, 2007). With the rising number of food insecure Ethiopians, combined with the current effects of climate change on agriculture as well as rising trends of livelihood vulnerability to climate variability and change, strongly suggest that the country will be unable to feed its growing population by 2080. Therefore, building climate resilient agricultural sector is required.

Agriculture, on the other hand, accounts for a significant portion of the country's greenhouse gas emissions (approximately 55%). (FDRE MoFECC 2015). To address the strong and bidirectional interdependence between climate change and agriculture, the agricultural sector must undergo climate-smart transformation. Climate-smart agriculture (CSA) is an integrative approach that addresses the interconnected challenges of food security and climate change by increasing agricultural productivity in a sustainable manner to support equitable increases in farm incomes, food security, and development. It also aids in the adaptation and resilience of agricultural and food security systems to climate change on multiple levels, as well as the reduction of greenhouse gas emissions. In this regard, there is an urgent need for appropriate and effective training on CSA to build a climate resilient agricultural sector.

What is climate-smart agriculture?

The CSA concept was launched by FAO at the Hague Conference on Agriculture, Food Security and Climate Change in 2010, contributes to the achievement of sustainable development goals.in 2010 (FAO, 2010). It is a holistic agricultural production and management system that adapts to climate change, mitigates environmental impacts, and ensures food security for the world's growing population. It is a new approach to creating the technical, political, and financial conditions for achieving sustainable development goals. Climate smart agriculture is built on three pillars, namely,

- Increasing agricultural productivity and incomes in a sustainable manner;
- Adapting and building resilience to climate change; and
- Reducing and/or removing greenhouse gases emissions, where possible.

Why CSA training?

Ethiopia is Africa's second most populous country, with a population of more than 120 million people (FAO 2021). Its population is expected to reach 190.8 million by 2050, requiring agricultural production to increase by at least 60%. Climate change, combined with rising population and food demand, is one of the most pressing issues of the twenty-first century. Maintaining agricultural production at a level that can meet food demand in changing climates remains a constant challenge, especially as food security has been increasingly disrupted by extreme weather events over the last few decades. Ethiopia, as an agrarian economy that relies heavily on domestic food production, is severely impacted by climate change. Agriculture is not only a victim of climate change, but it is also a major contributor to it due to GHG emissions. One of the major challenges is to adapt agriculture to changing climates at a level that ensures food security while reducing emissions from the sectors. Thus, CSA training is required to meet the growing challenges of food security in changing climates.

Objectives of training

The goal of this training is to provide trainers with knowledge and skills on the use of CSA technologies, innovations, and management practices to improve agricultural productivity and resilience.

The specific training objectives include -

- Understand the basic concept of climate change;
- Identify major causes of climate change and its impact on Agriculture and food security;
- Describe the different principles and practices of Climate Smart Agriculture:
- Apply and promote climate smart agriculture best practices, new technologies, and innovations;
- Provide the trainees with relevant attitude, knowledge and skills for implementing CSA technologies, innovations and practices;

Structure and content of the training

The training course is organized into ten chapters and systematically cover the importance, dimensions, management, barriers, mainstreaming, and policies of CSA.

- **Chapter 1: Basics to Climate: In this chapter**, the definition of climate, weather, climate change, components and roles of Earth's Climate System, and both natural and anthropogenic causes of climate change is briefed.

- **Chapter 2: Climate variability and change:** In this chapter, key concepts of the climate science such as atmosphere, weather, climate, climate variability and climate change, global warming, greenhouse gases and natural and anthropogenic drivers of climate change and variability, observed and projected changes in the climate since the industrial revolution and its impact are discussed.

- **Chapter 3: Climate-smart agriculture:** This chapter covers the concepts, characteristics and role of CSA. This also includes identification and selection of CSA technologies and practices.

- **Chapter 4: Climate-smart crop production:** This chapter covers the relationship between crop production and climate change and explores principles, practices, technologies and practices of CSA Climate-smart crop management.

- **Chapter 5: Climate-smart livestock and fishery production:** This chapter discuss the role, technologies and practices of livestock and fishery production in climate-smart agriculture.

- **Chapter 6: Climate-smart** natural resource management**:** This chapter focuses on CSA natural resource management and its critical role in climate-smart agriculture, and discuss possible natural resource management options for adaptation to climate change and for climate change mitigation.

- **Chapter 7: Socio-Economic and Gender Perspectives in CSA:** This chapter focuses on concepts and principles of socio-economic and gender perspectives in CSA.

- **Chapter 8: Agricultural Extension and Knowledge management towards CSA**: This chapter of the training provide learners with an insight into CSA issues from extension perspectives specifically deals with the role of extension services towards the adoption of CSA.

- **Chapter 9: Policies, Strategies and Institutions in CSA:** This chapter of the training covers existing policies, strategies and institutions that needs to be considered in planning, implementation and monitoring of CSA.

- **Chapter 10: Climate-smart agriculture solutions for Ethiopian Agriculture:** This chapter supported by examples or more elaborative case studies on CSA best practice, new technology and innovation from the Ethiopian Agricultural systems.

Chapter One: Basics to Climate

Session I: Chapter overview

This chapter provides fundamental knowledge on different scale spatio-temporal characteristics of climate and weather, as well as the drivers of climate variability and change, and an overview of the impacts of climate variability and change on various sectors (e.g., agriculture, hydropower, water, and so on) and society.

Chapter objectives:

By the end of the chapter, the trainee should be able to:

- Define key concepts of climate terms (e.g. temperature, precipitation, wind, humidity solar radition, cloud cover, atmospheric pressure, sea surface temperature, weather, climate, climate vatiability, climate change, etc).
- Discuss the difference between weather and climate
- Describe the climate system and its components
- Discuss the role of climate components and their interaction with respect to climate variation and change
- Discuss ground-based instruments to ships, buoys, ocean profilers, balloons, aircraft, satellite-borne sensors, etc.) how to Improved understanding and systematic monitoring of Earth's climate.
- Describe types and formats of observational data
- Define climate model
- Assessing capabilities in Global Climate Modelling
- Discuss main featurs of general atmospheric circulation
- Describe the vertical structure of Earth's atmosphere
- Describe the differential heating Earth experiences, and how heat is redistributed
- Diagram vertical atmospheric circulations (Hadley cell, Ferrel cell, Polar cell) and surface wind directions (trade winds, belt of westerlies, etc.)
- Discuss the distribution of heat over Earth's surface and how it drives global circulation, including its connection to the Coriolis force.
- Describe the main features of Ethiopian climate and associated mechanisms

Session II: Concepts and definitions of key terms

This section helps to identify main concepts of climate:

Precipitable water: The total amount of atmospheric water vapour in a vertical column of unit cross-sectional area. It is commonly expressed in terms of the height of the water if completely condensed and collected in a vessel of the same unit cross section.

Precipitation: is the term used to describe the water that clouds drop as rain, freezing rain, sleet, snow, or hail. It is the key link in the water cycle that ensures atmospheric water is delivered to the Earth.

Weather: is the state of the atmosphere at a given time and place in terms of important atmospheric variables such as temperature, precipitation/rain, humidity, air pressure, cloudiness, sunshine, fog, snow, blizzards, wind and thunder storms, tropical cyclones, and so on.

The term weather is generally limited to conditions over short periods of time (two weeks or less) and includes whatever is happening outdoors at a given location and time can change a lot within a very short time, which is what we learn about on TV/Radio and other news sources on a daily basis. Climate is the statistics of weather at any place over some specific, usually long, period of time.

Climate: Climate in a narrow sense is usually defined as the average weather, or more rigorously as the statistical description in terms of the mean and variability of relevant quantities over a period of time ranging from months to thousands or millions of years. The classical period for averaging these variables is 30 years, as defined by the World Meteorological Organization (WMO). The relevant quantities are most often surface variables such as temperature, precipitation and wind. Climate in a wider sense is the state, including a statistical description, of the climate system (IPCC, 2022).

Climate also describes the variability of weather events, e.g. the probability of a major rainfall event occurring in July in Addis Ababa, or variations in temperature that typically occur in January in Haramaya.

Weather and climate have a profound influence on life on Earth. They are part of the daily experience of human beings and are essential for health, food production and well-being.

Climatology: is the study of climate variability/change and the behavior of the atmosphere-the thin gaseous layer surrounding the earth's surface-as it has evolved over time, as well as the workings of the climate system, its variations and extremes, and their effects on a wide range of activities, including, but not limited to, agriculture, water resources, hydropower, human health, safety, and welfare.

Climate variability: Climate variability refers to variations in the average state of the climate, on all temporal and spatial scales, that exceed the typical scales of weather events (e.g. intra-seasonal, inter-annual and inter-decadal). Climate variability may be natural or anthropogenic. In general, climatic variability is connected with variations in the state of the atmospheric and ocean circulation and land surface properties (e.g. soil moisture) at the intra-seasonal to inter-decadal timescales.

Climate change: Climate change, in contrast, refers to a systematic change in the statistical properties of climate (e.g. mean and variance) over a prolonged period (e.g. decades to centuries) as manifested in an upward or downward trend in, for example, extreme rainfall values. For most of the Earth's climate history, systematic changes of climate have occurred because of natural causes such as variations in the nature of the Earth's orbit around the sun or solar output and the changing relationship between the "natural" components that make up the climate system. However, there is now mounting evidence that humans and their activities constitute an important component of the climate system.

Atmosphere: The gaseous envelope surrounding the Earth, divided into five layers – the troposphere which contains half of the Earth's atmosphere, the stratosphere, the mesosphere, the thermosphere and the exosphere, which is the outer limit of the atmosphere. The dry atmosphere consists almost entirely of nitrogen (78.1% volume mixing ratio) and oxygen (20.9% volume mixing ratio), together with a number of trace gases, such as argon (0.93% volume mixing ratio), helium and radiatively active greenhouse gases (GHGs) such as carbon dioxide (CO_2) (0.04% volume mixing ratio), methane (CH_4), nitrous oxide (N_2O) and ozone (O_3). In addition, the atmosphere contains the GHG water vapour (H_2O), whose concentrations are highly variable (0–5% volume mixing ratio) as the sources (evapotranspiration) and sinks (precipitation) of water vapour show large spatio-temporal variations, and atmospheric temperature exerts a strong constraint on the amount of water vapour an air parcel can hold. The atmosphere also contains clouds and aerosols (IPCC, 2022).

Climate system: The climate system is the highly complex system consisting of five major components: the atmosphere, the hydrosphere, the cryosphere, the lithosphere and the biosphere, and the interactions between them. The climate system evolves in time under the influence of its own internal dynamics and because of external forcings such as volcanic eruptions, solar variations and anthropogenic forcings such as the changing composition of the atmosphere and land use change.

Solar radiation/cloud cover: The existence of nearly all life on Earth is fueled by light from the Sun. Most plants use the energy of sunlight, combined with carbon dioxide and water through the process of photosynthesis, to grow. Animals, including humans, consume plants and other animals to survive and grow. Humans further use fossil fuels, the remnants of ancient plant and animal matter formed using solar energy, to support various activities.

Solar radiation is also the source of energy for movements within the climate system such as winds and ocean currents.

The amount of solar radiation that is received in a given location will depend mostly on the length of the day and cloud cover. The latter have different effects on the amount of energy received locally, details beyond the scope of this course. Solar radiation received in a given location can be measured in different ways: (i) *solar irradiance* – a direct measure of the instant energy received per unit of surface, in kW/m2, it can further be transformed into insolation i.e. energy received over a period of time; (ii) number of hours of sunshine, which is then transformed in solar energy received in a day; (iii) estimate of cloud cover, allowing estimation of total insolation in a day.

Winds are an important component of the climate system because they move different types of air masses (temperature, humidity). They have the ability to bring moist or dry air into a region, as well as blow away humid air generated locally through evaporation and evapotranspiration. It is not uncommon for the onset of the rainy season to be preceded by a change in prevailing winds, and the new winds carry moisture from surrounding oceanic or rainforest areas, fueling rainfall. The end of the rainy season frequently corresponds to the new winds no longer delivering moisture to the area. Wind is also significant in estimating plant evapotranspiration.

Atmospheric pressure:- The force or weight of the overlying air per unit area on the surface is measured as atmospheric pressure. Winds can be influenced by changes in atmospheric pressure, typically blowing from areas of higher pressure to areas of lower pressure in the tropics. With a few exceptions, lower atmospheric pressure typically occurs over locations experiencing warmer temperatures than their surroundings, while high pressure frequently occurs over cooler areas. Warmer air in low pressure zones rises, and if it contains enough humidity, the rising motion may result in rainfall because humid air cools at higher altitudes and cannot carry the same quantity of water vapor.

In high pressure locations, air frequently descends and is relatively dry because it originates from upper, cooler atmospheric layers with less moisture. Deserts, on the other hand, are an exception to this rule since greater pressures typically overlay heated surfaces. This is related to moist activities in the air, as well as general circulation patterns and the temperature diurnal cycle.

Session III: History of climate and the Earth System

History of climate

Humans have pondered their place in the universe since time immemorial. Early on, people believed that the earth was flat and at the center of the universe, and that all celestial bodies visible above and around them revolved around it. This geocentric viewpoint dominated human history for a long time, and was even supported by Aristotle in 320 B.C. and Ptolemy in the second century A.D. It wasn't until 1514 A.D. that a Polish priest named Copernicus challenged the Aristotle-Ptolemic theory and changed the earth's proud central position to one in which it revolved around the sun like any other planet in the solar system. Copernicus' heliocentric theory was strongly supported by the work of astronomers Johannes Kepler (1571-1630) in Germany and Galileo Galilei (1564-1642) in Italy. Kepler enunciated his celebrated three laws of planetary motion in 1609, based on the careful astronomical measurements of his predecessor, Tycho Brahe:

i. The planets revolve round the sun in elliptical orbits with the sun occupying one focus;
ii. The orbital velocity of a planet sweeps out equal areas in equal times; and
iii. The squares of the periods of revolution of the planets are proportional to the cubes of their orbital major axes.

Descriptions of the Earth's climates and the conditions that cause them began to emerge with the advent of extensive geographical exploration in the fifteenth century. The invention of meteorological instruments such as the thermometer by Galileo Galilei in 1593 and the barometer by Evangelista Torricelli in 1643 provided a greater impetus to the development of mathematical and physical relationships between the various characteristics of the atmosphere. This, in turn, led to the development of relationships that could describe the state of the climate at various times and locations.

George Hadley first interpreted the observed pattern of circulation linking the tropics and subtropics, including trade winds, tropical convection, and subtropical deserts, in 1735, and it later became known as the Hadley cell. Julius von Hann, who published the first of three volumes of the Handbook of Climatology in 1883, wrote the classic work on general and regional climatology, which included weather and climate data and eyewitness descriptions. Wladimir Köppen published the first detailed classification of world climates based on vegetative cover of land in 1918.

More detailed developments in descriptive climatology followed this endeavor. For example, geographer E.E. Federov (1927) attempted to describe local climates using daily weather observations. The diligent and combined use of global observations and mathematical theory to describe the atmosphere in the first thirty years of the twentieth century resulted in the identification of large-scale atmospheric patterns. Sir Gilbert Walker was a pioneer in this field, conducting detailed studies of the Indian monsoon, the Southern Oscillation, the North Atlantic Oscillation, and the North Pacific Oscillation.

Tor Bergeron (on dynamic climatology, published in 1930) and Wladimir Köppen and Rudolf Geiger, who produced a climatology handbook in 1936, were two other major works on climatology. Geiger described the concept of microclimatology in some detail in 1927, but the field did not develop until the Second World War. During the war, a probability risk concept of weather data for months or even years ahead was discovered to be necessary and tried for planning purposes. In 1948, C.W. Thornthwaite developed a climate classification based on a water budget and evapotranspiration. The development of climatology theories made significant progress in the following decades. The International Meteorological Organization (IMO) Conference of Directors met in Copenhagen in September 1929 and agreed to establish a technical commission for climatology "for the study of all questions relating to this branch of science." The establishment of WMO in 1950 (as the successor to IMO, which was founded in 1873) established a data collection system that led to systematic climate analysis and conclusions about the nature of climate. The issue of climate change drew attention to the need to understand climate as a major component of a global system of interacting processes involving all of the Earth's major domains in the latter decades of the twentieth century.

The Climate System

The climate system, is an interactive system consisting of five major components: the atmosphere, the hydrosphere, the cryosphere, the land surface and the biosphere, forced or influenced by various external forcing mechanisms, the most important of which is the Sun. Also the direct effect of human activities on the climate system is considered an external forcing. The climate system is constantly changing as a result of interactions among its components, as well as external factors such as volcanic eruptions or solar variations, and human-induced factors such as changes in the atmosphere and changes in land use. These components interact on various spatial and temporal scales through the exchanges of heat, momentum, radiation, water and other materials.

Session IV: The Components of Earth's Climate System and their role and interactions

1. The Components of Earth's Climate System

The climate system (Figure 1) is a complex, interactive system consisting of the atmosphere, land surface, snow and ice, oceans and other bodies of water, and living organisms.

- ✓ **Atmosphere:** The Earth's atmosphere is the gaseous envelope that surrounds it. The dry atmosphere is almost entirely composed of nitrogen and oxygen, but it also contains trace amounts of argon, helium, carbon dioxide, ozone, methane, and numerous other trace gases. Water vapour, condensed water droplets in the form of clouds, and aerosols are also present in the atmosphere.
- ✓ **Hydrosphere:** The hydrosphere is the component of the Earth's climate system that consists of liquid water distributed on and beneath the Earth's surface in oceans, seas, rivers, freshwater lakes, wetlands, underground reservoirs, and other bodies of water.
- ✓ **Cryosphere:** The components of the Earth system at and below the land and ocean surface that are frozen, including snow cover, glaciers, ice sheets, ice shelves, icebergs, sea ice, lake ice, river ice, permafrost and seasonally frozen ground.
- ✓ **Biosphere (terrestrial and marine):** The part of the Earth system comprising all ecosystems and living organisms, in the atmosphere, on land (terrestrial biosphere) or in the oceans (marine biosphere), including derived dead organic matter, such as litter, soil organic matter and oceanic detritus. **Biodiversity:** Biodiversity or biological diversity means the variability among living organisms from all sources including, among other things, terrestrial, marine and other aquatic ecosystems, and the ecological complexes of which they are part; this includes diversity within species, between species, and of ecosystems (UN, 1992).
- ✓ **Geosphere/Lithosphere:** The upper layer of the solid Earth, both continental and oceanic floor, which comprises all crustal rocks and the cold, mainly elastic part of the uppermost mantle.

Volcanic activity, although part of the lithosphere, is not considered as part of the climate system, but acts as an external forcing factor.

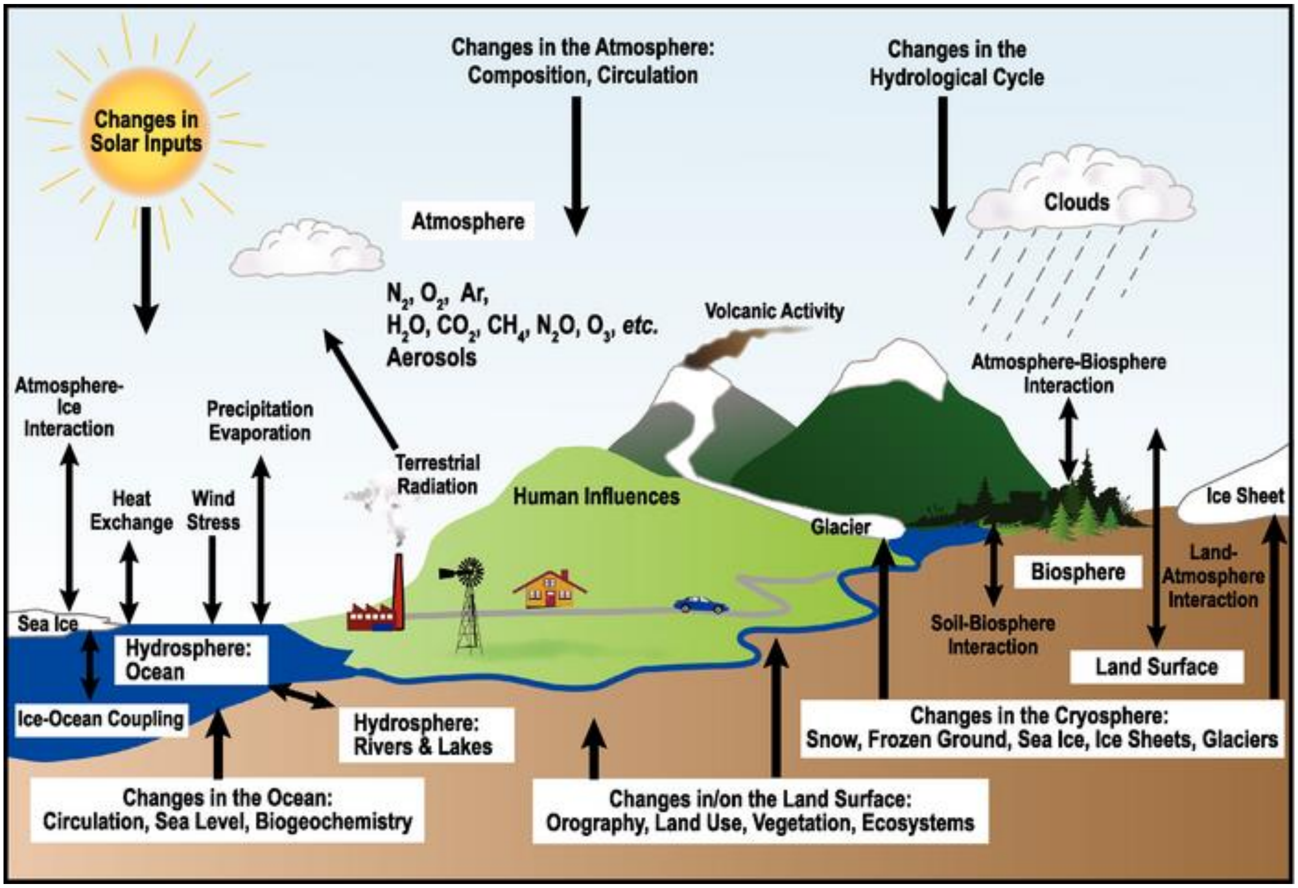

Figure 1. Climate system components interaction.

2. **Roles and Interactions among the climate components**

Material and energy moves between these reservoirs or components. On a wide range of space and time scales, many physical, chemical, and biological interaction processes occur among the various components of the climate system, making the system extremely complex. Although the components of the climate system differ greatly in composition, physical and chemical properties, structure, and behavior, they are all linked by mass, heat, and momentum fluxes: all subsystems are open and interconnected.

The Earth's climate is determined by interactions among the components of the climate system, which are influenced by solar radiation and the radiative properties of the Earth's surface. The interaction of the atmosphere with the other components is crucial in the formation of the climate. Energy is obtained by the atmosphere either directly from incident solar radiation or indirectly through processes involving the Earth's surface.

This energy is constantly redistributed vertically and horizontally via thermodynamic processes or large-scale motions, with the unattainable goal of achieving a stable and balanced system state. Water vapour is important in the vertical redistribution of heat via condensation and latent heat transport. With its vast heat capacity, the ocean slows the rate of temperature change in the atmosphere while also supplying it with water vapour and heat. Oceanic currents are affected by the distribution of continents, and mountains redirect atmospheric motions. Solar radiation is reflected back into space by polar, mountain, and sea ice. Sea ice acts as an insulator in high latitudes, protecting the ocean from rapid energy loss to the much colder atmosphere.

The biosphere, including human activities, influences atmospheric components like carbon dioxide as well as Earth's surface features like soil moisture and albedo. Interactions between components occur at all scales (Figure 1). The micro-scale encompasses climate characteristics over small geographic areas such as individual buildings, plants, or fields. When the physical characteristics of an area change, a change in microclimate can be very important. New buildings may produce extra windiness, reduced ventilation, excessive runoff of rainwater, and increased pollution and heat. Natural variations in microclimate, such as those related to shelter and exposure, sunshine and shade, are also important: they can determine, for example, which plants will prosper in a particular location or the need to provide for safe operational work and leisure activities.

The mesoscale encompasses the climate of a region of limited extent, such as a river catchment area, valley, conurbation or forest. Mesoscale variations are important in applications including land use, irrigation and damming, the location of natural energy facilities, and resort location. The macroscale encompasses the climate of large geographical areas, continents and the globe. It determines national resources and constraints in agricultural production and water management, and is thus linked to the nature and scope of human health and welfare. It also defines and determines the impact of major features of the global circulation such as the El Niño/Southern Oscillation (ENSO), the monsoons and the North Atlantic Oscillation.

The Climate System is described using science

The climate system is described by an equation system consisting of fluid dynamics, radiation transfer, turbulence, dry/moist convection... , and the interactions among components. Current climate models are collections of our understandings of the climate system. Building simpler approximation systems by selecting important processes and reducing spatiotemporal dimensions has helped to elucidate the essence of the climate system.

Session IV: The Components of Earth's Climate System and their role and interactions

1. Observing and modeling the Climate

1.1. Observations

Local and national climate data generation is typically the responsibility of a country's national meteorological service (NMS). The Ethiopian Meteorological Institute (EMI) is in charge of generating weather and climate data as well as issuing forecasts and warnings. Data generation necessitates a functional, well-maintained, and well-distributed network of stations, as well as the ability to store, analyze, and model future conditions. A country's adaptive capacity, as well as its capacity to manage water resources, food security, and disaster risks, can all benefit from strong climate data, information, and analytical capacity. More and more data can also be accessed on line and it is important to understand the advantages and limitations of each type of data, and select data and information that is the best compromise between intended use and ease of access.

1.2. Historical and Current Data

Station data[1]

Station data capture local conditions best as they are in situ (“in position”) measurements (Figure 2) of meteorological variables. Station data, or information based on such data, can be obtained from the Ethiopian Meteorological Institute (EMI) but is not always free of charge. Furthermore, in most African countries, the spatial (and often temporal) coverage (Figure 3) of such data may be insufficient to capture local details important for adaptation projects. The data quality may also vary, and quality checks are always required. Additional information may have been gathered by businesses, farmers' associations, agricultural extension services, and academic institutions but may not have been included in the main database. A subset of station data is available on line through the Global

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[1] Station data are exact measurements in a given location, mostly at the surface of the Earth, although radar and stationary balloons also record information about the atmosphere above.

Telecommunication System (GTS) but the completeness of that data and their spatial and temporal coverage are usually less extensive than the data archived at the NMS/EMI.

Figure 2 Weather Station

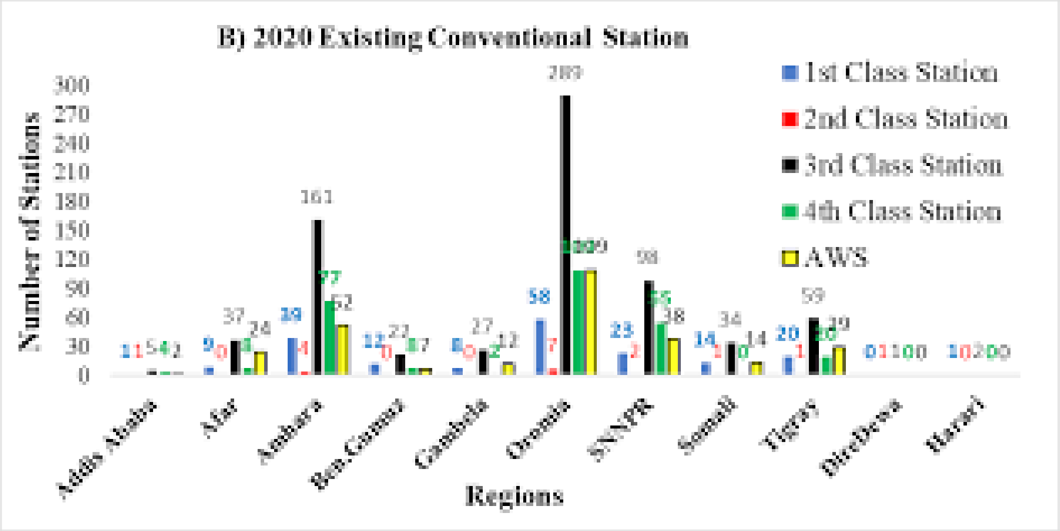

Figure 3 Number of existing Meteorological stations (2020)

Satellite data

Satellites (Figure 4) have been recording some meteorological variables at high spatial and temporal resolution since the early 1980s, and these archives are now long enough for climatic analyses. Satellite-based rainfall and temperature estimates are available online in various data repositories and have continuous spatial coverage in the form of a grid of values. They are typically global in scope. However, because those data are based on indirect measurements (proxies) of rainfall amounts and temperature, they can present a skewed picture of the conditions on the ground. Satellite rainfall estimates, for example, are based on the temperature at the top of the clouds, which is then correlated to temperature and rainfall records from ground stations.

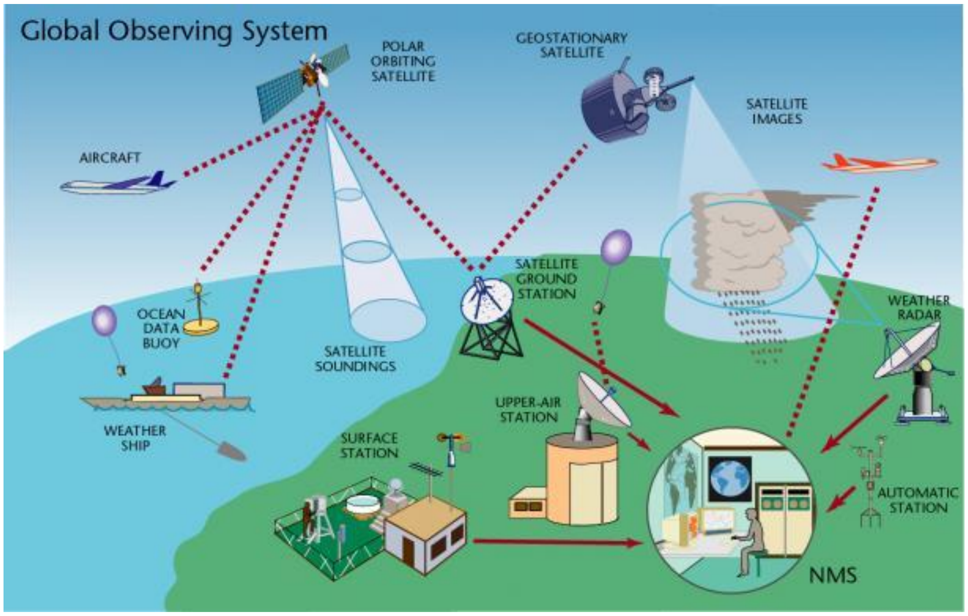

Figure 4 Global observing system

- CPC Morphing Technique (CMORPH) – a high spatial and temporal resolution dataset in real time. Only available since 2002.
- Tropical Rainfall Measurement Mission (TRMM) focuses on rainfall estimates in the Tropics and is available since 1998. There is however a delay of about a month in data availability and monthly aggregates are more accurate than higher temporal resolution products.

- Land Surface Temperature (LST) provides land-surface estimates for Africa and Latin America and is available since July 2002 for Africa.
- Climate Hazards Group InfraRed Precipitation With Station Data (CHIRPS): available since 1981.

In addition to meteorological variables, satellites also capture useful indicators such as vegetation cover with the Global Normalized Difference Vegetation Index (NDVI), available for 1981-2006 period and the TERRA-MODIS NDVI and Enhanced Vegetation Index (EVI) since 2000. More recently, soil moisture data have also become available. When using satellite rainfall data it is important to remember that precipitation estimates have different validity in different regions, and thus need to be validated with in-situ observations for local applications.

Gridded data[2]

Another class of data providing continuous spatial coverage are so called 'gridded data.' From a user's perspective they are similar to satellite data in that data are available on a regular grid and for a given period of time. Most of these datasets are based on in-situ (station) information interpolated to a regular grid. Some datasets merge in-situ observations with satellite records to compensate for biases in satellite data. The quality of these merged products depends on the quantity of the in-situ data incorporated. Gridded datasets are usually global in nature and their spatial resolution is variable. Among the gridded datasets are:

- Global Precipitation Climatology Project (GPCP), combined satellite and station data; this product is available since 1979 for monthly rainfall data and since 1996 for daily rainfall data, but has a low spatial resolution.
- Climate Prediction Center Merged Analysis of Precipitation (CMAP) is similar to GPCP and the differences mainly come from different algorithms used.

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[2] Grid data divides the Earth's surface into small squares and assigns a value to each square based on a weather/climate variable. The Earth's surface is thus uniformly covered with values, even where there is no observation. The method used to derive values in regions where there are no observations varies on the dataset and its details, and can range from a basic mean of closest observed values to more complex algorithms that consider, for example, elevation. The benefit of such datasets is that there are no blank spaces, which aids in a variety of studies. The majority of these datasets are likewise global. However, there are constraints on how well data in regions where there are no observations represents reality. Currently, the resolution of gridded datasets – the size of the squares – ranges between a few km^2 to a few hundreds of km^2.

- African Rainfall Estimate (RFE) combines satellite and station data for Africa. It has high spatial resolution and is available since 2001 but only with 10 day temporal resolution.
- Enhancing National Climate Service (ENACTS) program combines in situ observations retrieved from various Met Services with satellite data to provide a merged product with greater weight assigned to in-situ observations. The product is available since 1983 but on a country-by-country basis as data is provided by the countries themselves.
- Climate Hazards Group Infrared Precipitation with Stations (CHIRPS) is elaborated in a similar way but with less close collaboration with National Meteorological Services.
- Climate Research Unit (CRU), gridded dataset for rainfall and temperature based solely on station data; has relatively high spatial and temporal resolution.

Another class of gridded data is called 'reanalysis' data, which uses observations from sources at the surface and higher in the atmosphere (planes, radio soundings, etc.) to interpolate meteorological variables using physical models, ensuring stronger consistency between variables and values. It provides a wider array of meteorological variables, including atmospheric measurements above the surface. Reanalysis products are usually high-resolution and date further back in time than other data types. However, this method relies strongly on dynamical models and some variable types are more reliable than others; for example, wind and pressure are fairly accurately captured through reanalysis while rainfall data are often biased. It is most useful for researchers studying the causes of climatic phenomena rather than for direct applications in adaptation.

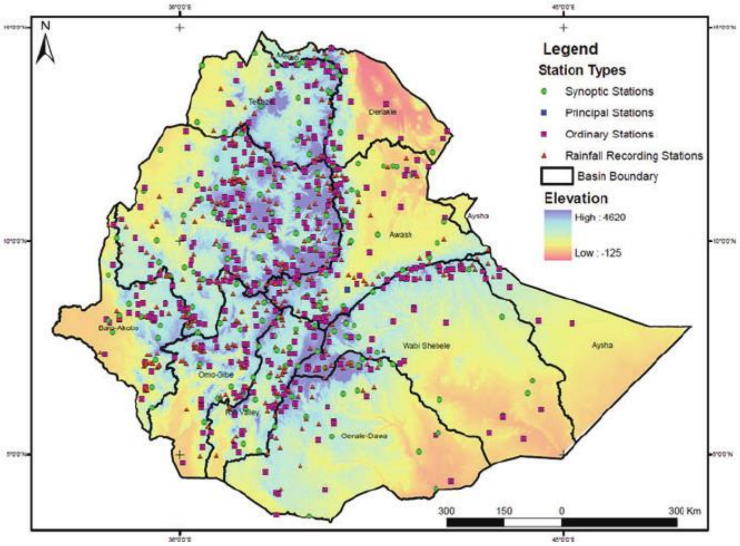

Figure 5 Meteorological station distribution and types per basin and elevation variation in Ethiopia

2. Climate Modelling

A climate model is a set of differential equations that is based on the physical, chemical, and biological aspects of its constituents, as well as their interactions and feedback processes and its conceptual frameworks is shown in Figure 6. Climate modeling history begins with conceptual models, which are followed in the nineteenth century by mathematical models of energy balance and radiative transmission, as well as rudimentary analog models. Since the 1950s, computer simulation models of the global general circulation have been the primary tools of climate science. From the 1990s to the present, the area has been dominated by a trend toward increasingly comprehensive coupled models of the entire climate system. Climate model evaluation and intercomparison is transforming modeling into a more standardized, modular approach, with the ability to bring together research and operational components of climate science.

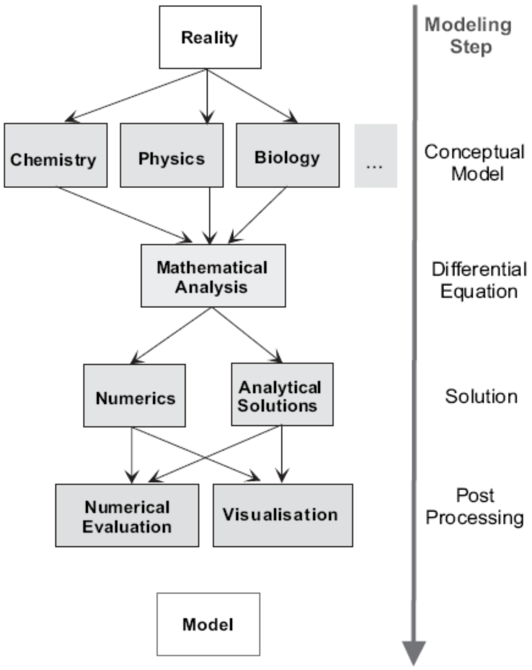

Figure 6 Conceptual framework of Modelling.

Difference between weather and climate models

- Weather consists of the short-term (minutes to months) changes in the atmosphere. Weather is described in terms of temperature, humidity, precipitation, cloudiness, brightness, visibility, wind, and atmospheric pressure, as in high and low pressure. In most places weather changes from minute-tominute, hour-to-hour, day-to-day, and season-to-season. Weather is predictable up to about 2 weeks ahead in the mid-latitudes and in the tropics somewhat longer.

- ➢ Climate is the description of the long-term pattern of weather in a particular area. Climate is the average weather for a particular region and time period, and the probability of extremes. Usually a period of 30 years is used to describe the climate. Examples of described climate variables are precipitation, temperature, humidity, sunshine, wind velocity, phenomena such as fog, frost and hail storms. Also vegetation changes, changes in glaciers/icecaps etc. can be described.

Weather and climate models both follow the basic laws of physics, fluid motion and chemistry. However, they differ in some aspects:

- ➢ Weather model: predicts in most cases til about 15 days into the future, while a climate model can integrate forward in time for hundreds of years. In a weather model, we care about when and where a storm or front occurs. In a climate model we care about the statistics (averages and probabilities of extremes). Since the weather of tomorrow depends strongly on the weather of today, the initial conditions for the simualtion of the weather are very important (initial value problem)
  - ✓ Model-based weather forecasts are generally less reliable beyond a week, because the atmosphere is an inherently chaotic system. Small changes in observed conditions, which are fed to the model regularly, can produce completely different weather forecasts a week into the future, because the atmosphere is very dynamic.
- ➢ In climate models you get climate variables for each day, but you don't really care on which day and exact location you get a certain value for this variable as long as the long term statistics are correct for this location. This does not depend on the initial conditions of the simulation, but it depends on the parameters in the model itself (boundary value problem).
  - ✓ Climate models aren't trying to predict what is going to happen at a specific place and point in time. They cannot produce a forecast for, say, the 15th of March 2077, or even not for tomorrow! Instead, climate models are used to determine how the average and extreme conditions will change. Will it be on average warmer or cooler, wetter or drier, in England

over the next 50 years? This is information we need if we're going to construct e.g. bridges or the water management system for the next decades.

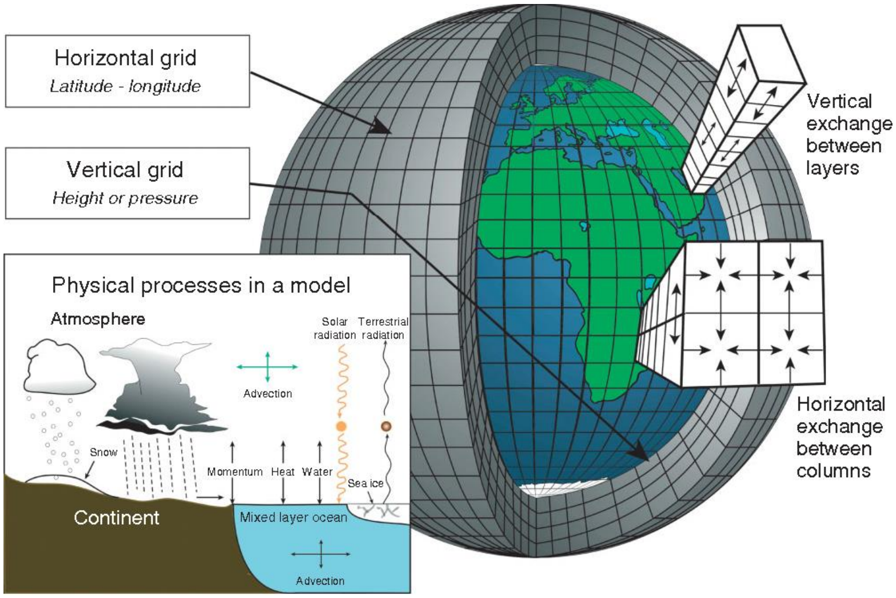

Figure 7 Schematic representation of the Cartesian grid structure used in finite-difference GCMs. Graphic by Courtney Ritz and Trevor Burnham.

Capabilities in Global Climate Modelling

Several developments have especially pushed the capabilities in modelling forward over recent years. There has been a continuing increase in horizontal and vertical resolution. This is especially seen in how the ocean grids have been refined, and sophisticated grids are now used in the ocean and atmosphere models making optimal use of parallel computer architectures. More models with higher resolution are available for more regions. Figure 7 show the large effect on surface representation from a horizontal grid spacing (higher resolution than most current global models and similar to that used in today's highly resolved models). Representations of Earth system processes are much more extensive and improved, particularly for the radiation and the aerosol cloud interactions and for the treatment of the cryosphere. The representation of the carbon cycle was added to a larger number of models and has been improved since AR4. A high-resolution stratosphere is now included in many models. Other ongoing process development in climate models includes the enhanced representation of nitrogen effects on the carbon cycle. As new processes or treatments are added to the models, they are also evaluated and tested relative to available observations. For example: spatial land surface heterogeneity in CLM is represented as a nested subgrid hierarchy in which grid cells are composed of multiple land units, snow/soil columns, and PFTs (Figure 8). Each grid cell can have a different number of land units, each land unit can have a different number of columns, and each column can have multiple PFTs.

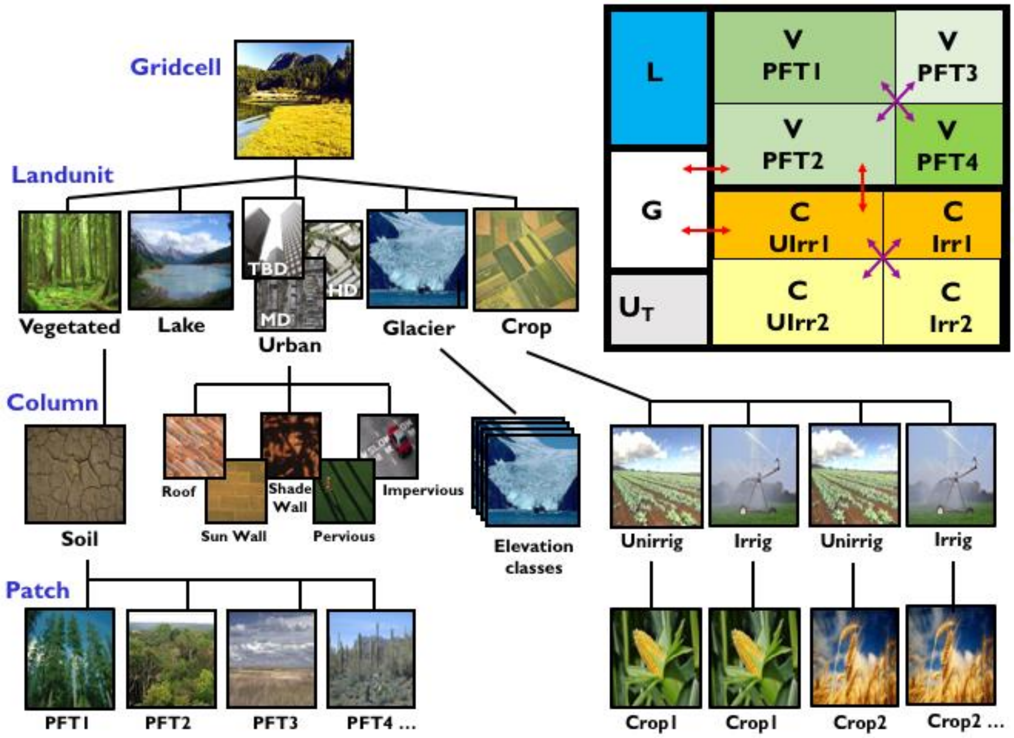

Figure 8 Configuration of the CLM subgrid hierarchy[3].

Ensemble[4] techniques (multiple calculations to increase the statistical sample, to account for natural variability, and to account for uncertainty in model formulations) are being used more frequently, with larger samples and with different methods to generate the samples (different models, different physics,

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[3] Box in upper right shows hypothetical subgrid distribution for a single grid cell. Note that the Crop land unit is only used when the model is run with the crop model active. Abbreviations: TBD – Tall Building District; HD – High Density; MD – Medium Density, G – Glacier, L – Lake, U – Urban, C – Crop, V – Vegetated, PFT – Plant Functional Type, Irr – Irrigated, UIrr – Unirrigated. Red arrows indicate allowed land unit transitions. Purple arrows indicate allowed patch-level transitions.

[4] **Ensemble:** a collection of model simulations characterizing a climate prediction or projection. Differences in initial conditions and model formulation result in different evolutions of the modeled system and may give information on uncertainty associated with model error and error in initial conditions in the case of climate forecasts and on uncertainty associated with model error and with internally generated climate variability in the case of climate projections.

different initial conditions). Coordinated projects have been set up to generate and distribute large samples (ENSEMBLES, climateprediction.net, Program for Climate Model Diagnosis and Intercomparison). The Coupled Model Intercomparison Project, which began in 1995 under the auspices of the World Climate Research Programme (WCRP), is now in its sixth phase (CMIP6). CMIP6 coordinates somewhat independent model intercomparison activities and their experiments which have adopted a common infrastructure for collecting, organizing, and distributing output from models performing common sets of experiments. The simulation data produced by models under previous phases of CMIP have been used in thousands of research papers, and the multi-model results provide some perspective on errors and uncertainty in model simulations. This information has proved invaluable in preparing high profile reports assessing our understanding of climate and climate change (e.g., the IPCC Assessment Reports).

Forecasts and Projections

Climate prediction: A climate prediction or climate forecast is the result of an attempt to produce (starting from a particular state of the climate system) an estimate of the actual evolution of the climate in the future, for example, at seasonal, interannual, or decadal time scales. Because the future evolution of the climate system may be highly sensitive to initial conditions, such predictions are usually probabilistic in nature. See also Climate projection, Climate scenario, and Predictability.

Weather forecasts are the most widely known class of future information and are usually provided by the NMS. They are used in EWS and other short term (a few days) outlooks. In the last two decades additional forecast systems have been implemented by the WMO to make predictions over longer time scales. The most advanced systems currently available provides seasonal climate forecasts in the tropics.

Seasonal forecasts

Seasonal forecasts take advantage of the fact that Sea Surface Temperatures (SSTs) influence moisture and atmospheric circulation in the tropics, but tend to evolve more slowly than the atmosphere by several months.As a result, SSTs can be used to predict the overall state of the atmosphere in a given region/climatic system in the coming months. A number of regions have been running seasonal forecasts over past decades and, in Africa, most notable seasonal forecasts are elaborated during the

Climate Outlook Fora organized by ACMAD and ICPAC. During such fora the general tendencies of the season are predicted and presented in probabilistic format (Figure 9). These predictions can be helpful in planning water resource and on-farm management at national, subnational and individual levels.

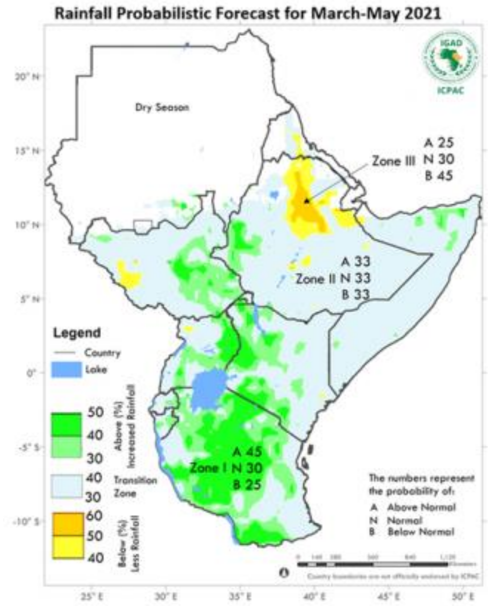

Figure 9 Probabilistic seasonal forecast for the March-May 2021 season in East Africa (WMO).

Climate projections

Projection: A projection is a potential future evolution of a quantity or set of quantities, often computed with the aid of a model. Unlike predictions, projections are conditional on assumptions concerning, for example, future socioeconomic and technological developments that may or may not be realized. See also Climate prediction and Climate projection.

Parameterization: In climate models, this term refers to the technique of representing processes that cannot be explicitly resolved at the spatial or temporal resolution of the model (sub-grid scale processes) by relationships between model-resolved larger-scale variables and the area- or time-averaged effect of such sub-grid scale processes.

Climate projection: A climate projection is the simulated response of the climate system to a scenario of future emission or concentration of greenhouse gases and aerosols, generally derived using climate models. Climate projections are distinguished from climate predictions by their dependence on the emission/concentration/radiative-forcing scenario used, which is in turn based on assumptions concerning, for example, future socioeconomic and technological developments that may or may not be realized.

A wide range of regional and international initiatives allow access to climate change projection data. Some of the portals giving access to projections are listed below: However, to make best use of the available data and information, the following needs to be considered:

- ✓ **Scope of the study:** how much climate information is really needed. E.g., general tendencies vs. precise high resolution data for further impact modeling
- ✓ **Accuracy of climate models over the region of interest:** at local scale GCMs can present strong biases (e.g., precipitation can be strongly underestimated and using direct raw data may lead to biased conclusions with respect to future conditions); a thorough literature review is needed to assess such biases and eventually correct them
- ✓ **Uncertainty:** is usually assessed through the use of a variety of models and assessment of minimum vs. maximum changes projected
- ✓ **Documentation about data source:** sufficient explanations with respect to how the data were processed; this is particularly important when working with downscaled data.

Downscaled information

Downscaling: Downscaling is a method that derives local- to regional-scale (10 to 100 km) information from larger-scale models or data analyses. Two main methods exist: dynamical downscaling and empirical/statistical downscaling. The dynamical method uses the output of regional climate models, global models with variable spatial resolution, or high-resolution global models. The empirical/statistical methods develop statistical relationships that link the large-scale atmospheric variables with local/regional climate variables. In all cases, the quality of the driving model remains an important limitation on quality of the downscaled information.

GCMs are valuable predictive tools, they cannot account for fine-scale heterogeneity of climate variability and change due to their coarse resolution. Numerous landscape features such as mountains, water bodies, infrastructure, land-cover characteristics, and components of the climate system such as convective clouds and coastal breezes, have scales that are much finer than 100–500 kilometers. Such heterogeneities are important for decision makers who require information on potential impacts on crop production, hydrology, species distribution, etc. at scales of 10–50 kilometers.

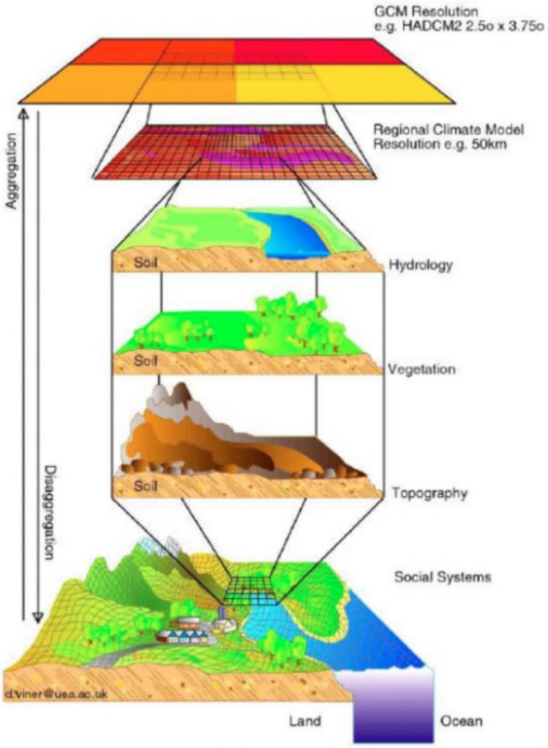

Figure 10 Many of the processes that control local climate, e.g. topography, vegetation, and hydrology, are not included in coarse-resolution GCMs. The development of statistical relationships between the local and large scales may include some of these processes implicitly. Source: Viner, 2012

Various methods have been developed to bridge the gap between what GCMs can deliver and what stakeholders require for decision-making. The derivation of fine-scale climate information is based on the assumption that the local climate is conditioned by interactions between large-scale atmospheric characteristics (circulation, temperature, moisture, etc.) and local features (water bodies, mountain ranges, land surface properties, etc.). It is possible to model these interactions and establish relationships between present-day local climate and atmospheric conditions through the downscaling process. It is important to understand that the downscaling process adds information to coarse GCM outputs so that information is more realistic at a finer scale, capturing sub-grid scale contrasts and inhomogeneities. Figure 10 presents a visual representation of the concept of downscaling.

Downscaling can be used to increase spatial or temporal resolution. There are two principal downscaling methods:

- **Dynamical**: Similar to GCMs, this method involves incorporating additional data and physical processes in regional- or local-scale models, at a much higher resolution than is seen in GCMs. This method has numerous advantages but is computationally intensive and requires large volumes of data and a high level of expertise to implement and interpret. The resources required place this method beyond the capacities of most institutions in developing countries.
- **Statistical**: This method involves establishing statistical relationships between large-scale GCM-modeled climate features and local climate characteristics. In contrast to the dynamical method, statistical methods are easy to implement and interpret. They require minimal computing resources but rely heavily on historical climate observations and the assumption that currently observed relationships will carry into the future. However, high quality historical records often are not available in developing countries.

The diversity of existing downscaling methods reflects the diversity of goals of and resources for each downscaling exercise. Thus, there is no single best downscaling approach, and downscaling methods will depend on the desired spatial and temporal resolution as well as the impacts being assessed. In most cases, a sequence of different methods is needed to obtain results at the desired resolution. When working with downscaled information the following needs to be kept in mind:

- Information on downscaling and the limitations of the results need to be understood and taken into account. Any results at resolutions higher than the native resolution of the GCMs has undergone downscaling and may mislead the user that the results are automatically more accurate because of their finer scale.
- Downscaling processes usually adds uncertainty to projections. Additional uncertainty should be factored into the interpretation of the results or indeed into the decision of whether downscaling is appropriate.
- Downscaling methods should be validated first on historical data to assess their potential biases and uncertainties.

In summary, downscaling is not a trivial process and requires some expertise. It may require significant investment in time, tools and capacity. The user should not believe that the results are automatically more true or valid because they are presented at higher resolution. The need for downscaling and the tradeoff between higher-resolution and increased uncertainty need to be carefully assessed.

Model Data

Model Data refer to data generated by Numerical models. Such models -**General or Regional Circulation Models (GCM or RCM**) -are based on a collection of equations capturing physical and chemical laws governing the weather and climate system. By ingesting available data describing current conditions and solving these equations using powerful computers they are able to predict weather and climate conditions in the future as well as in places with no observations. At this stage, it is important to understand that they can generate gridded data, by filling missing data, on Earth's surface as well as in the atmosphere, through very complex procedures based on physical equations. They create physically coherent gridded datasets and are particularly in favor with climate scientists, but may suffer from systematic biases, similar to those of gridded datasets (Figure 11). More demonstration needed

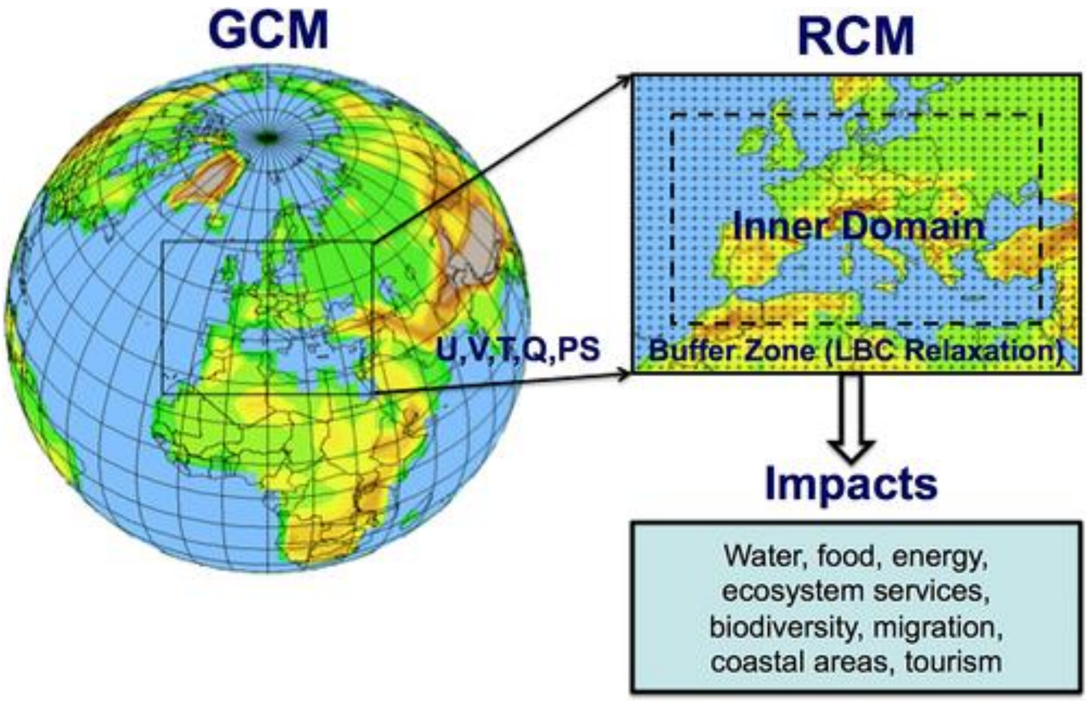

Figure 11 Schematic depiction of regional climate modeling and application to VIA studies. VIA = vulnerability, impacts, and adaptation; RCM = regional climate model; GCM = global climate model (Giorgi, 2019).

Session V: General atmospheric circulation

1. Differential Heating

The focus of this section is on the typical wind circulations found on Earth as a result of the forces affecting wind in the atmosphere. **Atmospheric circulation**[5] is the large-scale movement of air and together with ocean circulation is the means by which thermal energy is redistributed on the surface of the Earth. The average global winds are called the **general circulation of the atmosphere**. To find typical wind circulations, one needs to average wind speed and duration over a long period of time. Averaging over time removes short duration fluctuations, allowing the primary sense of movement to be visualized. The reason we have global wind patterns is ultimately due to a differentially heated, rotating Earth. The differential heating of Earth continually causes an imbalance in air pressure and temperature around the world, which in turn causes a continuous general circulation of winds that attempt to restore balance.

While actual winds in a given place and time may differ from the average general circulation, the average can provide an explanation for how and why the winds prevail from a particular direction in a certain place. The general circulation also serves as a model for how heat and momentum are transported from the equator to the poles.

Because the Earth is round, solar radiation is not equally spread at all latitudes. Near the equator where sunlight shines directly on Earth, more solar radiation per square meter is received as compared to near the poles where sunlight shines at sharp angles to the surface (see Figure 12). Toward Earth's poles, the same solar radiation is spread over a larger surface area such that each square meter of Earth's surface gets less radiation at the poles. As Earth rotates, the incoming solar radiation is zonally spread along latitude lines.

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[5] https://en.wikipedia.org/wiki/Atmospheric_circulation

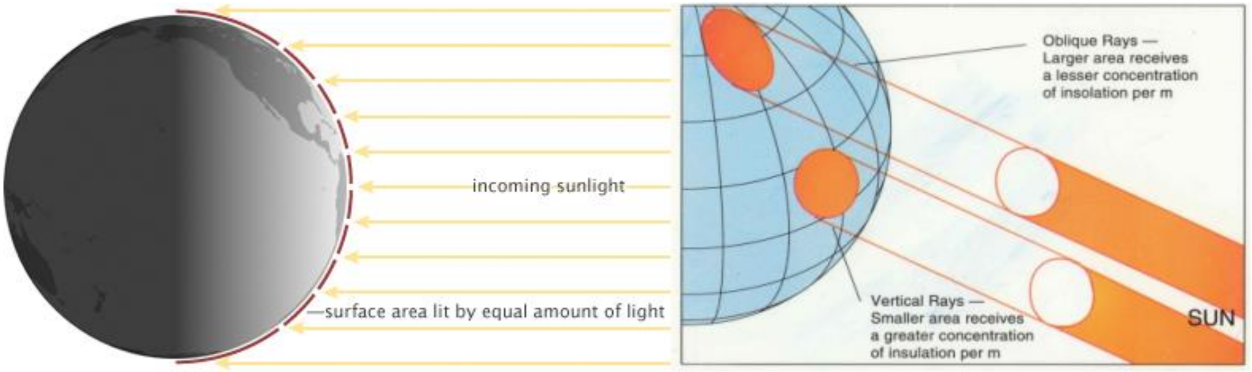

Figure 12 Earth's uneven heating by the sun due to the curvature of its surface NASA (Public Domain).

In this way, incoming solar radiation depends on latitude. The sun shines more directly on tropical regions at lower latitudes than at higher latitudes all year-round. Solar radiation adds heat to the Earth-atmosphere-ocean system, and thus lower latitudes get heated more than higher latitudes. This should be as expected because we know the tropics are warmer than the polar regions.

While Earth is continually heated by the sun, it is also continually losing energy by emitting outgoing longwave infrared (IR)[6] radiation at all latitudes, and at all times, both on the light and the dark side of the globe.

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[6] **Outgoing Long-wave Radiation** (**OLR**) is electromagnetic radiation of wavelengths from 3–100 µm emitted from Earth and its atmosphere out to space in the form of thermal radiation. It is also referred to as up-welling long-wave radiation and terrestrial long-wave flux, among others. The flux of energy transported by outgoing long-wave radiation is measured in W/m^2. In the Earth's climate system, long-wave radiation involves processes of absorption, scattering, and emissions from atmospheric gases, aerosols, clouds and the surface.

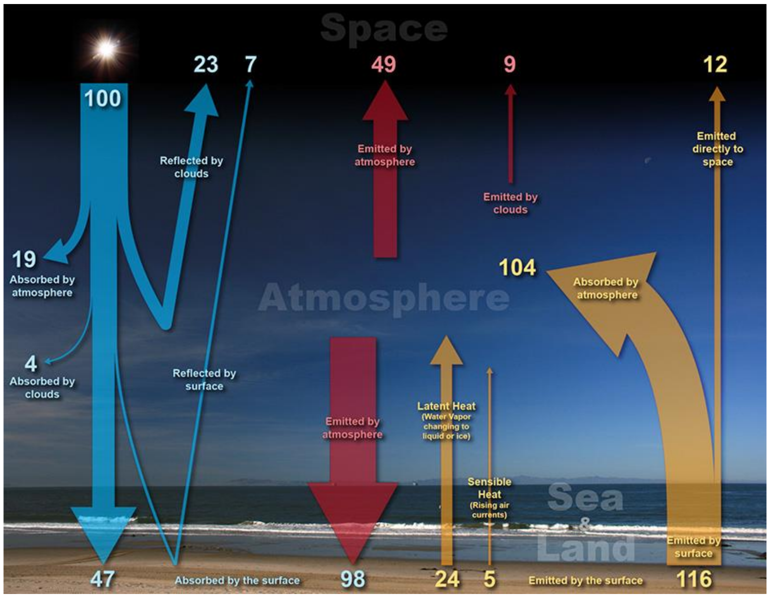

Figure 13 Energy balance (https://www.weather.gov/jetstream/energy).

When averaged over the globe and over long time scales, incoming UV radiation exactly balances outgoing IR (Figure 13) radiation. But, latitude by latitude, incoming UV and outgoing do not perfectly balance. More solar energy is received by the Earth in the tropics, and while the cooling by outgoing IR[7] radiation helps to offset this, there is still a net gain of radiative energy in the tropics. However, near Earth's poles, incoming solar radiation is less direct and too weak to offset the cooling by outgoing IR radiation, so there is net cooling at the poles. This causes warmer air at the equator, and cold air at the poles and drives Earth's atmospheric general circulation.

Earth's general circulation attempts to redistribute heat around the globe and rebalance the energy imbalances inherent in an unevenly heated, rotating planet. However, the general circulation cannot instantly balance global temperature, especially when the uneven heating is continuous. Therefore, a meridional temperature gradient always remains.

In an attempt to balance out Earth's incoming and outgoing energy[8], warm air is transported toward the poles, while cool air flows back toward the equator. This seems simple enough. However, this

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[7] https://en.wikipedia.org/wiki/Outgoing_longwave_radiation

[8] http://pressbooks-dev.oer.hawaii.edu/atmo/chapter/chapter-2-solar-and-infrared-radiation/

seemingly simple flow is complicated by many factors, including Earth's rotation, the position of continents, interactions with the oceans and many others.

Three-Cell Model (Figure 14)[9]

More demonstration needed

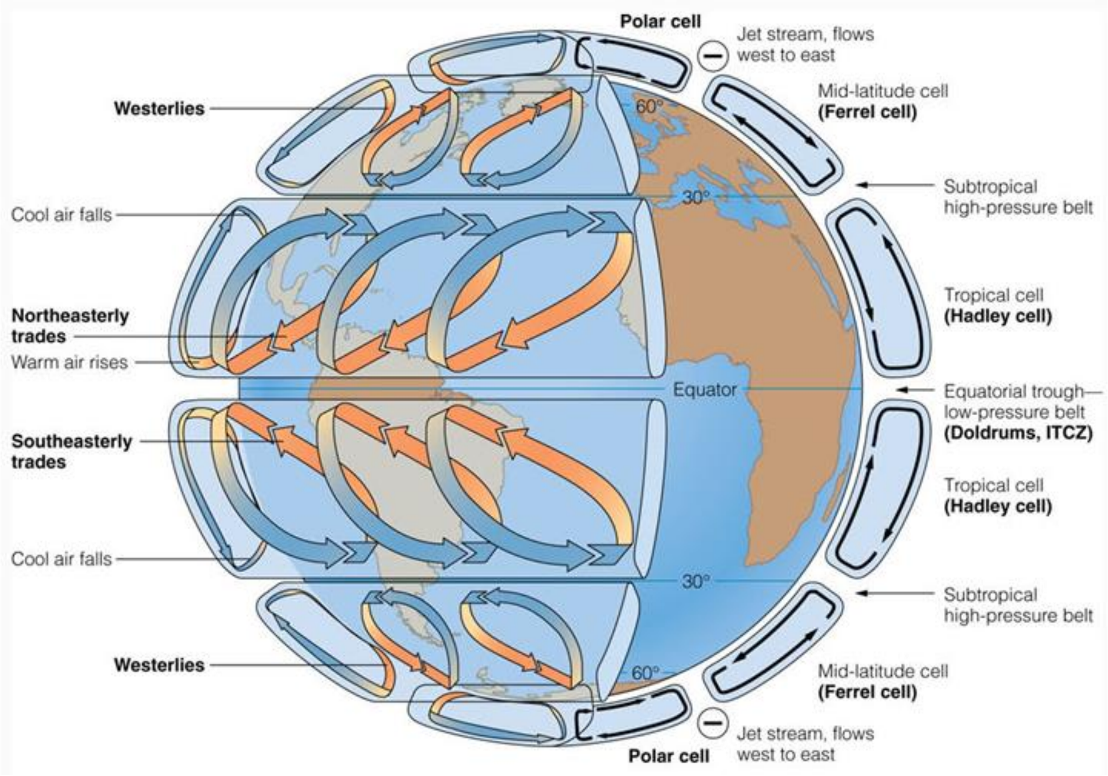

Figure 14 Circulation of Earth's atmosphere: Average winds, three-cell model.

2. Global Surface Winds

The following graphic nicely illustrates all of the above phenomenon for global surface winds. The polar easterlies, mid-latitude westerlies, and tropical trade winds are all visible. Now with the continents and land masses added, we are able to see where on Earth these surface winds are observed.

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[9] Hadley circulation A direct, thermally driven overturning cell in the atmosphere consisting of poleward flow in the upper troposphere, subsiding air into the subtropical anticyclones, return flow as part of the trade winds near the surface, and with rising air near the equator in the so-called Inter-tropical Convergence Zone.

Jet streams

There is one final important piece of general circulation that deserves a discussion, and that is jet streams. In the below image you can see two jet streams: the subtropical jet and the polar jet. The figure shows the average position of the jet streams in the Northern Hemisphere in the winter, as well as their relation to the tropopause. The figure shows jet streams flowing from west to east. We can see that there are two jets located right under the tropopause. The **subtropical jet stream** is located near 30° latitude about 13 km up, above the tropical high. The **polar jet stream** is located near the polar front about 10 km up, near 50° to 60° latitude. The difference in height of these jets is due to their location at the tropopause, and the fact that the tropopause is found higher in tropical regions than in polar regions due to average layer temperature differences of the troposphere underneath. The troposphere is thinner in polar regions than in tropical regions due to colder, denser air at the poles (Figure 15).

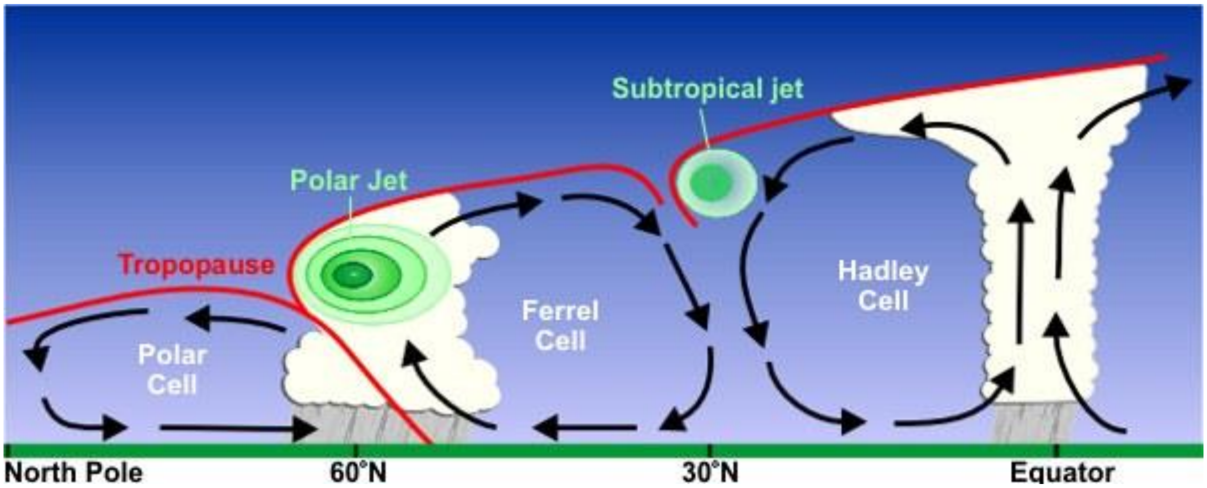

Figure 15 Cross-section of the northern hemisphere circulation, and the positions of the polar and subtropical jet streams (Public Domain).

If the general circulation of the atmosphere is like a giant meandering river of air around the globe, then **jet streams** are swiftly flowing currents within that river. Jet streams are thousands of kilometers in length, and hundreds of kilometers in width. In the core of a jet stream (called a **jet streak**), wind speeds are often higher than 100 knots and are occasionally higher than 200 knots. The polar jet can sometimes merge with the subtropical jet if it sweeps southward enough, and it occasionally splits into two jet streams.

The existence of jet streams is ultimately due to the energy imbalance between tropical and polar regions. How exactly do they form? As mentioned before, the polar front is a boundary between colder polar air and warmer subtropical air. Because of this, the strongest temperature gradient occurs along the polar frontal zone. This rapid change of temperature with distance also causes a rapid pressure change, due to the thermal wind effect (a vertical shear in the geostrophic wind caused by a horizontal temperature gradient). This strong pressure gradient across the polar front causes intense wind speeds that become the jet stream. The temperature contrast between north and south along the polar front is more intense during the winter than during the summer, so the polar jet is also stronger during the winter. During winter, the leading edge of the cold polar air pushes further south into subtropical areas. During the summer, the polar front retreats into higher latitudes and is weakened.

The subtropical jet stream tends to form just above the descending branch of the Hadley cell, at about 12 km altitude. Here, a boundary exists between warmer equatorial air and cooler air that has been cycled up and around the Ferrel cell from the polar front. This is sometimes referred to as the subtropical front, but it does not extend all the way to the surface. Here, the temperature gradient is strongest aloft near the tropopause, which induces a sharp pressure gradient and strong winds aloft as well.

3. Main feature of Ethiopian Climate

This section, focus on the description of the spatio-temporal characteristics of climate and its causes over Ethiopia.

1. Spatial Distribution of Climates

Ethiopia is the country, with its topography varying from about 4,550[10] m above sea level in the north and central regions to about 130[11] m below sea level over the lowland in the northeastern regions of the country (Figure 16). The main topographic feature of the country consists of a high plateau and mountain chains; which include the great East African Rift Valley that runs northeast to southwest across the country, the highlands to the west and east of the rift valley and the lowlands surrounding the highlands (Chisholm 1911, Paul 2000). The western highlands cover large part of the country and

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[10] https://en.wikipedia.org/wiki/Ras_Dashen

[11] https://en.wikipedia.org/wiki/Danakil_Depression

run south to north while the eastern highlands run southwest to east as shown in Figure 16. Because of these complex topographical and geographical features, the climate of Ethiopia exhibits strong spatial variations and different rainfall regimes (National Meteorology Service Agency 1996; Slingo et al. 2005; Mengistu Tsidu 2012). The rainfall distribution is also closely related to topography, but interestingly, the highest amounts of annual rainfall are observed west of mountain peaks and lowest temperatures, further from intuitive moisture sources such as the Red Sea and the Indian Ocean. For example, the northwestern regions of Ethiopia are characterized by a single summer (June-September) rainy season (Kassahun 1987; Degefu 1987; Segele et al. 2009a, 2009b; Diro et al. 2011a; Zeleke et al. 2012, 2013; Mengistu Tsidu 2012) with characteristics similar to the Sahel and the Indian monsoon (Bhatt 1989; Camberlin 1997). The eastern regions exhibit a bimodal (two wet periods throughout the year) pattern long rainy season summer and a second short rainy season in the spring (February-May); which mainly due to the moist easterly flow from the northwestern Indian Ocean associated with high pressure over the Arabian Sea (Camberlin and Philippon 2002; Diro et al. 2011b). Similarly, the southern regions show a bimodal rainfall pattern with maxima in spring and autumn (October-December), a pattern similar to that found over equatorial eastern Africa caused by the north-south migration of the Intertropical Convergence Zone (ITCZ). The southwestern regions exhibit a unimodal (Figure 16) rainfall peak in summer like the northwest, but they also receive rainfall throughout the year (Kassahun 1987; Degefu 1987; Diro et al. 2011a; Zeleke et al. 2012, 2013; Mengistu Tsidu 2012). This rainfall distribution explains why the lowlands to the west, which experience similar temperatures, are covered with wooded grassland, whereas the lowlands to the east are only covered with acacia and bush land.

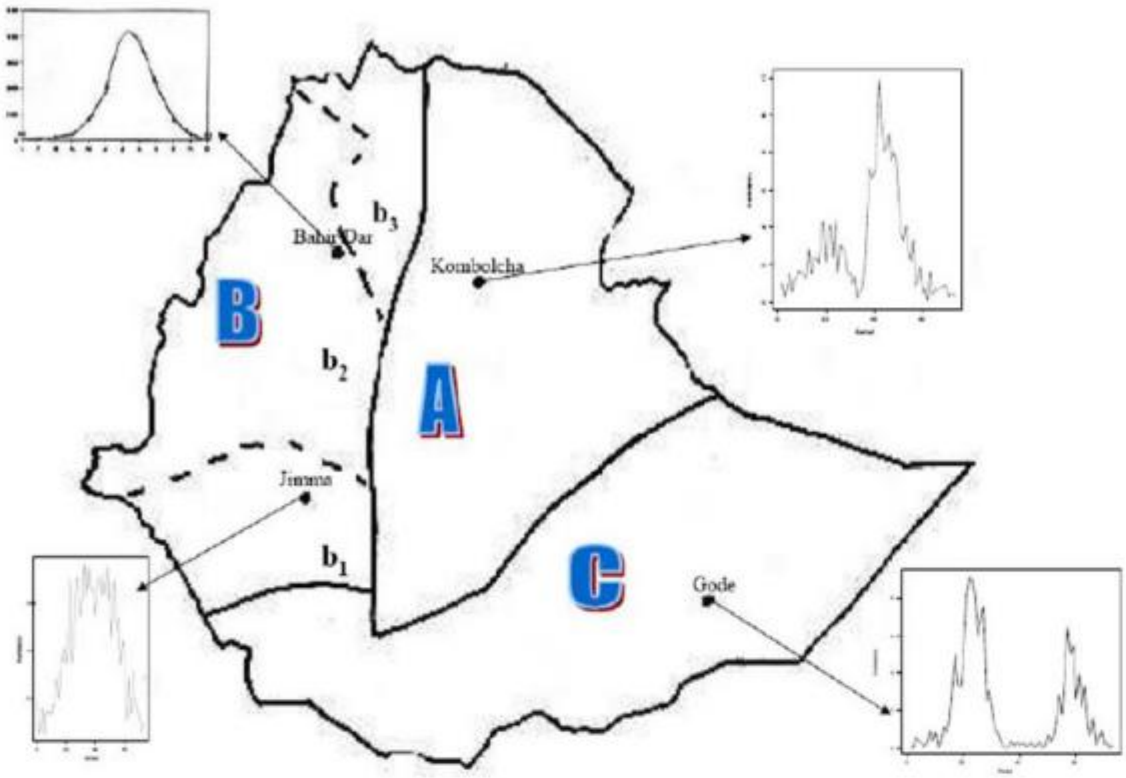

Figure 16 Different types of seasonal cycles of rainfall in Ethiopia. (after Tesfaye Haile)

Temporal Characteristics of Climates in Ethiopia

The climate at a given location results from an interaction between global (Figure 17) and local factors (Figure 18) see section 0.

Global Factors

- The latitude,
- The rotation of the Earth around the sun.
- The distribution of ocean- and land-masses.

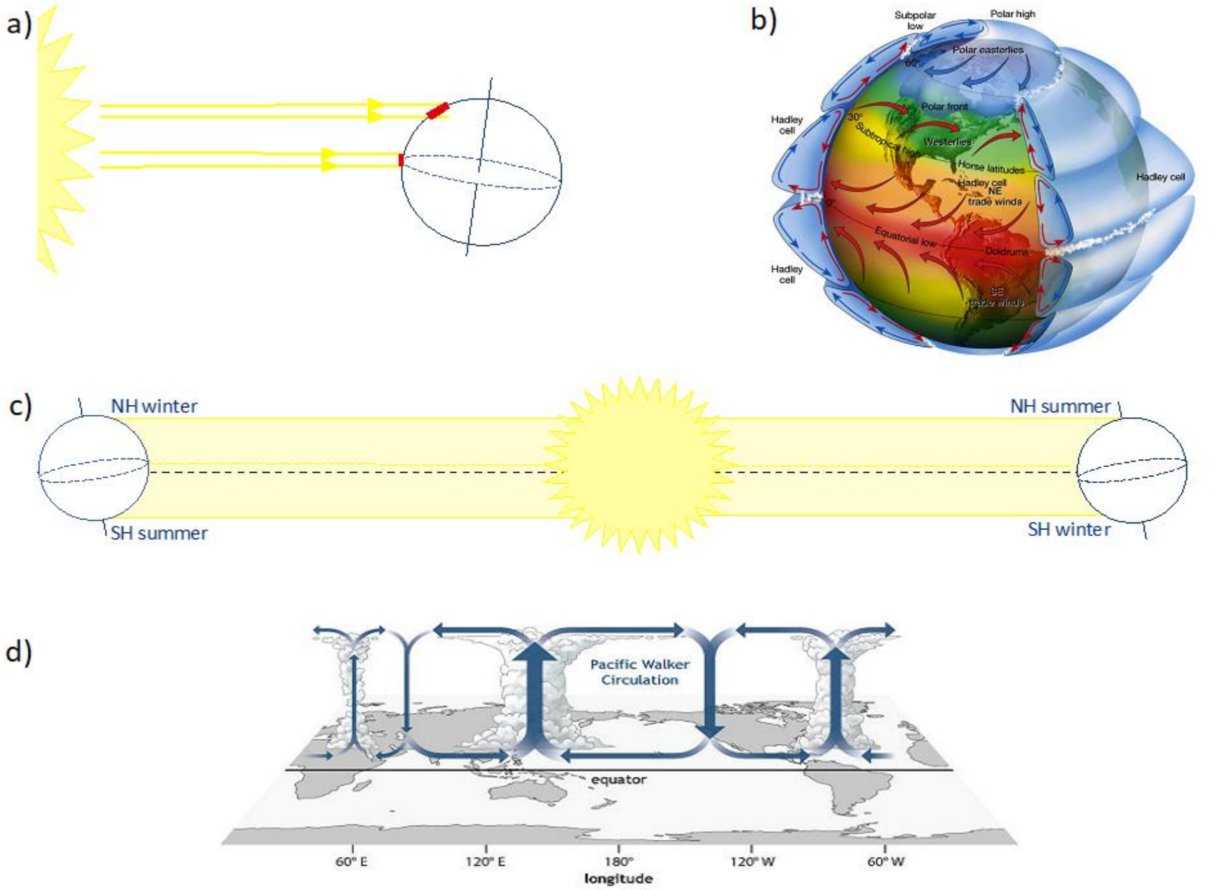

Figure 17 Schematic representation of the main global factors influencing local climate. a) differences in energy received by latitude; b) resulting atmospheric circulations, in the absence of land- masses; c) the seasonal cycle and d) the distribution of land-masses and oceans. Sources: http://www.ux1.eiu.edu/~cfjps/1400/circulation.html, https://www.climate.gov/news-features/blogs/enso/walker-circulation-ensos-atmospheric-buddy

Local Factors

Local factors that can affect Ethiopian climate, the reasons for the rainfall distribution will be explained further in section 0.

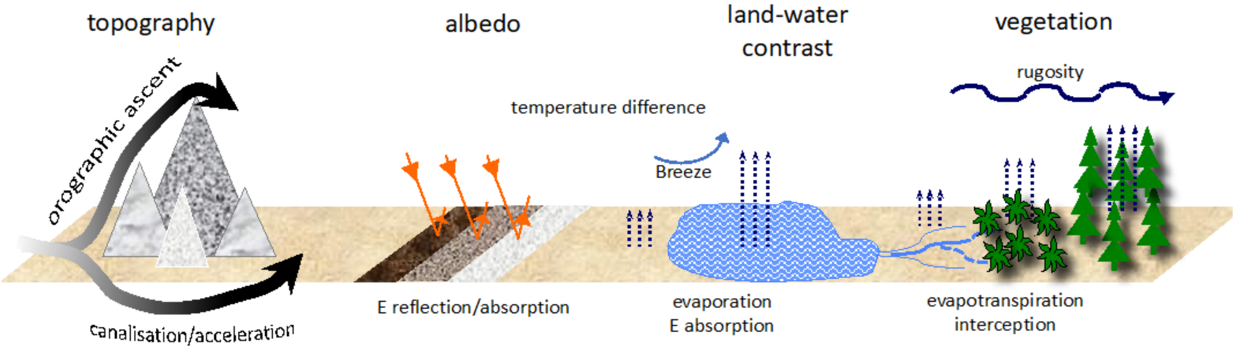

Figure 18 Schematic representation of local factors influencing local climate.

Seasonal Circulations in Ethiopia

In addition to spatial distribution, rainfall is also unevenly distributed during the year, leading to rainy and dry seasons. The length of these seasons will define the type of vegetation and crops that can be grown in a given location. Note that the length of the rainy season is not necessarily related with the total amount rainfall, especially in the regions experiencing two rainy seasons. Figure 16 depict the mean annual cycle for the Figure 16 homogeneous rainfall regions using different sets of observations (gauge, GPCP, and CRU) and RegCM4 simulation. Figure 16 depicts unimodal and bimodal regions of Ethiopia by averaging the annual cycle values for each homogeneous region (Figure 16) over the entire observation and simulation periods (Zeleke et al., 2013).

Main factors determining climate of Ethiopia

Ethiopian climate variability drivers are large-scale modes of climate variability that affect the region's macroscale pressure systems and atmospheric dynamics (Zeleke et al., 2013 and references therein). Variability in the duration and intensity of the summer rains (June–August) have been linked to activity of the tropical easterly jet (TEJ), intertropical convergence zone (ITCZ), quasi-biennial oscillation (QBO), African easterly jet, winds from the Atlantic and Indian Ocean, the East African low-level jet (EALLJ) and the Mascarene, St. Helena, and Azores subtropical high-pressure systems (Shanko and Camberlin, 1998; Segele and Lamb, 2005; Yeshanew and Jury, 2007; Segele et al., 2009a; Diro et al., 2011b; Zeleke et al., 2013). Spring rain over southern Ethiopia, in contrast, is affected by the ITCZ, the subtropical westerly jet streams, easterly anomalies and tropical cyclones from the Indian Ocean (Kassahun, 1987; Camberlin, 1995, 1997; Camberlin and Philippon, 2002).

These atmospheric circulations are affected by sea surface temperature (SST) anomalies over different oceanic basins. For instance, summer rainfall over the Ethiopian highlands is positively correlated with the equatorial East Pacific sea-level pressure and the southern oscillation index (Figure 19) and negatively correlated with SST over the tropical eastern Pacific Ocean (Diro et al., 2011a). High-positive SST (El Niño[12]) anomalies during the summer are associated with high drought probability over most of the agricultural productive land and major water reservoir areas of the country (Degefu, 1987; Tadesse, 1994; Seleshi and Demaree, 1995; Conway et al., 2004; Bewket and Conway, 2007) Figure 20 and Figure 21. This phenomenon (variability of ocean basins) has significant impact on the displacement and weakening of the rain-producing mechanisms in Ethiopia (Korecha and Barnston, 2007; Segele et al., 2009b; Diro et al., 2011b, 2011a). Overall, SST anomalies in the equatorial Pacific Ocean are significantly correlated with East African seasonal rainfall variations, but the signs of the correlations and their phase vary from region to region (Camberlin, 1995; Nicholson, 1996; Segele et al., 2009a; Diro et al., 2011b; Lyon and DeWitt, 2012; Zeleke, 2013; Funk et al., 2014; Liebmann et al., 2014; Yang et al., 2014; Funk and Hoell, 2015; Vigaud et al., 2016).

Studies have also emphasized the influence of other oceanic basins on Ethiopian seasonal/annual rainfall (Kassahun, 1987; Camberlin, 1995, 1997; Camberlin and Philippon, 2002; Giannini et al., 2003; Williams and Funk, 2011; Williams et al., 2012; Berhane et al., 2014; Funk and Hoell, 2015; Vigaud et al., 2016). For example, the model-based study of Giannini et al. (2003) demonstrated that warming of oceanic basins surrounding Africa could trigger wide spread droughts over regions ranging from Senegal to Ethiopia by suppressing the continental convergence associated to the monsoon flow. Diro (2008) showed the association of decadal and multidecadal oscillations of the Atlantic Ocean SSTs with Ethiopian climate. Similarly, Jury (2010) highlighted the impact of the warm phase of the Atlantic multidecadal oscillation on the enhancement of rainfall patterns over northern Ethiopia. The Indian Ocean SST variability (Figure 22 and **Error! Reference source not found.**) has a dominating role in setting up a dipole precipitation (wet and dry) pattern over eastern and southern Africa and tends to be associated with the inter-annual climate variability of Ethiopian climate (Shanko and Camberlin,

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[12] El Niño-Southern Oscillation (ENSO) is a phenomenon in the ocean and in the atmosphere in the equatorial Pacific region. In neutral conditions, due to trade winds, there is an accumulation of warm waters and a lot of evaporation and rainfall in the eastern equatorial Pacific, and in general wet climatic condition in southeastern Asia. On the western side of equatorial Pacific, surface waters are cooler and the atmosphere is drier, leading to dry conditions on the west coast of tropical South America (Figure *19*). Periodically, these conditions are relaxed, warmer waters and rain-producing systems spread westward and can cause torrential rains on the coast of South America (Figure *19*). This is an El Niño episode. During the opposite episode, La Niña, the atmospheric circulations and the contrast in oceanic temperatures strengthen. El Niño/La Niña mostly occur around December-January ad draw their name from their co-occurrence with Christmas (El Niño=the Child).

1998). Recently, several studies confirmed the impact of the Indian Ocean Dipole (IOD[13]) mode on the East African seasonal variability of rains (Saji et al., 1999; Webster et al., 1999, Zeleke et al., 2017).

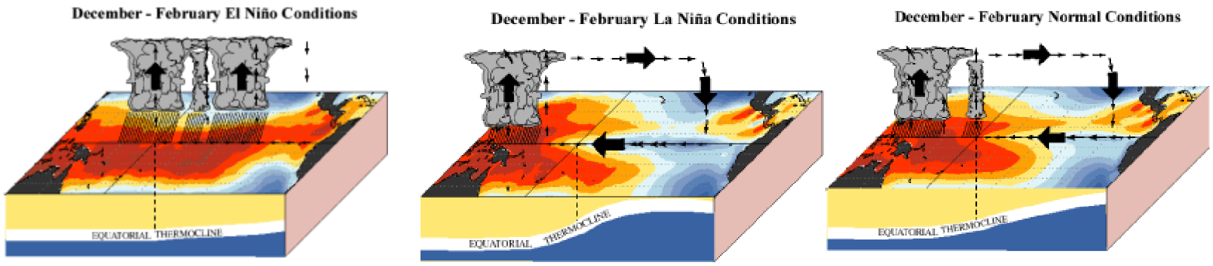

Figure 19 Schematic representation of (a) Neutral, (b) El Niño and (c) La Niña conditions in the Pacific Ocean basin.

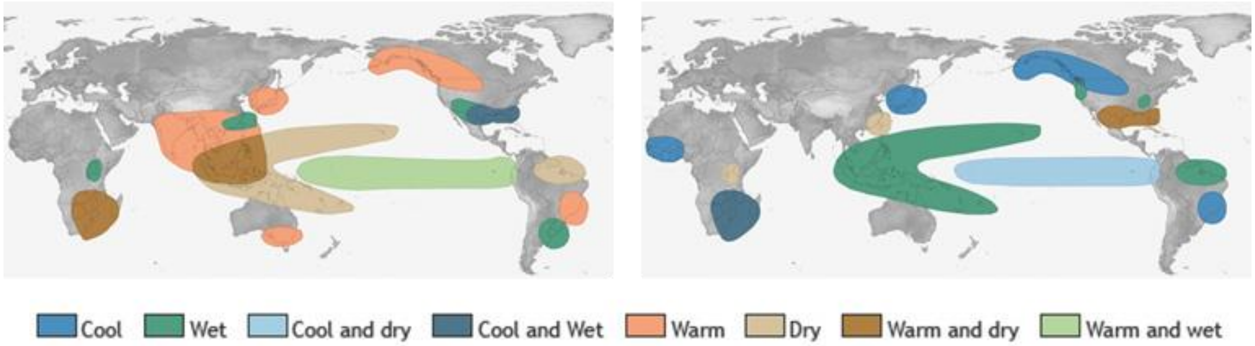

Figure 20 Impacts of (left) El Niño and (right) La Niña on temperature and rainfall around the globe in the December-February season. Source: NOAA, https://www.climate.gov/news-features/featured-images/global-impacts-el-niño-and-la-niña, accessed February 8, 2021.

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[13] Indian Ocean Dipole (IOD) is another ocean-atmosphere phenomenon that influences rainfall and temperatures in East Africa. Figure *22* displays a schematic view of the IOD and **Error! Reference source not found.** displays the time evolution of associates sea surface temperatures a nomalies.

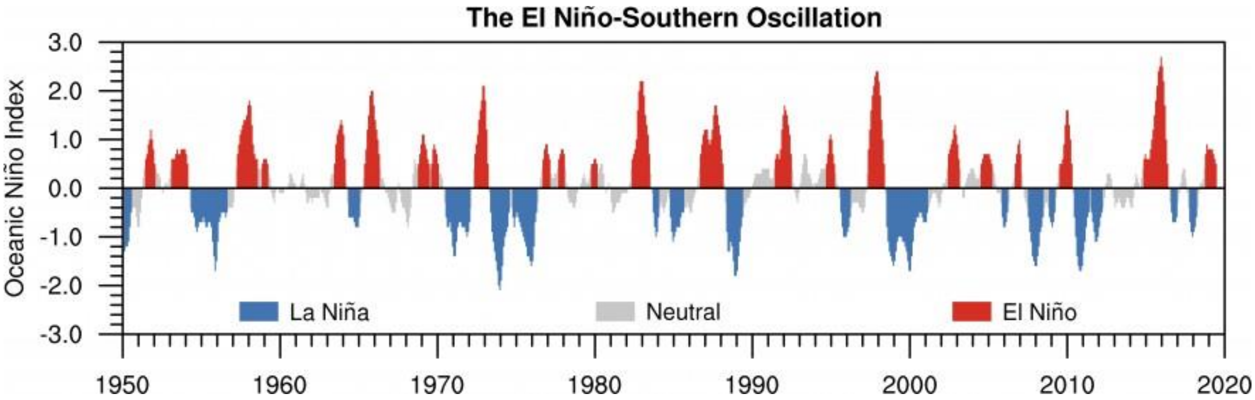

Figure 21 Time series of SST anomalies in equatorial Pacific over the period 1950-2020. Source: https://fews.net/el-niño-and-precipitation, accessed Feb 8, 2021.

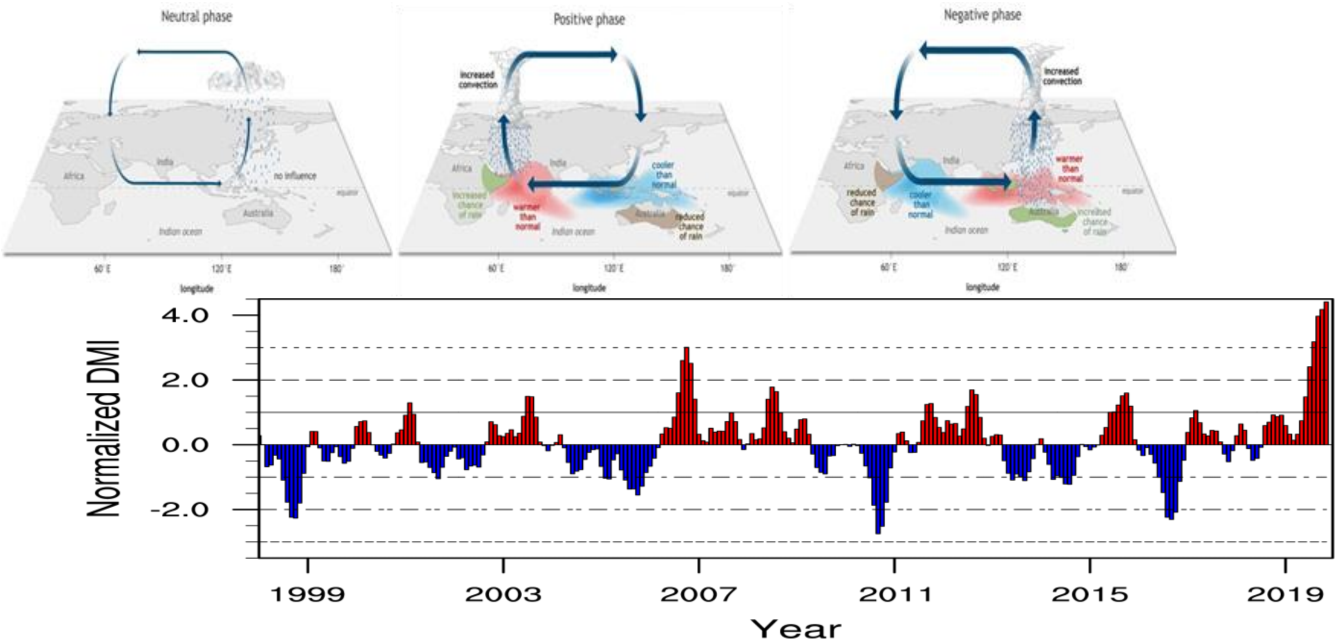

Figure 22 Indian Ocean Dipole. Neutral, positive, negative phases and their impacts on left, middle and right panels respectively. Source: NOAA, https://www.climate.gov/news-features/blogs/enso/meet-enso’s-neighbor-indian-ocean-dipole, accessed February 8, 2021.

Chapter self-evaluation question

Reading materials

Chapter Two: Climate variability and change

Session I: Chapter overview

This chapter will discuss historical, current, and future climate aspects, as well as the associated causes and consequences in major economic sectors. Climate change will also be discussed from a political standpoint.

Learning Objectives

By the end of this chapter, you should be able to:

- ✓ Explain the fundamentals of climate change science
- ✓ Identify the difference between climate variability and climate change
- ✓ Discuss of the influence of air-sea interaction on weather and climate systems.
- ✓ Describe the main features of atmospheric-ocean interactions
- ✓ Discuss the occurrence of ENSO, IOD, PDO, AMO, NAO, MJO and the connection with Ethiopian climate
- ✓ Describing global and local causes of climate variability and climate change
- ✓ Identify the anthropogenic drivers of climate change
- ✓ Explain observed and projected trends and impacts in the climate
- ✓ Analyse different climate change scenarios and their implications
- ✓ Describe the expected consequences of climate change in the main-economic sectors
- ✓ Present the international climate change legal and policy framework and explain key issues under negotiation
- ✓ Analyse principal challenges and opportunities for climate change action.

Session II: Definitions of key terms of climate variability and climate change

Anthropogenic: Resulting from or produced by human activities (IPCC, 2022).

Anthropogenic emissions: Emissions of greenhouse gases (GHGs), greenhouse gas precursors, and aerosols caused by human activities. These activities include the burning of fossil fuels, deforestation, land use changes, livestock production, fertilization, waste management, and industrial processes (IPCC, 2022).

Anthropogenic removals: The withdrawal of greenhouse gases (GHGs) from the atmosphere as a result of deliberate human activities. These include enhancing biological sinks of CO_2 and using chemical engineering to achieve long-term removal and storage. Carbon dioxide capture and storage (CCS), which alone does not remove CO_2 from the atmosphere, can help reduce atmospheric CO_2 from industrial and energy-related sources if it is combined with bioenergy production (BECCS), or if CO_2 is captured from the air directly and stored (DACCS). [Note: In the 2006 IPCC Guidelines for national GHG Inventories (IPCC, 2006), which are used in reporting of emissions to the UNFCCC, 'anthropogenic' land-related GHG fluxes are defined as all those occurring on 'managed land', i.e., 'where human interventions and practices have been applied to perform production, ecological or social functions'. However, some removals (e.g., removals associated with CO_2 fertilization and N deposition) are not considered as 'anthropogenic', or are referred to as 'indirect' anthropogenic effects, in some of the scientific literature assessed in this report. As a consequence, the land-related net GHG emission estimates from global models included in this report are not necessarily directly comparable with land use, land-use change and forestry (LULUCF) estimates in national GHG Inventories] (IPCC, 2022).

Anthropogenic subsidence: Downward motion of the land surface induced by anthropogenic drivers (e.g., loading, extraction of hydrocarbons and/or groundwater, drainage, mining activities) causing sediment compaction or subsidence/deformation of the sedimentary sequence, or oxidation of organic material, thereby leading to relative sea level rise (IPCC, 2022).

Carbon dioxide removal (CDR): Anthropogenic activities removing carbon dioxide (CO_2) from the atmosphere and durably storing it in geological, terrestrial, or ocean reservoirs, or in products. It includes existing and potential anthropogenic enhancement of biological or geochemical CO_2 sinks and direct air carbon dioxide capture and storage (DACCS), but excludes natural CO_2 uptake not directly caused by human activities.

Climate Variability: variations in the mean state and other statistics (i.e., standard deviations, occurrence of extremes, etc.) of the climate across all spatial and temporal scales beyond that of individual weather events (e.g. intra-seasonal, inter-annual and inter-decadal). Variability may be due to natural internal processes within the climate system (internal variability), or to variations in natural or anthropogenic external forcing (external variability). In general, climatic variability is connected with variations in the state of the atmospheric and ocean circulation and land surface properties (e.g. soil moisture) at the intra-seasonal to inter-decadal timescales.

Climate change: A change in the state of the climate that can be identified (e.g., by using statistical tests) by changes in the mean and/or the variability of its properties and that persists for an extended period, typically decades or longer. Climate change may be due to natural internal processes or external forcings such as modulations of the solar cycles, volcanic eruptions and persistent anthropogenic changes in the composition of the atmosphere or in land use. Note that the United Nations Framework Convention on Climate Change (UNFCCC), in its Article 1, defines climate change as: 'a change of climate which is attributed directly or indirectly to human activity that alters the composition of the global atmosphere and which is in addition to natural climate variability observed over comparable time periods'. The UNFCCC thus makes a distinction between climate change attributable to human activities altering the atmospheric composition and climate variability attributable to natural causes (IPCC, 2022).

Abrupt change: A change in the system that is substantially faster than the typical rate of the changes in its history (IPCC, 2022).

Abrupt climate change: A large-scale abrupt change in the climate system that takes place over a few decades or less, persists (or is anticipated to persist) for at least a few decades and causes substantial impacts in human and/or natural systems (IPCC, 2022).

Climate extreme (extreme weather or climate event): The occurrence of a value of a weather or climate variable above (or below) a threshold value near the upper (or lower) ends of the range of observed values of the variable. By definition, the characteristics of what is called extreme weather may vary from place to place in an absolute sense. When a pattern of extreme weather persists for some time, such as a season, it may be classified as an extreme climate event, especially if it yields an average or total that is itself extreme (e.g., high temperature, drought, or heavy rainfall over a season). For simplicity, both extreme weather events and extreme climate events are referred to collectively as 'climate extremes' (IPCC, 2022).

Climate feedback: An interaction in which a perturbation in one climate quantity causes a change in a second, and the change in the second quantity ultimately leads to an additional change in the first. A negative feedback is one in which the initial perturbation is weakened by the changes it causes; a positive feedback is one in which the initial perturbation is enhanced. The initial perturbation can either be externally forced or arise as part of internal variability (IPCC, 2022).

Climate prediction: A climate prediction or climate forecast is the result of an attempt to produce (starting from a particular state of the climate system) an estimate of the actual evolution of the climate in the future, for example, at seasonal, interannual or decadal time scales. Because the future evolution of the climate system may be highly sensitive to initial conditions, has chaotic elements and is subject to natural variability, such predictions are usually probabilistic in nature (IPCC, 2022).

Climate projection: Simulated response of the climate system to a scenario of future emissions or concentrations of greenhouse gases (GHGs) and aerosols and changes in land use, generally derived using climate models. Climate projections are distinguished from climate predictions by their dependence on the emission/concentration/radiative forcing scenario used, which is in turn based on assumptions concerning, for example, future socio-economic and technological developments that may or may not be realized (IPCC, 2022).

Climate response: A general term for how the climate system responds to a radiative forcing (IPCC, 2022).

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

Climate indicator: Measures of the climate system, including large-scale variables and climate proxies. **Key climate indicators:** Key indicators constitute a finite set of distinct variables that may collectively point to important overall changes in the climate system of broad societal relevance across the atmospheric, oceanic, cryospheric and biospheric domains, with land as an implicit cross-cutting theme. Taken together, these indicators would be expected to both have changed and continue to change in the future in a coherent and consistent manner.

Climate metrics: Measures of aspects of the overall climate system response to radiative forcing, such as equilibrium climate sensitivity (ECS), transient climate response (TCR), transient climate response to cumulative CO_2 emissions (TCRE) and the airborne fraction of anthropogenic carbon dioxide.

Climate sensitivity: The change in the surface temperature in response to a change in the atmospheric carbon dioxide (CO_2) concentration or other radiative forcing. See also Climate feedback parameter. **Earth system sensitivity:** The equilibrium surface temperature response of the coupled atmosphere–ocean–cryosphere–vegetation–carbon cycle system to a doubling of the atmospheric carbon dioxide (CO_2) concentration is referred to as Earth system sensitivity. Because it allows ice sheets to adjust to the external perturbation, it may differ substantially from the equilibrium climate sensitivity derived from coupled atmosphere–ocean models. **Effective equilibrium climate sensitivity:** An estimate of the surface temperature response to a doubling of the atmospheric carbon dioxide (CO_2) concentration that is evaluated from model output or observations for evolving non-equilibrium conditions. It is a measure of the strengths of the climate feedbacks at a particular time and may vary with forcing history and climate state, and therefore may differ from equilibrium climate sensitivity. **Equilibrium climate sensitivity (ECS):** The equilibrium (steady state) change in the surface temperature following a doubling of the atmospheric carbon dioxide (CO_2) concentration from pre-industrial conditions. **Transient climate response (TCR):** The surface temperature response for the hypothetical scenario in which atmospheric carbon dioxide (CO_2) increases at 1% yr^{-1} from pre-industrial to the time of a doubling of atmospheric CO_2 concentration (year 70). **Transient climate response to cumulative CO_2 emissions (TCRE):** The transient surface temperature change per unit cumulative carbon dioxide (CO_2) emissions, usually 1000 GtC. TCRE combines both information on the airborne fraction of cumulative CO_2 emissions (the fraction of the total CO_2 emitted that remains in the atmosphere, which is determined by carbon cycle processes) and on the transient climate response (TCR) (IPCC, 2022).

Drought: An exceptional period of water shortage for existing ecosystems and the human population (due to low rainfall, high temperature and/or wind). **Megadrought:** A very lengthy and pervasive drought, lasting much longer than normal, usually a decade or more. **Hydrological drought:** A period with large runoff and water deficits in rivers, lakes and reservoirs. **Agricultural and ecological drought:** Agricultural and ecological drought (depending on the affected biome): a period with abnormal soil moisture deficit, which results from combined shortage of precipitation and excess evapotranspiration, and during the growing season impinges on crop production or ecosystem function in general. **Meteorological drought:** A period with an abnormal precipitation deficit (IPCC, 2022).

Emission Scenario: a plausible representation of the future development of emissions of substances that are potentially radiatively active (i.e., greenhouse gases, aerosols) based on a coherent and internally consistent set of assumptions about driving forces (such as demographic and socio-economic development, technological change, energy and land use) and their key relationships. Concentration scenarios, derived from emission scenarios, are used as input to a climate model to compute climate projections. In IPCC (1992) a set of emission scenarios was presented which were used as a basis for the climate projections in IPCC (1996). These emission scenarios are referred to as the IS92 scenarios. In the IPCC Special Report on Emissions Scenarios (IPCC, 2000a) emission scenarios, the so-called SRES scenarios, were published, some of which were used, among others, as a basis for the climate projections presented in Chapters 9 to 11 of IPCC WGI TAR (IPCC, 2001a) and Chapters 10 and 11 of IPCC WGI AR4 (IPCC, 2007) as well as in the IPCC WGI AR5 (IPCC, 2013b). New emission scenarios for climate change, the four Representative Concentration Pathways, were developed for, but independently of, the current IPCC assessment, AR5.

External Forcing: external forcing refers to a forcing agent outside the climate system causing a change in the climate system. Volcanic eruptions, solar variations and anthropogenic changes in the composition of the atmosphere and land-use change are external forcings. Orbital forcing is also an external forcing as the insolation changes with orbital parameters eccentricity, tilt and precession of the equinox.

Extreme Heat Event: three or more days of above-average temperatures, generally defined as passing a certain threshold (for example, above the 85th percentile for average daily temperature in a year).

Extreme weather event: An event that is rare at a particular place and time of year. Definitions of 'rare' vary, but an extreme weather event would normally be as rare as or rarer than the 10th or 90th percentile of a probability density function estimated from observations. By definition, the characteristics of what is called extreme weather may vary from place to place in an absolute sense (IPCC, 2022).

Flood: the overflowing of the normal confines of a stream or other body of water, or the accumulation of water over areas not normally submerged. Floods include river (fluvial) floods, flash floods, urban floods, pluvial floods, sewer floods, coastal floods and glacial lake outburst floods.

Global Warming: the gradual increase, observed or projected, in global surface temperature, as one of the consequences of radiative forcing caused by anthropogenic emissions.

Hazard: the potential occurrence of a natural or human-induced physical event or trend or physical impact that may cause loss of life, injury, or other health impacts, as well as damage and loss to property, infrastructure, livelihoods, service provision, ecosystems and environmental resources. Here, hazard usually refers to climaterelated physical events or trends or their physical impacts.

Heat Wave: while there is no universally accepted definition, heat waves are understood to be periods of unusually hot and dry or hot and humid weather that have a subtle onset and cessation, a duration of at least two–three days, usually with a discernible impact on human and natural systems. Because there is no absolute universal value, such as a given temperature that defines what is extreme heat, heatwaves are relative to a location's climate: the same meteorological conditions can constitute a heatwave in one place but not in another.

Paleoclimate: the study of previous climates that have existed during Earth's different geologic ages.

Representative Concentration Pathways (RCPs): scenarios that include time series of emissions and concentrations of the full suite of greenhouse gases and aerosols and chemically active gases, as well as land use/land cover. Representative signifies that each RCP provides only one of many possible scenarios that would lead to the specific radiative forcing characteristics. Pathway emphasizes that not only the long-term concentration levels are of interest, but also the trajectory taken over time to reach that outcome. RCPs usually refer to the portion of the concentration pathway extending up to 2100, for which Integrated Assessment Models produced corresponding emission scenarios (IPCC, 2013). **RCP2.6:** One pathway where radiative forcing peaks at approximately 3 watts per meter2 (W/m2) before 2100 and then declines (the corresponding ECP assuming constant emissions after 2100). **RCP4.5 and RCP6.0:** Two intermediate stabilization pathways in which radiative forcing is stabilized at approximately 4.5 W/m2 and 6.0 W/m2 after 2100 (the corresponding ECPs assuming constant concentrations after 2150). **RCP8.5:** One high pathway for which radiative forcing reaches >8.5 W/m2 by 2100 and continues to rise for some amount of time (the corresponding ECP assuming constant emissions after 2100 and constant concentrations after 2250).

Greenhouse gases (GHGs): Gaseous constituents of the atmosphere, both natural and anthropogenic, that absorb and emit radiation at specific wavelengths within the spectrum of radiation emitted by the Earth's surface, by the atmosphere itself, and by clouds. This property causes the greenhouse effect. Water vapour (H_2O), carbon dioxide (CO_2), nitrous oxide (N_2O), methane (CH_4) and ozone (O_3) are the primary GHGs in the Earth's atmosphere. Human-made GHGs include sulphur hexafluoride (SF_6), hydrofluorocarbons (HFCs), chlorofluorocarbons (CFCs) and perfluorocarbons (PFCs); several of these are also O_3 -depleting (and are regulated under the Montreal Protocol) (IPCC, 2022).

Greenhouse effect: The infrared radiative effect of all infrared-absorbing constituents in the atmosphere. Greenhouse gases (GHGs), clouds, and some aerosols absorb terrestrial radiation emitted by the Earth's surface and elsewhere in the atmosphere. These substances emit infrared radiation in all directions, but, everything else being equal, the net amount emitted to space is normally less than would have been emitted in the absence of these absorbers because of the decline of temperature with altitude in the troposphere and the consequent weakening of emission. An increase in the concentration of GHGs increases the magnitude of this effect; the difference is sometimes called the enhanced greenhouse effect. The change in a GHG concentration because of anthropogenic emissions contributes to an instantaneous radiative forcing. Earth's surface temperature and troposphere warm in response to this forcing, gradually restoring the radiative balance at the top of the atmosphere (IPCC, 2022).

Intergovernmental Panel on Climate Change (IPCC): The Intergovernmental Panel on Climate Change (IPCC) is the leading international body for the assessment of climate change. It was established by the United Nations Environment Programme (UNEP) and the World Meteorological Organisation (WMO) to provide the world with a clear scientific view on the current state of knowledge in climate change and its potential environmental and socio-economic impacts[14].

Session III: Atmosphere-Ocean Interaction

In this section fundamentals of atmospheric-ocean interaction will be discussed as well as some prominent atmosphere-ocean interactions (e.g ENSO, IOD, etc) will be discussed.

1. El Niño-Southern Oscillation (ENSO)

El Niño-Southern Oscillation (ENSO)[15]: The term El Niño was initially used to describe a warm-water current that periodically flows along the coast of Ecuador and Peru, disrupting the local fishery.

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[14] http://www.ipcc.ch/organization/organization.shtml#.UV0NEqLwnw0

[15] IPCC, 2021: Climate Change 2021: The Physical Science Basis. Contribution of Working Group I to the Sixth Assessment Report of the Intergovernmental Panel on Climate Change [Masson-Delmotte, V., P. Zhai, A. Pirani, S.L. Connors, C. Péan, S. Berger, N. Caud, Y. Chen, L.

It has since become identified with a basin-wide warming of the tropical Pacific Ocean east of the dateline. This oceanic event is associated with a fluctuation of a global scale tropical and subtropical surface pressure pattern called the Southern Oscillation. This coupled atmosphere–ocean phenomenon, with preferred time scales of two to about seven years, is known as the El Niño-Southern Oscillation (ENSO). It is often measured by the surface pressure anomaly difference between Tahiti and Darwin or the sea surface temperatures in the central and eastern equatorial Pacific. During an ENSO event, the prevailing trade winds weaken, reducing upwelling and altering ocean currents such that the sea surface temperatures warm, further weakening the trade winds. This event has a great impact on the wind, sea surface temperature and precipitation patterns in the tropical Pacific. It has climatic effects throughout the Pacific region and in many other parts of the world, through global teleconnections. The cold phase of ENSO is called La Niña.

2. Indian Ocean Dipole (IOD)

Indian Ocean Dipole (IOD): A mode of interannual variability that features an east–west dipole of sea surface temperature anomalies in the tropical Indian Ocean. Its positive phase shows concurrent sea surface cooling off Sumatra and Java and warming off Somalia in the west, combined with anomalous surface easterlies along the equator, while the opposite anomalies are seen in the negative phase. The IOD typically develops in boreal summer and matures in boreal autumn and controls part of the rainfall interannual variability in Australia, South Eastern Asia and Eastern Africa. See Section AIV.2.4 in Annex IV of the AR6 WGI report for further demonstration.

3. Pacific Decadal Oscillation (PDO)

Pacific Decadal Variability (PDV): Coupled decadal-to-inter-decadal variability of the atmospheric circulation and underlying ocean that is typically observed over the entire Pacific Basin beyond the El Niño–Southern Oscillation (ENSO) time scale. In the AR6 WGI report, PDV encapsulates the Pacific Decadal Oscillation (PDO), the South Pacific Decadal Oscillation (SPDO), tropical Pacific decadal variability (also called decadal ENSO), and the Inter-decadal Pacific Oscillation (IPO). Typically, the positive phase of the PDV is characterized by anomalously high sea surface temperatures in the

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Goldfarb, M.I. Gomis, M. Huang, K. Leitzell, E. Lonnoy, J.B.R. Matthews, T.K. Maycock, T. Waterfield, O. Yelekçi, R. Yu, and B. Zhou (eds.)]. Cambridge University Press, Cambridge, United Kingdom and New York, NY, USA, 2391 pp. doi:10.1017/9781009157896.

central-eastern tropical Pacific that extend to the extratropical North and South Pacific along the American coasts, encircled to the west by cold sea surface anomalies in the mid-latitude North and South Pacific. The negative phase is accompanied by sea surface temperature anomalies of the opposite sign. Those sea surface temperature anomalies are linked to anomalies in atmospheric and oceanic circulation throughout the whole Pacific Basin. The PDV is associated with decadal modulations in the relative occurrence of El Niño and La Niña.

Inter-decadal Pacific Oscillation (IPO): An equatorially symmetric pattern of sea surface temperature variability at decadal-to-inter-decadal time scales. While the Pacific Decadal Oscillation (PDO) and its South Pacific counterpart, the South Pacific Decadal Oscillation (SPDO), are considered as physically distinct modes, the tropical Pacific decadal–inter-decadal variability can drive both the PDO and SPDO, forming the IPO as a synchronized pan-Pacific variability. Its spatial pattern of sea surface temperature anomalies is similar to that of the El Niño–Southern Oscillation (ENSO), but with a broader meridional extent in the tropical signal and more weights in the extratropics compared to the tropics.

Pacific Decadal Oscillation (PDO): The leading mode of variability obtained from decomposition in empirical orthogonal function of sea surface temperature over theNorth Pacific north of 20°N, and characterized by a strong decadal component. The positive phase of the PDO features a dipole of sea surface temperature anomalies in the North Pacific, with a cold lobe near the centre of the basin and extending westward along the Kuroshio, encircled by warmer conditions along the coast of North America and in the subtropics. A positive PDO is accompanied by an intensified Aleutian Low and an associated cyclonic circulation enhancement leading to teleconnections over the continents adjacent to the North Pacific.

4. Atlantic Multidecadal Variability (AMV)

Atlantic Multi-decadal Variability (AMV): Large-scale fluctuations observed from one decade to the next in a variety of instrumental records and proxy reconstructions over the entire North Atlantic ocean and surrounding continents. Fingerprints of AMV can be found at the surface ocean, which is characterized by swings in basin-scale sea surface temperature anomalies reflecting the interaction with the atmosphere. The positive phase of the AMV is characterized by anomalous warming over the entire North Atlantic, with the strongest amplitude in the subpolar gyre and along sea ice margin zones in the Labrador Sea and Greenland/Barents Sea and in the subtropical North Atlantic basin to a lower extent.

Tropical Atlantic Variability (TAV) A generic term to describe the climate variability of the tropical Atlantic which is dominated at interannual to decadal time scales by two main climate modes: the Atlantic Zonal Mode (AZM) and the Atlantic Meridional Mode (AMM). The Atlantic Zonal Mode, also commonly referred to as the Atlantic Niño or Atlantic equatorial mode, is associated with sea surface temperature anomalies near the equator, peaking in the eastern basin, while the Atlantic meridional mode is characterized by an inter-hemispheric gradient of sea surface temperature and wind anomalies. Both modes are associated with significant teleconnections over Africa and South America. Atlantic Meridional Mode (AMM) The Atlantic Meridional Mode (AMM) refers to the interannual to decadal variability of the cross-equatorial sea surface temperature gradients and surface wind anomalies in the tropical Atlantic. It modulates the strength and latitudinal shifts of the Inter-tropical Convergence Zone (ITCZ), which impacts regional rainfall over Northeast Brazil and Atlantic hurricane activity.

Atlantic Zonal Mode (AZM) An equatorial coupled mode in the Atlantic similar to El Niño–Southern Oscillation (ENSO) in the Pacific,and therefore sometimes referred to as the Atlantic Niño. The AZM is associated with sea surface temperature anomalies near the equatorial Atlantic and rainfall disturbances over the African monsoon domain. Its variations are mostly observed in the interannual scale. It is called also Atlantic equatorial mode.

5. North Atlantic Oscillation (NAO)

North Atlantic Oscillation (NAO) The leading mode of large-scale atmospheric variability in the North Atlantic basin characterized by alternating (see-saw) variations in sea level pressure or geopotential height between the Azores High in the subtropics and the Icelandic Low in the mid- to high latitudes, with some northward extension deep into the Arctic. It is associated with fluctuations in the strength and latitudinal position of the main westerly winds across a vast North Atlantic–Europe domain, and thus with fluctuations in the embedded extratropical cyclones and associated frontal systems leading to strong teleconnection over the entire North Atlantic adjacent continents. The positive and negative phases of the NAO show similar characteristics described for the Northern Annular Mode (NAM).

6. Madden-Julian Oscillation (MJO)

Madden–Julian Oscillation (MJO) The largest mode of tropical atmospheric intra-seasonal variability with typical periods ranging from 20 to 90 days. The MJO corresponds to planetary-scale disturbances of pressure, wind and deep convection moving predominantly eastward along the equator. As it progresses, the MJO is associated with the temporal alternation of large-scale enhanced and suppressed rainfall, with maximum loading over the Indian and western Pacific oceans, although influences of the MJO can be tracked over the Atlantic/Africa in dynamical fields.

Session III: Causes and mechanisms of climate change and variability

1. Causes climate variability

Climate variability: Deviations of climate variables from a given mean state (including the occurrence of extremes, etc.) at all spatial and temporal scales beyond that of individual weather events. Variability may be intrinsic, due to fluctuations of processes internal to the climate system (internal variability), or extrinsic, due to variations in natural or anthropogenic external forcing (forced variability). **Decadal variability:** Decadal variability refers to climate variability on decadal time scales. **Internal variability:** Fluctuations of the climate dynamical system when subject to a constant or periodic external forcing (such as the annual cycle). **Natural variability:** Natural variability refers to climatic fluctuations that occur without any human influence, that is, internal variability combined with the response to external natural factors such as volcanic eruptions, changes in solar activity and, on longer time scales, orbital effects and plate tectonics (IPCC, 2022).

Global and local causes of climate variability will be discussed in detail with appropriate figures , demonstrations, examples

Anthropogenic emissions contribution for climate variation

Global and local causes of extreme events will be discussed in detail with appropriate figures , demonstrations, examples

Anthropogenic emissions contribution for climate extreme events

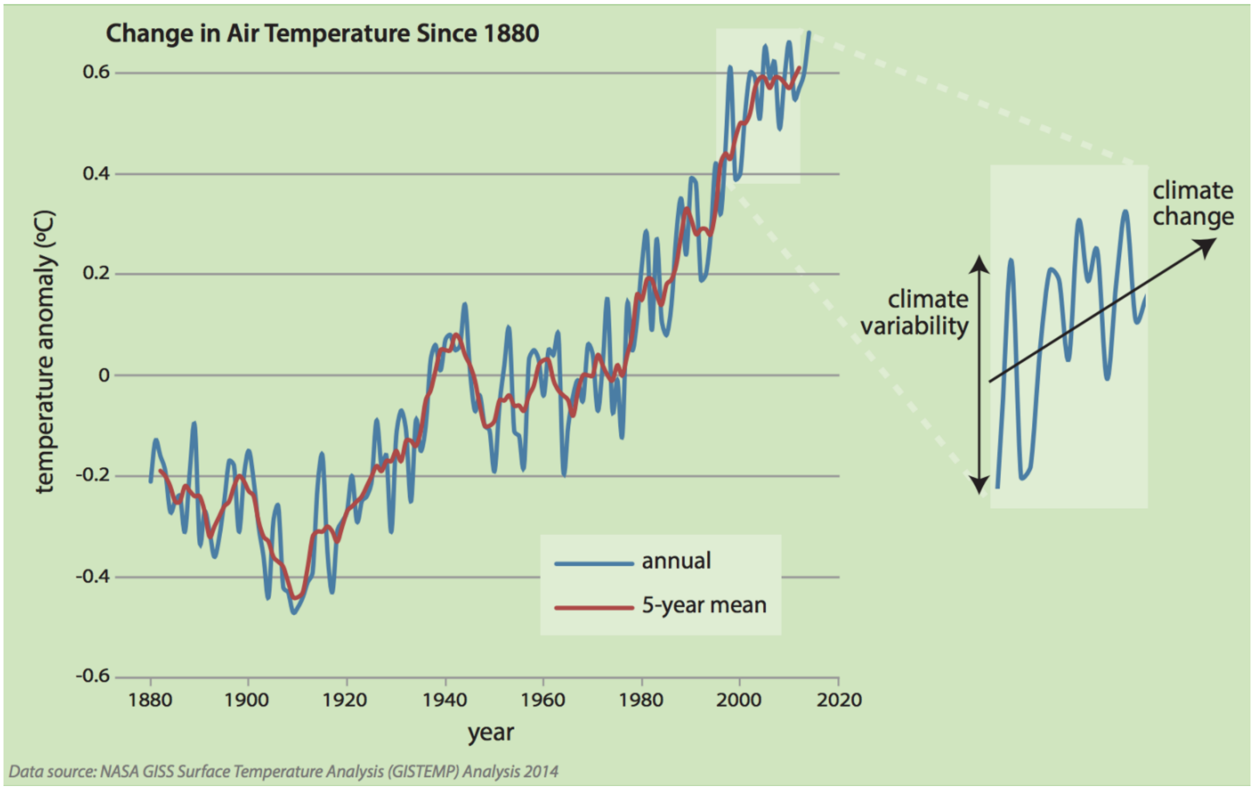


Figure 23 Climate variability is often natural, however climate change is causing an increase in the probability of many extreme weather events, and those events contribute to climate variability.

Extreme events are specific weather events that depart from the average in some significant. For example, days that exceed 100° F (37.8° C) are called extreme heat events in many locations. While it's possible that any given summer day might be over 100° F, climate warming is causing the frequency of extreme heat days to increase. In other words, the probability of a summer day with extreme hear is becoming higher as climate warms.

Extreme precipitation events are also important. Precipitation patterns that deviate significantly from the average can result in droughts or floods. The flooding in Texas in August 2017 caused by Hurricane Harvey is a recent and devastating example of an extreme precipitation event.

As we have seen, climate variability describes short-term changes in climate that take place over months, seasons and years. This variability is the result of natural, large-scale features of the climate that we looked at earlier. It is likely that you have heard of El Niño and La Niña, these are the two phases of the El Niño-Southern Oscillation (sometimes shortened to ENSO – see Figure 24) which is the most important driver of year-to-year variability in climate in the Pacific region. The different phases of ENSO can cause droughts and floods. Each El Niño and La Niña event is different and so they have different impacts. El Niño and La Niña events drive changes in circulation, winds, rainfall and ocean surface temperatures.

Normal conditions, or the neutral phase of ENSO, is shown on the left in Figure 24. The trade winds (white arrows) blow to the west and cause a build up of warm surface water (orange-red areas) and higher sea level in the West Pacific. The warm water heats the air above it, making the moist air rise and forming clouds (this is called convection). This warmer air then moves east to where the air is cooler, the cooler air sinks towards the surface and moves west, creating a convective circulation.

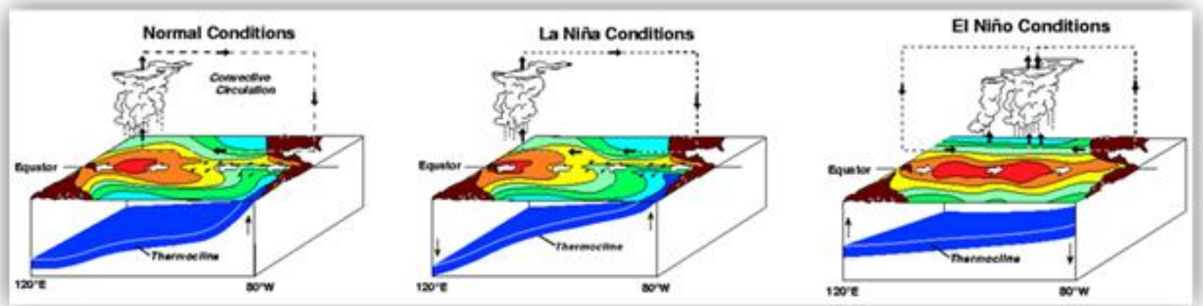


Figure 24 Three-dimensional depiction of three important phases of the El Niño-Southern Oscillation (ENSO): Normal (left), La Niña (centre) and El Niño (right). (Image source: NOAA, http://www.pmel.noaa.gov/tao/elnino/nino-home.html).

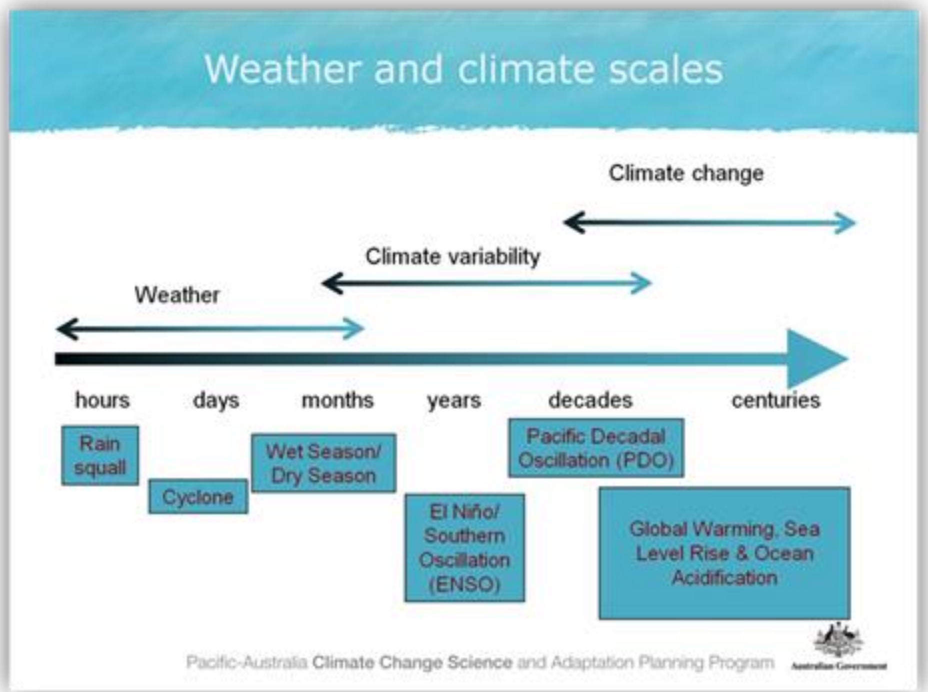
Under La Niña conditions, shown in the centre of Figure 24, ocean temperatures across the central and eastern tropical Pacific Ocean are cooler than normal (blue and green areas) and the easterly trade winds are stronger than normal across the Pacific Ocean. La Niña usually brings wetter than normal conditions to countries like Australia, Niue and Tonga because rainfall moves farther to the south-west than under normal conditions.

El Niño (Figure 24, right) brings extensive warming of the central and eastern Pacific and weaker than normal (easterly) trade winds leading to a major shift in weather patterns across the Pacific. Typical El Niño conditions in the northern hemisphere winter result in the western Pacific experiencing very dry conditions and the central Pacific around the equator experiencing wetter conditions. The 1997 El Niño brought drought to countries like Papua New Guinea

2. Causes of climate change

Advances in the science and observation of climate change are providing a clearer understanding of the inherent variability of Earth's climate system and its likely response to human and natural influences. The implications of climate change for the environment and society will depend not only on the response of the Earth system to changes in radiative forcings, but also on how humankind responds through changes in technology, economies, lifestyle and policy. Extensive uncertainties exist in future forcings of and responses to climate change, necessitating the use of scenarios of the future to explore the potential consequences of different response options. To date, such scenarios have not adequately examined crucial possibilities, such as climate change mitigation and adaptation, and have relied on research processes that slowed the exchange of information among physical, biological and social scientists. Here we describe a new process for creating plausible scenarios to investigate some of the most challenging and important questions about climate change confronting the global community.

The big arrow in Figure 25 refers to different periods of time – days, months, years, decades and centuries. We can see here that weather refers to hours, days and maybe months; climate refers to months, years and decades, and climate change refers to decades and centuries. Examples of weather are rain storms that might last one or two hours and tropical cyclones that may last days. Climate variability can be defined by climate patterns such as the El-Niño Southern Oscillation and climate change refers to things which happen over centuries, like global warming.



Weather and climate scales

Climate change

Climate variability

Weather

hours days months years decades centuries

Rain squall

Cyclone

Wet Season/ Dry Season

El Niño/ Southern Oscillation (ENSO)

Pacific Decadal Oscillation (PDO)

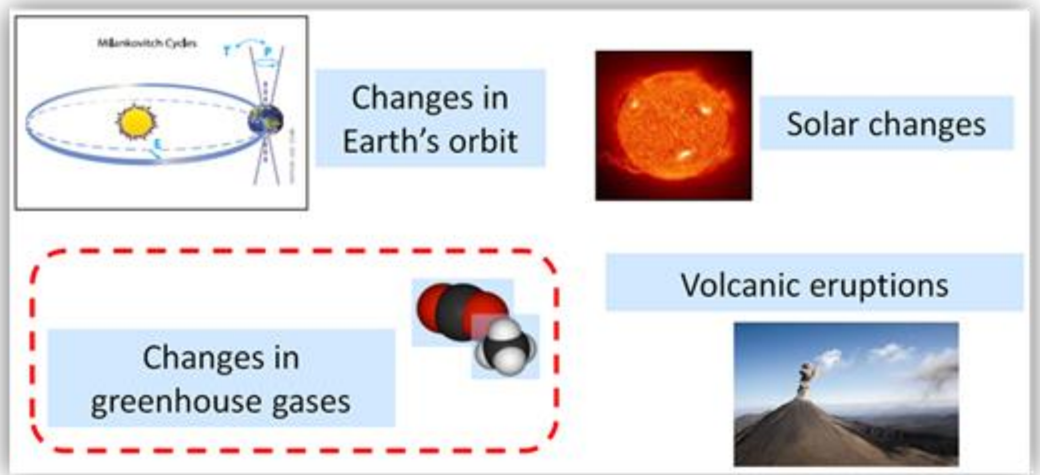
Global Warming, Sea Level Rise & Ocean Acidification

Pacific-Australia Climate Change Science and Adaptation Planning Program

Australian Government

Figure 25 A guide to the timescales applicable to weather, climate variability and climate change.

Further discussion with different factors (Anthropocentric,natural, large-scale) with connection of climate change will be discussed. The Earth's climate has changed over the centuries and millennia due to a number of different factors (see Figure 26).



Changes in Earth's orbit

Solar changes

Changes in greenhouse gases

Volcanic eruptions

Figure 26 Factors that lead to changes in the Earth's climate.

3. Human Impact and Climate Feedbacks

In this section discussion with atmospheric pollution anthropogenic redistribution of

By matter

By energy

will be discussed

Impacts these pollution in different sectors will be part of this section.

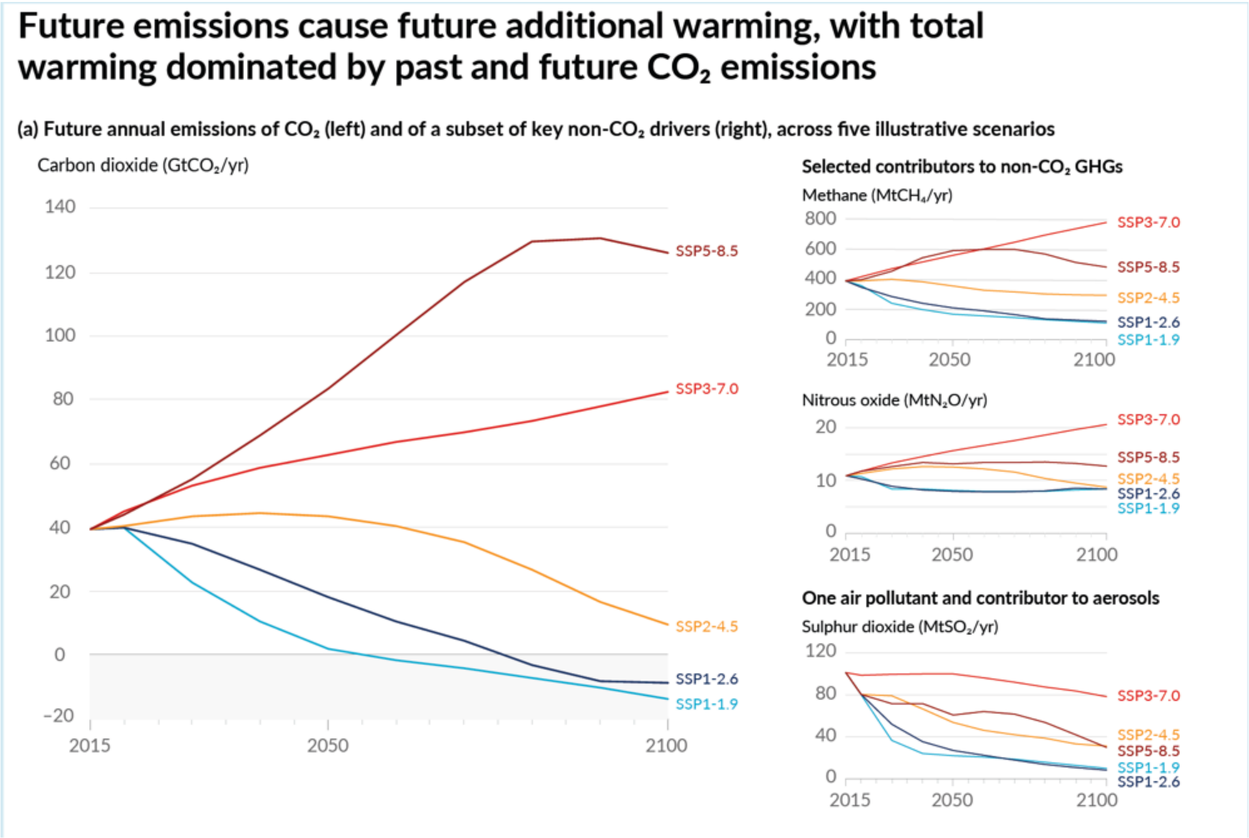
Session IV: Observed trends and impacts of climate change

Detection of past climate patterns requires accurate, long-period and representative records of the components of the global climate system. In most regions, such records are missing. The situation is worst in Africa. Most of the current information on climate change is largely based on the last three IPCC reports. The New IPCC report AR6 will be discussed (observed change of temperature, precipitation, sea surface temperature, sea level rise, glacial melting, etc with its impacts in different sectors)

Session V: Projected trends and impacts of climate change

1. Future Projections and Adaptations

Since many scientists started calling attention to the issue of climate change in the 1980s, there has been increasing concern about this critical issue. The Intergovernmental Panel on Climate Change (IPCC) is a consortium of thousands of scientists all over the world who analyze peer reviewed literature on the topic and conduct modeling studies for periodic reports on this critically important issue. The latest IPCC Report (the sixth Assessment Report) just came out within the last few months. The webpage can be found here: https://www.ipcc.ch/. The work is divided into three working groups: WGI on the physical science, WGII on impacts, adaptation and vulnerability and WGIII on mitigation. The work done by the second group can potentially help inform society on how to adapt to the climate risks and changes that are already upon us. The work done by WGIII can help us to develop energy systems and societal structures that enable more sustainable living. The scenarios used in IPCC AR6 (2022) are shown below.



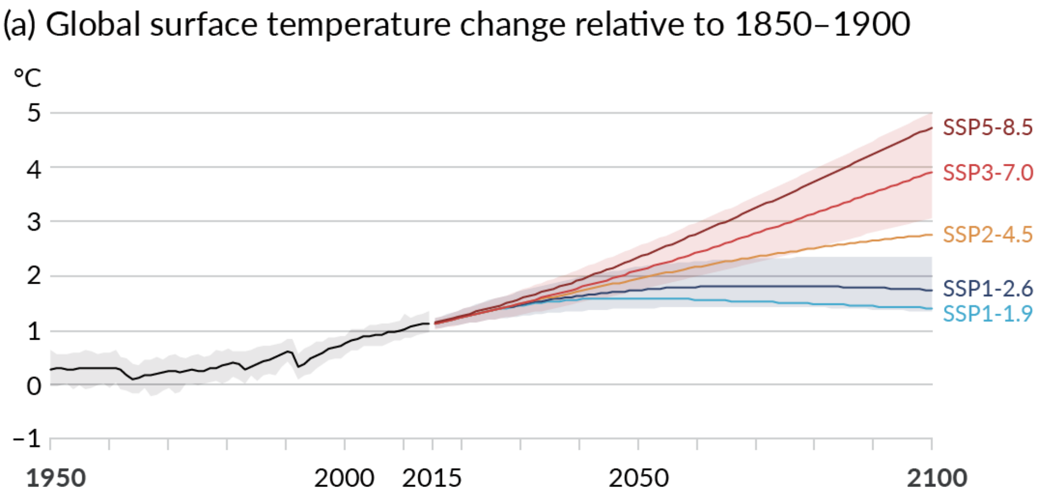


Figure 27 Greenhouse Gas Emissions projections from the Shared Socioeconomic Pathways – IPCC, AR6

These differences in emissions trajectories are expected to produce a range of different outcomes. The projected changes in the global average temperature are shown in Figure 1.5.7.

Figure 28 Observed and simulated global surface temperature change relative to the 1850-1900 mean temperature for the different SSP emissions scenarios, IPCC, AR6

While there are many findings and analyses for many regions of the globe within the IPCC, the key messages with relevance for Ethiopia are that temperatures are likely to become hotter, heat waves are likely to become more frequent, cool spells are likely to happen less frequently and both droughts and floods are likely to become more frequent. The reason behind the increase in temperatures and heat extremes is fairly self-evident. But the reason for the anticipated increase of both droughts and floods is part of a broader narrative of "hydrological intensification". As the atmosphere warms and can retain more water vapor, stronger, wetter storms are possible – and so flooding risk and intense precipitation risk is likely to increase. But heat extremes can also exacerbate and intensify (and be exacerbated by) drought conditions by increasing the rate of evapotranspiration from the land surfaces and vegetation. When there is less soil moisture and moisture in plants, the Earth's radiated energy does more to directly heat the surface. When some of the energy the Earth emits is absorbed by soil moisture and vegetation, the warming impact is reduced. This feedback between heat and drought can enhance the likelihood of soil desiccation, crop damage and wild-fires. The spatial distribution of rainfall and drought extremes over time depends on the dynamics of individual storm systems and the phenomenon of atmospheric "blocking" patterns which may cause dry, subsiding air to persist over some regions while preventing a heavy rainstorm from moving quickly. It may be difficult to predict how an individual extreme event is likely to unfold, but many regions of the world are expected to see increases in the frequency of both flooding and drought under climate change.

These changes in the climate system are likely to have significant impacts on ecosystems and the water, agriculture, energy and health sectors. Climate change may also amplify risks to urban dwellers or lead to some migration. However, there are a range of recommended approaches to managing climate risks; including developing early warning systems, community engagement-based projects, ecology-based adaptation measures, integration of climate adaptation into social protection plans and livelihood diversification.

Main points

- ✓ Our climate is changing and changing very rapidly
- ✓ Many factors control climate but main reason for change is increasing greenhouse gases, especially carbon dioxide

- ✓ Reason for that increase carbon dioxide is extremely rapid population growth and corresponding increased demand for energy and resources
- ✓ Carbon dioxide levels in the atmosphere have risen due to anthropogenic burning of fossil fuels and land use change

2. What is our climate going to be like by 2100?

Potential for sudden shifts in climate state that involve ocean circulation/sea ice changes/biosphere changes

Ice sheet volume loss – will the flow of the big ice sheets change enough to significantly affects the amount of sea level rise expected in a warming world?

But by far the biggest uncertainty going forward are human factors

Changes by 2100: Temperature

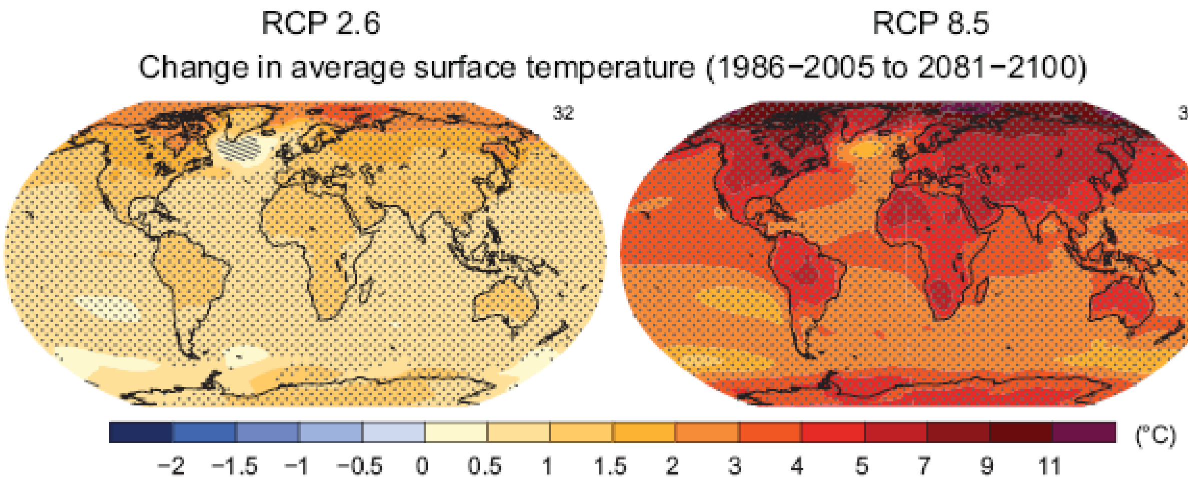


Figure 29 **Low estimate: 1.5°C ~2.5°F, High estimate: 4°C ~ 6°F**

Changes by 2100: Precipitation

Contrast between wet and dry regions and wet and dry seasons will increase modelling precipitation is very hard to do so much less certainty

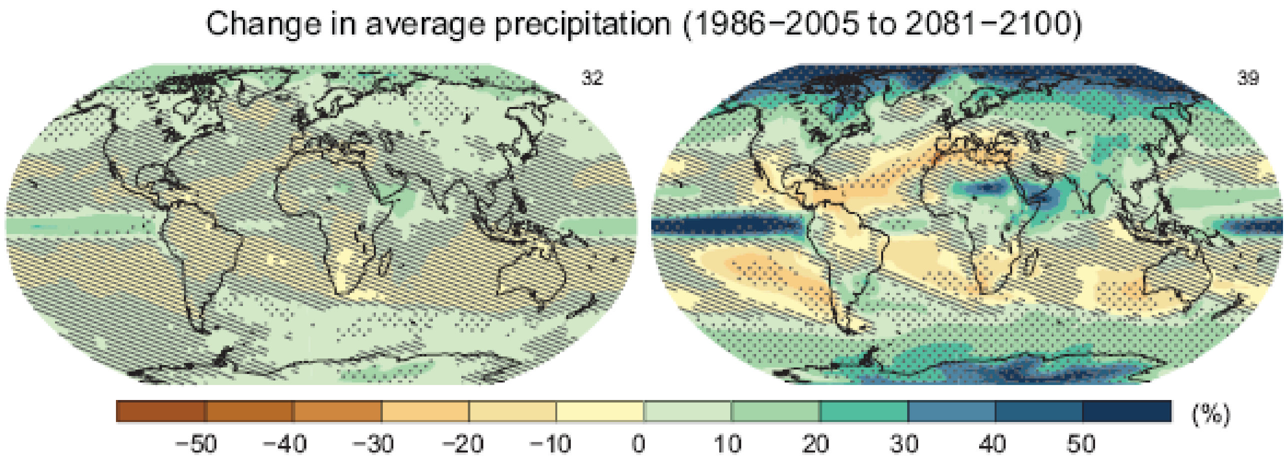


Figure 30 **Changes by 2100: Precipitation**

Changes by 2100: Cryosphere

Continued melting of cryosphere components e.g. sea ice

Changes by 2100: Sea level

Projected sea level rise = 45 – 75 cm

Further sea level rises would continue after 2100 as the oceans take a long time to warm and icesheets continue to melt

Changes by 2100: Ocean pH

3. How will that effect humans and natural ecosystems?

Key message

Snowpack and streamflow amounts are projected to decline, decreasing water supply for cities, agriculture, and ecosystems.

Reduced yield of high-value specialty crops due to higher temperatures and increased competitions for scarce water supplies.

Increased warming and drought will increase wildfires and impacts of wildfire on people and ecosystems.

Flooding and erosion in coastal areas due to sea level rise.

Higher temperature and resulting disruptions to urban electricity and water supplies will pose increased threats and costs to public health.

4. What can we do to avoid the most extreme changes?

The world will not end if we do not stop burning fossil fuels but it will be drastically different – the question is how much adaptation is needed and what kind of world do we WANT to live in?

In the world, we will not necessary experience the worst changes and we have resources to adapt. What responsibility do we have for those who do not or will suffer more as a result our activities and way of life?

How much responsibility should we take given that current CO_2 levels are mostly as a result of activities in the developed world?

What right do we have to restrict how much CO_2 developing countries are using to improve the standard of life for its residents?

How much are you willing to alter your way of life to prevent these changes?

What role should the government have? To what extent?

5. Climate change in context (politics of greenhouse gases, international/national concern and interest)

Climate change entered the political agenda in 1988 with the Toronto Conference on the Changing Atmosphere and has experienced fluctuations in attention levels ever since. National governments committed themselves to addressing climate change through the adoption of the United Nations Framework Convention on Climate Change (UNFCCC) in 1992, marking a peak in political attention. The parties to the UNFCCC have met annually from 1995 onwards at the Conference of the Parties (COP) to evaluate progress in tackling climate change. Important milestones were reached, first in 1997 with the establishment of the Kyoto Protocol to limit the greenhouse gas (GHG) emissions of industrialized countries. This was followed in 2015 by the adoption at COP21 of the Paris Agreement, which relies on nationally determined contributions (NDCs), that is, efforts by each country to reduce national GHG emissions (see, e.g., Falkner, 2016; Morrison et al., 2017; Tobin, 2017; Tobin et al., 2018). All countries that have ratified the Paris Agreement are obliged to report regularly on the adoption and implementation of policy measures that reduce GHG emissions, thereby helping them reach their self-determined goals – a common mechanism in various areas of international governance (see, e.g., Sawer, 2021).

1. The United Nations Framework Convention on Climate Change (UNFCCC) and Its Instruments

The section provides some information on the United Nations Framework Convention on Climate Change (UNFCCC), its associated instruments, together with other related subjects.

The United Nations Framework Convention on Climate Change (UNFCCC)

Climate change is considered to be one of the most serious threats to sustainable development, with adverse impacts expected on the environment, human health, food security, economic activity, natural resources and physical infrastructure. Global climate varies naturally, but scientists agree that rising concentrations of anthropogenically emitted greenhouse gases in the Earth's atmosphere are leading to changes in the climate. The international political response to climate change began with the adoption of the United Nations Framework Convention on Climate Change (UNFCCC) in 1992. The UNFCCC sets out a framework for action aimed at stabilizing atmospheric concentrations of greenhouse gases in order to avoid "dangerous anthropogenic interference" with the climate systems. The UNFCCC entered into force in March

The Kyoto Protocol

In 1995, the first meeting of the Conference of the Parties (COP 1) established the Ad hoc Group on the Berlin Mandate, and charged it with reaching agreement on strengthening efforts to combat climate change. In December 1997 in Kyoto Japan, delegates agreed to a Protocol to the UNFCCC that commits developed countries and countries making the transition to a market economy (Annex 1 Parties) to achieve quantified emission reduction targets. It contains legally binding emissions targets for Annex I countries for the post-2000 period. These countries commit themselves to reduce their collective emissions of six key greenhouse gases by at least 5% below 1990 levels between 2008 – 2012 (the first commitment period) with specific targets varying from Country to Country.

Each country's emissions target is to be calculated as an average over the five years. "Demonstrable progress" towards meeting the target must be made by 2005. Cuts in the three most important gases – carbon dioxide (CO_2), methane (CH_4), and nitrous oxide (N_20) - will be measured against a base year of 1990 (with exceptions for some countries with economies in transition). The Protocol also established three mechanisms to assist Annex I Parties in meeting their national targets cost-effectively namely: an emissions trading system; Joint Implementation (JI) of emission – reduction projects between Annex I Parties; and a Clean Development Mechanism (CDM) that encourages projects with sustainable development benefits to be hosted by Non-Annex I (developing Country) Parties. The Kyoto Protocol came into force on 16th February 2005.

The Conference of the Parties (COP) and Subsidiary Body for Scientific and Technical Advice (SBSTA)

The Conference of the Parties (COP) is the 'Supreme body' of the Climate Change Convention. It is responsible for keeping international efforts to address climate change on track. It reviews the implementation of the Convention and examines the commitments of Parties in light of the Convention's objective, new scientific findings and experience gained in implementing climate change policies. A key task is to review the National Communications submitted by Parties. Based on this information, the COP assesses the effects of measures taken by Parties and the progress made in achieving the ultimate objective of the Convention.

The Convention also established two standing 'subsidiary bodies': the Subsidiary Body for Scientific and Technical Advice (SBSTA) and the Subsidiary Body for Implementation (SBI). These bodies give advice to the COP and each has a specific mandate. SBSTA's task is to provide the COP with advice on scientific, technological and methodological matters relating to the Convention. It serves as the link between the scientific information provided by expert sources such as the Intergovernmental Panel on Climate Change (IPCC) on the one hand, and the policy-oriented needs of the COP on the other. The SBSTA works closely with the IPCC, sometimes requesting specific studies from it. The Conference of the Parties (COP) of the Convention also serves as the meeting of the Parties (MOP) for the Protocol. This structure has been established to facilitate the management of the intergovernmental process. Parties to the Convention that are not Parties to the Protocol will be able to participate in Protocol-related meetings as observers.

The National Communication (NC)

The National Communication (NC) is a collective effort of relevant stakeholders for highlighting the national actions needed in addressing climate change issues, including adaptation options for addressing adverse climate change impacts and GHG mitigation options in various socio-economic sectors. Data and information reported would have implications for national planning and for future funding of projects (e.g., CDM, etc), and hence they must be as accurate as possible. It is a useful document that should be fully integrated with the national sustainable development plan.

The National Communication should contain the following among others a national inventory of anthropogenic emissions by sources and removal by sinks of all GHGs; a general description of steps taken or envisaged by the non-Annex I Party to implement the Convention and any other information considered relevant to the achievement of the objective of the .

The Clean Development Mechanism (CDM)

The purpose of the Clean Development Mechanism (CDM) is to assist parties not included in Annex1 of UNFCCC in achieving sustainable development and in contributing to the ultimate objective of the Convention and to assist Parties included in Annex 1". One issue of great concern to African countries is the lack of CDM projects in sub-Saharan Africa and the resulting imbalance in the geographical distribution of the CDM. Africa accounts for less than three percent of the value of total CDM transactions worldwide, and sub-Saharan Africa for less than 2 percent.

There are a number of causes contributing to the lack of CDM projects in Africa and these include:

- ✓ Lack of enabling CDM investment environments;
- ✓ Inadequate access to commercial credit;
- ✓ Low level of fossil fuel use resulting in few opportunities to reduce emissions.

The Least Developed Countries Fund (LDCF) and the National Adaptation Programmes of Action (NAPA)

Adaptation is vital, even if countries reduce their greenhouse gas emissions, and also sustainable development attained in any country. Any successful adaptation strategy needs to be based on sound scientific assessment. In response to this need, the Nairobi work programme on impacts, vulnerability and adaptation to climate change was launched in 2005. The objective of the five-year programme is to help countries improve their understanding of the impacts of climate change and to make informed decisions on practical adaptation actions and measures.

Developing countries are the most vulnerable to climate change impacts. A number of developing countries have drawn up adaptation plans or are in the process of finalizing them. This includes the National Adaptation Programmes of Action (NAPAs) of least developed countries. The NAPAs allow identification of priority activities that respond to immediate needs and concerns for adaptation to climate change. They build upon existing coping strategies at the grassroots level and promote the use of relevant traditional knowledge and practice.

The Least Developed Countries Fund (LDCF) was also established to assist Least Developed Country Parties (LDCs) carry out, inter alia, the preparation and implementation of National Adaptation Programme of Action (NAPA). In order to address the urgent adaptation needs of LDCs, NAPAs focus on enhancing adaptive capacity to climate variability, which itself would help address the adverse effects of climate change (See http://unfccc.int/essential_background/kyoto_protocol/items/1678.php)

1.6.2. Millennium Development Goals (MDGs)

The world's concern about the human condition in the 21st Century is voiced in the Millenium Declaration, which calls on governments to put in place actions that will lead to noticeable improvements in the human condition by 2015. The dream of making significant differences in human well being by 2015 is given concrete expression in the Millenium Development Goals (MDGs); a set of quantified and time-bound targets for reducing poverty by 2015.

The MDGs give governments a common framework for structuring policies and practices. The framework facilitates speed and efficiency in complying with the MDG spirit in planning, budgeting and monitoring at the national level. The MDGs also bring clarity to the shared and individual roles and responsibilities of key actors: of Governments to achieve or enable the achievement of goals and targets; of the network of international organizations to marshal their resources and expertise in the most strategic and efficient way possible to support and sustain the efforts of partners at the global and country levels; and of citizens, civil society organizations and the private sector to engage fully in tremendously improving human conditions by 2015. The goals are as listed below:

- Goal 1: Eradicate Extreme Poverty And Hunger.

- Goal 2: Achieve Universal Primary Education.
- Goal 3: Promote Gender Equality And Women Empowerment.
- Goal 4: Reduce Child Mortality
- Goal 5: Improve Maternal Health.
- Goal 6: Combat HIV/AIDS, Malaria and Other Diseases.
- Goal 7: Ensure Environmental Sustainability
- Goal 8: Develop Global Partnership For Development.

The next section examines the climate change risks and vulnerability on the Socio-economic sectors in Africa.

Chapter Three: Climate-smart agriculture

Session I: Chapter overview

Agriculture must address three interconnected challenges at the same time: increasing productivity and income to ensure food security, adapting to climate change, and contributing to climate change mitigation. Addressing these challenges, the sector must become more efficient and resilient at all scales, from the farm to the global level. They must become more resource efficient (using less land, water, and inputs to produce more food sustainably) and more resilient to changes and shocks. Ethiopia, as an agrarian economy that relies heavily on domestic food production, is severely impacted by these abrupt climate changes. Agriculture is not only affected by climate change, but it is also a major contributor to it, owing to GHG emissions. In this context, the Climate Smart Agriculture (CSA) approach would simultaneously increase food productivity, sustainability, resilience, and food security in the system. Climate Smart Agriculture is a comprehensive agricultural production and management system that adapts to climate change, mitigates environmental impacts, and ensures food security for the world's growing population. This chapter of the module provides an overview of CSA as a strategy for addressing the interconnected challenges of food security and climate change. The first section describes the main impacts of climate change on agriculture as well as the contribution of agriculture to global greenhouse gas emissions. The second section describe the concept of climate smart agriculture (CSA) and the importance of changes of the sector to be more efficiency in the use of resources, to increase production while reducing emissions intensity of the food produced and consumed and more resilience, to get prepared to variability and change. The third section briefly touches upon some of the issues to be addressed to monitor climate-smart technologies and practices. The last section articulates the importance of indigenous knowledge for CSA. This will help the trainees understand and relate to the applicability of CSA in their circumstances.

Chapter objectives:

By the end of the chapter, the trainee should be able to:

- Define CSA
- Describe CSA pillars
- Describe the characteristics of CSA
- Identify practical examples of CSA practices that are location specific
- Describe and explain CSA practices in their locality

Time needed 8hrs

Session II. Agriculture and Climate change

The agricultural industry produces massive greenhouse gas (GHG) emissions, which significantly contribute to climate change and global warming. Thus, agriculture is both a victim of and a contributor to climate change (figure 31).

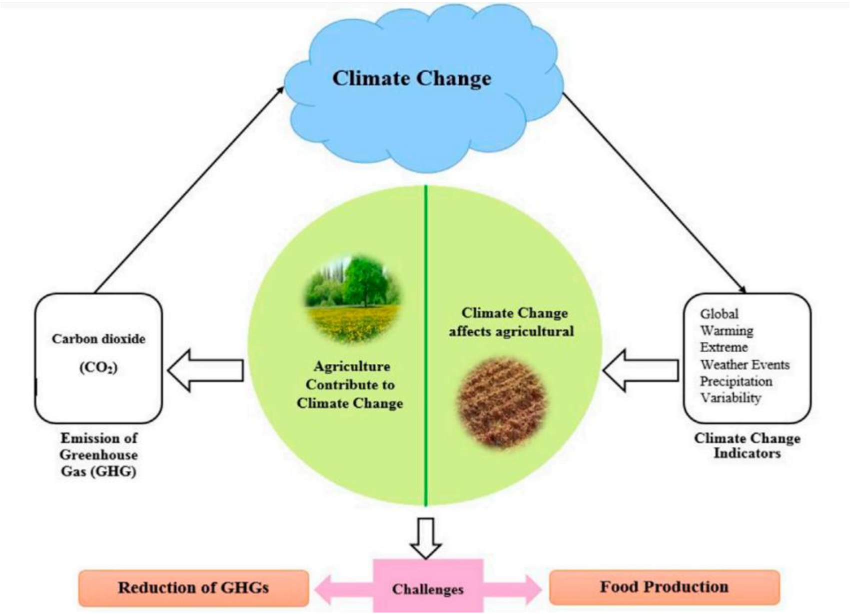


Figure 31. The relation between agricultur and climate change (Naseem et al., 2021).

Impact of Climate Change on Agriculture

Climate change affects agriculture in a variety of ways that differ from region to region (figure 31; 32). It increases the variability of temperature and precipitation, reduces the predictability of seasonal weather patterns, and increases the frequency and intensity of extreme weather-related events such as floods, drought, cyclones, and hurricanes. Such changes has already had a significant impact on agriculture (FAO 2013) and is expected to have an even greater impact on food production, both directly and indirectly (figure 32).

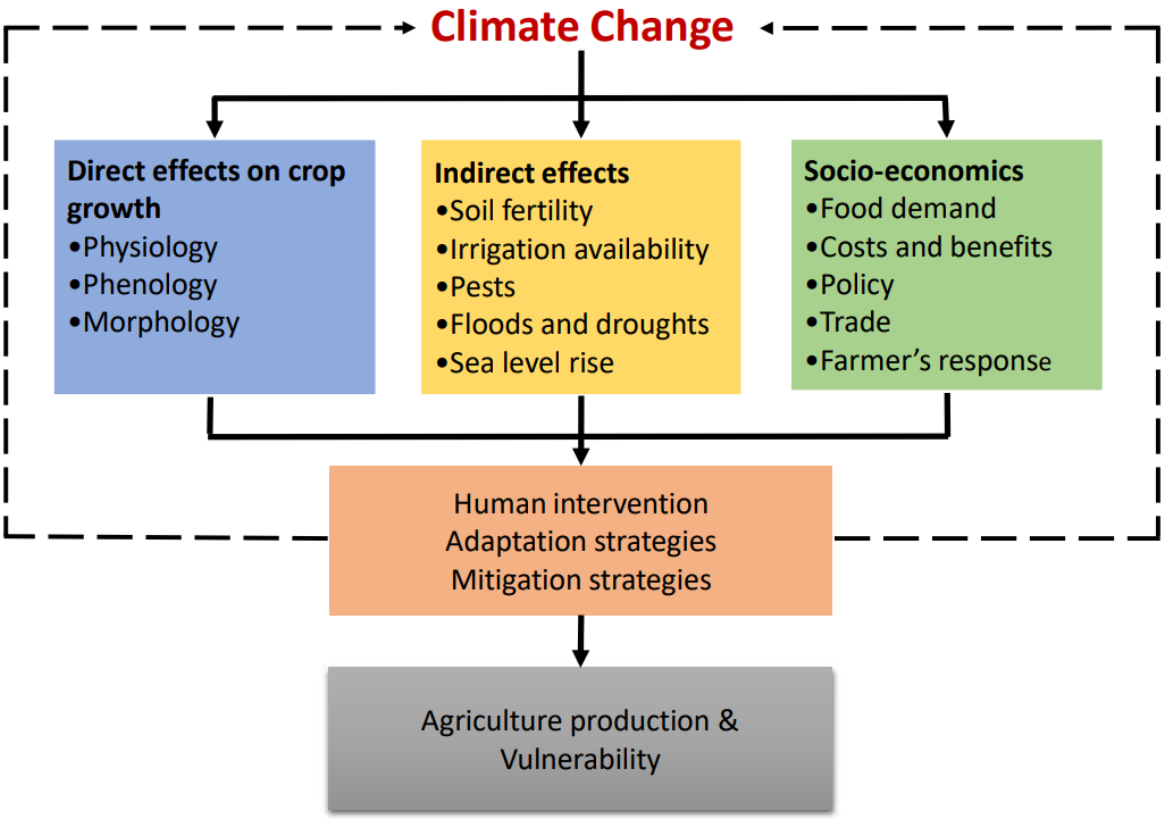


Figure 32. Effect of climate change on Agriculture

The impacts range from yield reductions and increased yield variability to displacement of crops and the loss of agrobiodiversity and ecosystem services (figure 33). Most, but not all, of the impacts of climate change on agriculture are expected to be negative. All the agriculture sectors – crops, livestock, fisheries and forestry are affected by climate change in different ways. Same of climate change impacts on agriculture are;

- Increased frequency and intensity of extreme climate events such as heat waves, droughts and floods, leading to loss of agricultural infrastructure and livelihoods;
- Temperature increase and water scarcity due to climate change affecting plant and animal physiology and productivity;
- Climate change decrease availability water resources, which results in increased demand for water for agriculture, leading to water scarcity in arable areas and for livestock watering;
- Climate change related flood results soil erosion and crop water logging which leads to decreasing yields and increasing food insecurity;

- Increased aridity and higher temperatures cause livestock stress, increase fish mortality, lower crop yields and increase pest infestation;
- Climate change cause changes in plant, livestock and fish diseases and in pest species;
- Climate change causes damage to forestry, livestock, fisheries and aquaculture;
- The marine and inland fishes are affected in terms of change in the breeding season, increase in the growth rates and breeding cycles, and horizontal and vertical extension of fish habitats.
- Acidification of the oceans, with extinction of fish species

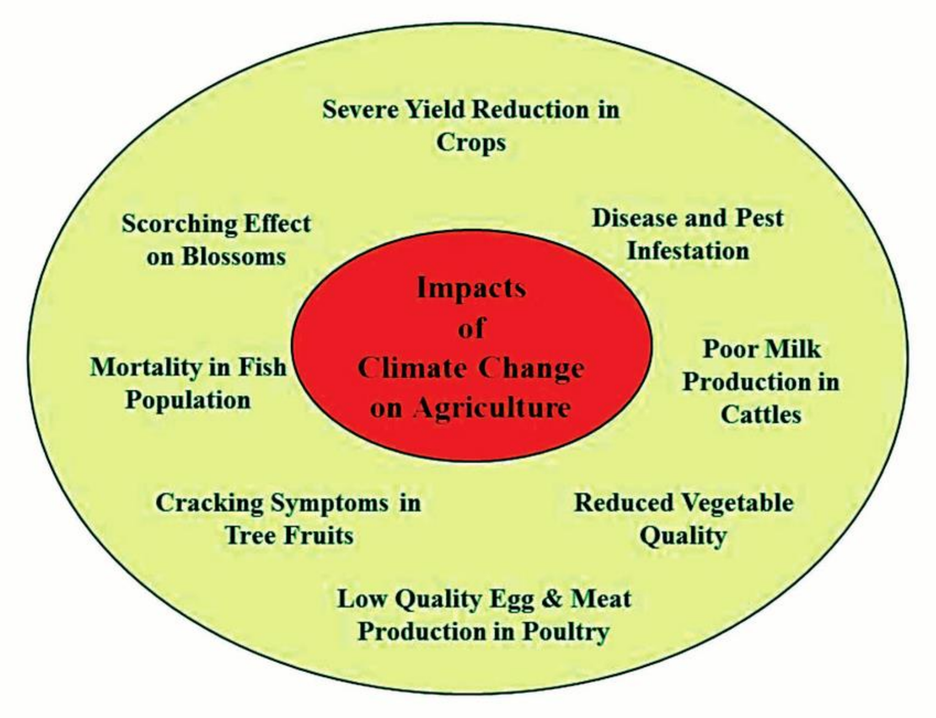


Figure 33. Impacts of climate change on Agriculture

Climate change is already affecting agriculture in many parts of the world, and its effects will be amplified in the coming years and decades. A large body of evidence suggests that negative outcomes are common, with many agricultural systems becoming less productive and some plant and animal species becoming extinct. These changes will have a direct impact on agricultural production, which will have economic, social, and ultimately food security implications. The effects will be transmitted through various channels and will have an impact on food security in all four dimensions: access, availability, utilization, and stability. At each stage of the transmission chain, the severity of impact will be determined by both the shock itself and by the vulnerability of the system or population group under stress.

Agriculture’s impact on climate change

The agricultural industry emits massive amounts of greenhouse gases (GHGs), which contribute significantly to climate change and global warming. In 2021, agriculture generates about 21% of the world's total GHG emissions, predominantly CH_4 and N_2O. Livestock production contributing two-thirds of GHG emission form the sector, in particular, CH4 emissions from enteric fermentation in digestive systems of ruminant livestock continued to be the single largest component (about 25%). Smaller emissions components include managed soils and pasture, rice cultivation, and manure management, biomass burning, and synthetic fertilizer application. Furthermore, agriculture is a major contributor to deforestation, which also contribute to GHG emissions. In Ethiopia, agricultural emissions accounted for 55% of total GHG emissions, with enteric fermentation accounting for the most (52%), followed by manure left on pasture (37%), and savanna burning (4%). Agriculture, on the other hand, is a critical sector that, when managed effectively, can lead to biological carbon capture and storage in biomass and soil, serving as "carbon sinks." Their management can be critical in addressing climate change.

Several studies and reports showed that climate change is real and that it is changing quickly, affecting the agricultural sector negatively. However, the negative consequences are more concerning, necessitating immediate and long-term solutions. Furthermore, solutions should not exacerbate climate change. As a result, climate-smart agriculture is one of the answers and a need of the century, as it is both climate-resilient and addresses food security and GHG mitigation issues. In the following sections, we will discuss the importance of climate-smart agriculture, as well as its relevance and dimensions.

Session III. Concepts of climate-smart agriculture (CSA)

What is Climate Smart Agriculture (CSA)

Climate-smart agriculture defined as an integrated approach for developing technical, policy, and investment conditions to achieve sustainable agricultural development for food security under climate change. FAO has forged the concept of CSA at the Hague Conference on Agriculture, Food Security and Climate Change in 2010, contributes to the achievement of sustainable development goals. The CSA aims to improve food security, helps communities to adapt climate change, and contributes to climate change mitigation by adopting appropriate practices, developing policies and mobilizing needed finances.

Why is climate-smart agriculture needed?

The world's population will grow by one-third between now and 2050. The majority of the extra 2 billion people will live in developing countries. Simultaneously, more people will live in cities. If current income and consumption growth rates continue, FAO estimates that agricultural production will need to increase by 60% by 2050 to meet expected food and feed demand. Agriculture must therefore transform if it is to feed the world's growing population while also providing the foundation for economic growth and poverty reduction. Under a business-as-usual scenario, climate change will make this task more difficult due to negative impacts on agriculture, necessitating spiraling adaptation and related costs.

Climate change adaptation and lower emission intensities per output will be required to achieve food security and agricultural development goals. This transformation must take place while preserving the natural resource base. Climate change is already having an impact on agriculture and food security due to an increase in the frequency of extreme weather events and the unpredictability of weather patterns. This can result in decreased output and lower incomes in vulnerable areas. These changes may have an impact on global food prices. These changes are especially hard on developing countries and smallholder farmers and pastoralists. Many of these small-scale producers already have a depleted natural resource base. They frequently lack knowledge about potential options for adapting their manufacturing systems, as well as limited assets and risk-taking capacity to access and use technologies and financial services.

To improve food security while also contributing to climate change mitigation and preserving the natural resource base and vital ecosystem services, agricultural production systems must become more productive, use inputs more efficiently, have less variability and greater stability in their outputs, and be more resilient to risks, shocks, and long-term climate variability. More productive and resilient agriculture necessitates a significant shift in the management of land, water, soil nutrients, and genetic resources to ensure that these resources are used more efficiently. This shift necessitates significant changes in national and local governance, legislation, policies, and financial mechanisms. This transformation will also include improved market access for producers. These changes will significantly contribute to climate change mitigation by lowering greenhouse gas emissions per unit of land and/or agricultural product and increasing carbon sinks (figure 34).

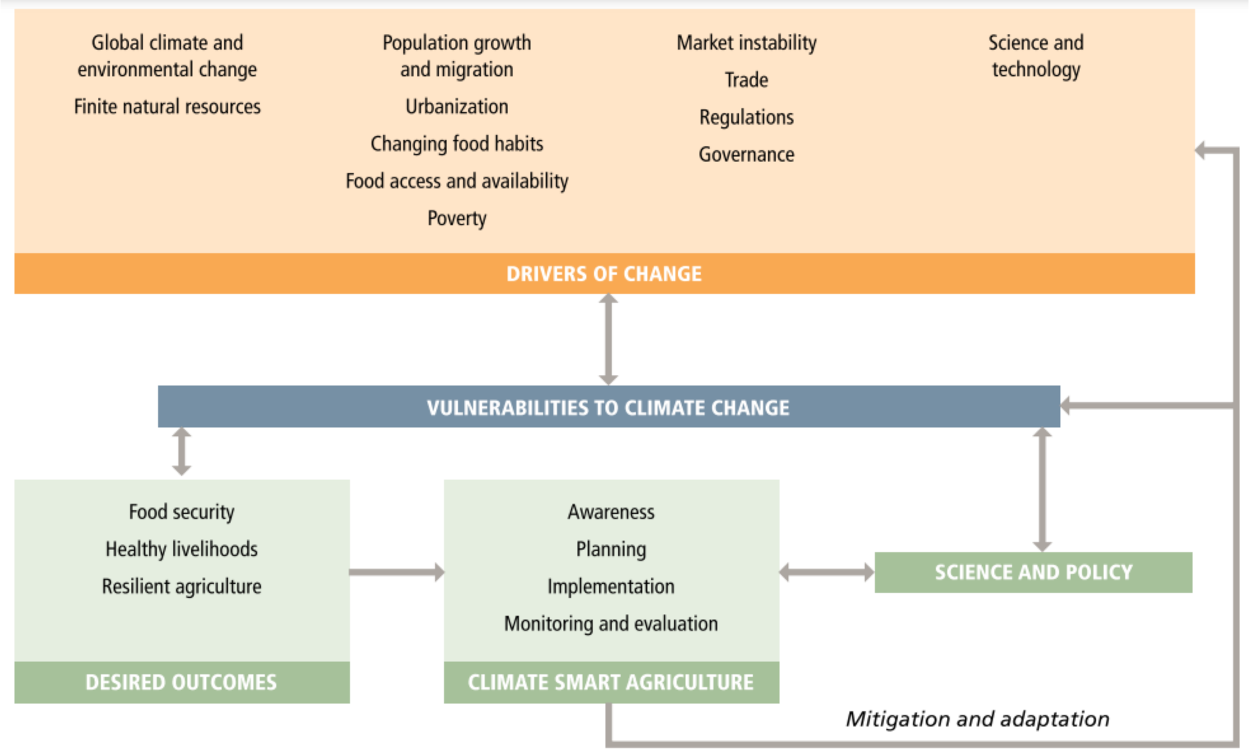


Figure 34. Diagram illustrating how climate-smart agriculture can be utilized as an agent for developing resilience, mitigation and adaptation within the agricultural system (Adopted from Steenwerth et al., 2014).

Pillars of Climate-Smart Agriculture (CSA)

There are three pillars of CSA, namely,

i. **Productivity:** Increase agricultural productivity and income from crops, livestock, and fish while minimizing environmental impact. Thus, food and nutritional security will improve.

ii. **Adaptation:** Reduce farmers' exposure to climate related risks while also strengthening their resilience capacity by increasing their ability to adapt and thrive in the face of shocks and longer-term stresses. Enhancing the ecosystem services that ecosystems provide to farmers and others receives special attention.

iii. **Mitigation:** It also aim to reduce and/or eliminate greenhouse gas (GHG) emissions from the agricultural sector through enhancing to serve as a carbon sinks and absorb CO_2 from the atmosphere.

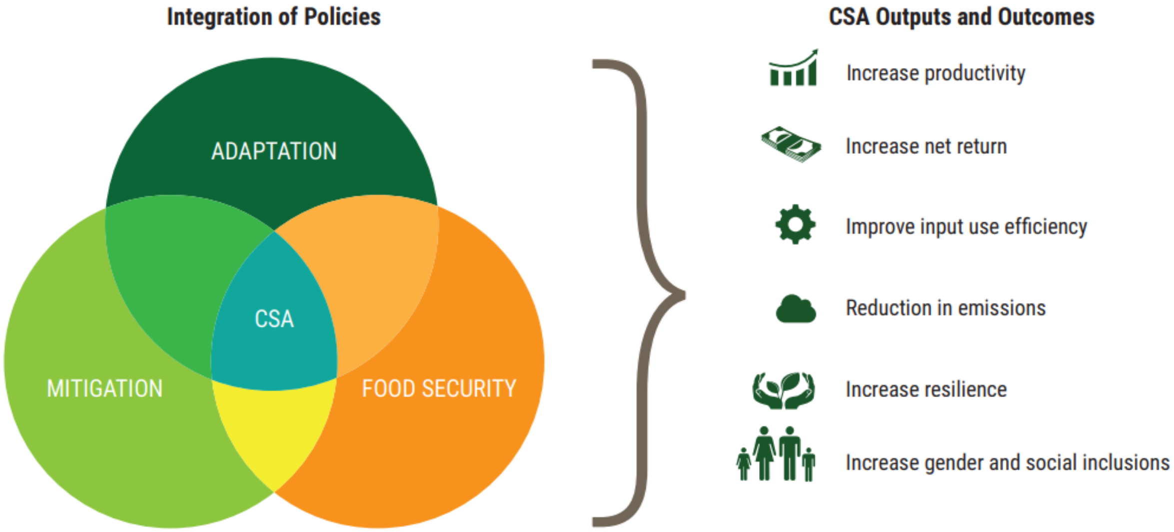


Figure 35. FAO conceptual framework of Climate-Smart Agriculture

Key Characteristics of CSA

- Addresses climate change by taking note of its impacts during planning and development of agricultural systems; CSA, in contrast to conventional agricultural development, integrates climate change into the planning and development of sustainable agricultural systems on a systematic basis.
- Integrates multiple goals (productivity adaptation and mitigation); CSA results in three wins: increased productivity, increased resilience, and lower emissions. However, it is not always possible to achieve all three.
- Maintain ecosystem function and services: Ecosystems provide farmers with essential services such as clean air, water, food, and materials. Thus, CSA takes a landscape approach to integrated planning and management that builds on the principles of sustainable agriculture but goes beyond the narrow sectoral approaches that result in uncoordinated and competing land uses for maintaining ecosystem functions and survives
- Goes beyond single technologies, innovation and management practices; CSA should not be thought of as a collection of practices and technologies. It has several entry points, including the development of technologies and practices, the development of climate change models and scenarios, information technologies, insurance schemes, value chains, and the strengthening of institutional and political enabling environments. As such, it extends beyond single farm-level

technologies to include the integration of multiple interventions at the food system, landscape, value chain, and policy levels.

- It is context specific: CSA is context dependent: What is climate-smart in one place may not be suitable for another, and no intervention is climate-smart everywhere or all of the time. Interventions must consider how various elements interact at the landscape level, within or between ecosystems, and as part of various institutional arrangements and political realities. Because CSA frequently strives to achieve multiple objectives at the system level, it is especially difficult to transfer experiences from one context to another.
- Takes into account impacts of climate change on gender: CSA approaches must include the poorest and most vulnerable groups in order to achieve food security goals and boost resilience. These communities are frequently found on marginal lands, which are particularly vulnerable to climate events such as drought and flooding. As a result, they are the most vulnerable to climate change. Another important aspect of CSA is gender. Women typically have less access and legal rights to the land on which they farm, as well as other productive and economic resources that could aid in the development of their adaptive capacity to deal with events such as droughts and floods. All local, regional, and national stakeholders are encouraged to participate in decision-making by CSA.

Dimensions of Climate-Smart Agriculture

The CGIAR Research Program on Climate Change, Agriculture, and Food Security (CCAFS) developed a framework for climate-smart options and classified CSA technologies and practices within it. To make agriculture climate-smart, technologies and practices for adaptation and mitigation are classified as weather smart, water smart, crop smart, nutrient smart, carbon smart energy smart, and institutional-smart (CCAFS, 2016; figure table 1). A single CSA technology or practice can also contribute to multiple smartness criteria. The use of drought-tolerant varieties, for example, is a weather-smart technology that can also be considered water-smart technology. Similarly, a solar-powered irrigation system is considered a water-smart technology, but it can also be classified as a carbon-smart technology due to its role in lowering GHG emissions. The key dimensions of CSA are (Table 1).

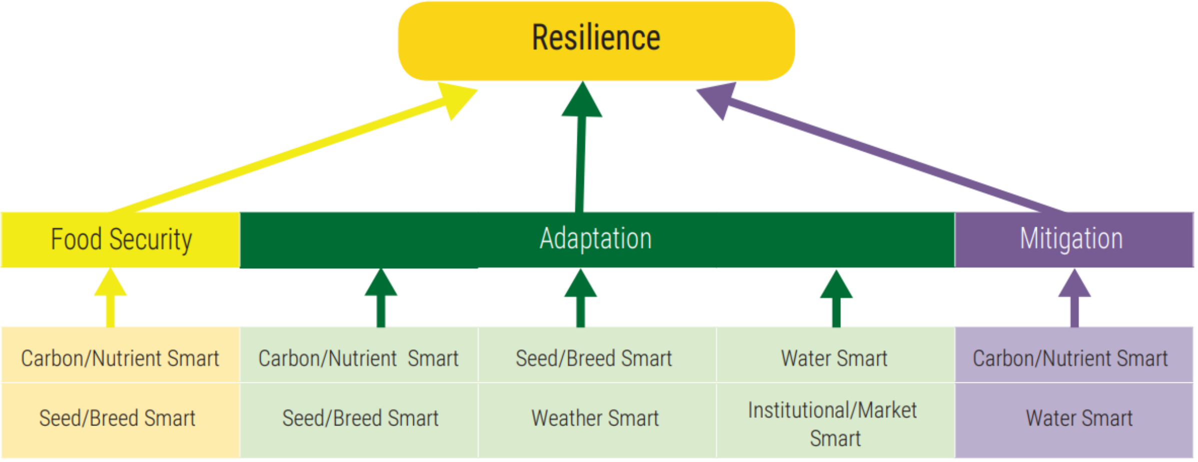


Figure 36. climate-smart dimensions and their contribute to the three pillars of CSA

Table 1. Description of dimensions of CSA

Dimensions of CSA	**Description**
Weather-Smart CSA	Real-time monitoring and reporting of weather parameters, weather-based crop agro-advisory (CA) services, real-time weather-fluctuation-based crop insurance (CI), climate awareness, and climate-smart livestock housing are all components of the weather-smart dimension. Continuous monitoring of basic agricultural weather parameters such as temperature, rainfall, and relative humidity is required for any type of climate-smart agriculture.
Water-Smart CSA	Any water-efficient technology or practice can be considered water-smart because water-smart technologies use water effectively and efficiently. This practice aids in reducing yield loss caused by extreme weather conditions. Rainwater harvesting, drip irrigation, solar-powered irrigation, water harvesting/collection tanks, drainage management, cover crops, mulching, flood/drought-tolerant varieties, direct-seeded rice, alternate wetting and drying, sprinkler irrigation, and other methods are examples of the water smart CSA dimension.
Crop-Smart CSA	Crop adaptation strategies, which ensure food, livelihood, and environmental security in the face of climate change including introduction of abiotic stress cultivars, improvement, and adaptation

	of varieties having higher input use efficiencies, mixed cropping, intercropping, legume-based crop diversification, and changing in planting methods.
Nutrient-Smart CSA	Nutrient management ensuring higher production, system resilience, and GHG mitigation includes green manuring (GM), brown manuring (BM), site-specific integrated nutrient management (SINM), leaf color chart (LCC)-based nitrogen application, soil test-based nutrient management (SSNM), and soil health card-based nutrient management
Carbon-smart	Technologies and practices that reduce GHGs emissions and increase the carbon sequestration for maintaining good environmental condition can be considered as Carbon-smart/Nutrient-smart.
Institutional-smart/Market-smart	The institutional linkages need strengthening for enhanced agriculture production. Examples of institutional/market-smart practices include Inter-sectoral linkage, capacity building programs, financial services, market information, etc. These practices help farmers in accessing resources, information, and market outlets and address gender related issues.

Drought-resistant crop varieties, stress-adapted livestock breeds, diversified cropping systems, intercropping, conservation agriculture, crop rotation, mulching, reducing post-harvest losses, integrated crop livestock management, agroforestry, improved grazing, improved water management, integrated soil fertility management market linkages, climate smart valuation are examples of proven practical CSA techniques in Ethiopia that could enhance adaptive and resilience capacity.

Session II: Climate-smart agriculture versus conventional agriculture

Climate-smart agriculture incorporates climate change into the planning and development of sustainable agricultural systems in a systematic manner. Interventions consider how various elements interact at the landscape level, within or between ecosystems, and as part of various institutional arrangements and political realities. It evaluates the risks and needs of a specific farm or farming community using a climate impact lens, then addresses them with practices tailored to the situation. It analyzes the site-specific socioeconomic and institutional context, as well as the prevailing agroecological conditions and potential climate change scenarios, risks, and impacts, before selecting appropriate climate-smart agriculture interventions for a specific area. This is not to say that every practice used in every location should result in "triple wins," because achieving benefits in all three dimensions is difficult. As a result, decisions must be made between competing investments and objectives. As a result, climate-smart agriculture seeks to identify and reduce trade-offs while also promoting synergies by taking these goals into account in order to inform decisions at all scales and derive nationally and locally acceptable solutions that are consistent with national development goals in the short and long term. Climate-smart agriculture considers a variety of social, economic, and environmental contexts, including agroecological zones and farming systems where it will be used. The emphasis is generally on improving existing techniques, such as the use of fertilizers and pesticides, but with greater efficiency and better seeds (for instance, drought tolerant seeds). Table 2 compares climate-smart agriculture to conventional agriculture.

Table 2. The difference between Climate-smart agriculture and conventional agriculture

Key features of conventional agriculture intensification	Key features of climate-smart agriculture
Energy conversion from human to animal and fossil fuel is machinery dependent	Use of energy-efficient agricultural technologies (irrigation or tillage)
Increased use of fertilizers, pesticides, and herbicides (all of which are heavily reliant on fossil fuels) that are generally applied inefficiently.	Fertilizer efficiency is being improved, and organic fertilizers are being used more widely.
Increase in agricultural land area due to deforestation and conversion of grasslands to croplands	Intensification on existing land areas rather than expansion to new areas as the primary source of production increase
Emphasizing improved and hybrid crop varieties	Valuing the resilience of traditional varieties

Section III: Selecting and monitoring climate-smart technologies and practices

There are several facets of beneficial effects of CSA in terms of increasing resilience, enhancing the productivity of the system, and mitigating GHGs emissions and climate change. Therefore, evaluation/assessment/monitoring criteria of CSA must be multidimensional covering multi-sector and multi-locations. The multi-criteria evaluation has to be performed on the basis of four major aspects. Those are, sustainable productivity, increasing resilience, adaptation, and reduction of vulnerability and mitigation of GHGs emissions and or climate change as described under table 3.

Table 3.Description of climate-smart technologies and practices monitoring criteria

Evaluation criterial	Description
Productivity	The sustainable productivity of the systems includes crop, livestock, pastures, rangelands, aquaculture, fisheries, forestry. Quantitative as well as qualitative measurements are required in those aspects. The assessment of productivity may be in short- as well as a medium-term basis. Productivity assessment should follow the system approach rather than an individual/single crop approach. Some indexes, like sustainable yield index, partial productivity index, etc., could be used for evaluation instead of a simple yield of crops.
Resilience	Climate resilience of a system refers to its ability to return to its original states after being distorted by climatic stresses. Physical, social, and economic resilience are all possible measurement. Water availability (higher quality and quantity), soil fertility/health improvement, and consistent supply of good quality seed in need/stress situations are all indicators of system physical resilience. Economic resilience of systems can be measured by indicators such as improvements in public health, education, livelihood, income, and employment. It is also measured by the increase in income diversity, gender equity, healthy market information, and so on. The enhancement of knowledge, technical skill, social networking, and the way general people/farmers manage information all contribute to the system's increased social resilience (particularly, weather and market).
Vulnerability	The reduction of vulnerability as a result of CSA practice adaptation is an important indicator of CSA assessment. Thus, adaptation enhancement or vulnerability reduction could be used to assess CSA performance. It is, however, a long-term phenomenon.

Mitigation	The CSA approach is novel and unique because it combines mitigation with adaptation and resilience. As a result, in order to assess the CSA, the mitigation must be quantified. Reducing GHG emissions (t CO_2 per ha or year) and/or mitigating global warming potential (GWP) (t CO_2 per ha or year) are critical evaluation criteria. Sustainable development in terms of agricultural production and agricultural economics is also an important component of CSA, so mitigation can be assessed in terms of GHGi (Greenhouse gases intensity, i.e., GHGs emissions per unit production).

Session IV. Indigenous knowledge for Climate-smart agriculture

Various types of traditional CSA practices have been implemented and adopted in Ethiopia. Such practices include the Derashe Traditional Conservation Agriculture, Konso Cultural Landscape, Hararghe Highland Traditional Soil and Water Conservation, Hararghe Cattle Fattening, Hararghe Small-Scale Traditional Irrigation, Ankober Manure Management and Traditional Agroforestry in Gedeo Zone, East Shewa Zone, East Wollega Zone and West Gojam Zone.

- **Case study 1:** Traditional conservation agriculture is practiced in a number of places in Ethiopia, one of which is Derashe (Sagandoye valley) special woreda in SNNP Regional State. Sagandoye valley in Derashe District is characterized by rainfall irregularity in terms of onset, dry spells and early cessation. Therefore, food insecurity caused by low agricultural production and productivity is a major challenge. As a result of the challenge, farmers in the valley have long practiced traditional conservation agriculture on an estimated 11 000 hectares. Under this traditional practice, sorghum and maize are grown without tilling the land. Seed placement is conducted in rows using pointed sticks. Weeding is done frequently, even during the dry season when there are no crops on the farm. After harvesting, crop residues are laid on the ground following the contour in a rectangular manner to conserve moisture from rain. Animals are not allowed to enter the farm and there is no crop residue removal at all. However, there is no systematic crop rotation and intercropping, and promotion of these aspects requires support from the extension service.

- **Case study 2:** Traditional conservation agriculture practices are also carried out by smallholder farmers in many woredas of the Gambella and Benishangul-Gumuz regions. Here the hoe is the main traditional implement used for seed placement without frequent ploughing of the land. However, similar to the Derashe District, traditional conservation agriculture in Benishangul-Gumuz and Gambella regions is not accompanied by crop rotation.
- **Case study 3:** The Konso Cultural Landscape is located in an SNNP Regional State close to Derashe Special Woreda. The area is characterized by hilly terrain and soil erosion is the major form of environmental degradation. Farmers in Konso practice a highly sophisticated yet traditional brand of terracing, agroforestry and manure management that consistently provides good harvests and maintains the integrity of the land. This traditional soil conservation activity has contributed to significant reductions in soil erosion and has also supported climate change adaptation. As a result of its traditional land terracing practices, the Konso Cultural Landscape is now registered as a UNESCO World Heritage Site

Chapter self-evaluation question

1. What is climate-smart agriculture?
2. How does climate-smart agriculture contribute to adaptation, mitigation and food security?
3. What makes climate-smart agriculture different from current agricultural practices?
4. What is the role of indigenous knowledge in climate-smart agriculture?

Reading materials

1. Food and Agriculture Organization (FAO) of the United Nations (2013) Climate-smart agriculture-sourcebook. E-ISBN978-92-5-107721-4
2. IPCC (2014) Summary for policymakers. Climate change 2014: impacts, adaptation, and vulnerability. Part A: global and sectoral aspects. Contribution of working group IIto the fifth assessment report of the intergovernmental panel on climate change. Cambridge University Press, Cambridge, UK and New York, NY, USA
3. Tripathi A, Tripathi DK, Chauhan DK, Kumar N, Singh GS (2016) Paradigms of climate change impacts on some major food sources of the world: a review on current knowledge and future prospects. Agr Ecosyst Environ 216:356–373
4. Rojas-Downing MM, Nejadhashemi AP, Harrigan T, Woznicki SA (2017) Climate change and livestock: Impacts, adaptation, and mitigation. Clim Risk Manage 16:145–163

5. Ketiem P, Makenzi PM, Maranga EK, Omondi PA (2017) Integration of climate change information into drylands crop production practices for enhanced food security: A case study of Lower Tana Basin in Kenya
6. Hasegawa T, Fujimori S, Havlík P, Valin H, Bodirsky BL, Doelman JC et al (2018) Risk of increased food insecurity under stringent global climate change mitigation policy. Nat Clim Change 8(8):699–703

Chapter Four: Climate-smart Crop Management

Session I. Chapter overview

Climate-smart crop production helps to ensure food security by addressing various aspects of current and projected climate change impacts through adaptation and mitigation measures. While agriculture contributes significantly to climate change, it also provides opportunities for adaptation and mitigation. Cereals, pulses, coffee, oilseeds, spices, herbs, vegetables, fruits, sugarcane, and potatoes are among the primary crops grown in Ethiopia. Crop production is the most important agricultural activity, and it is mostly produced under rain-fed conditions. Temperature and rain pattern changes, as well as the frequency and intensity of weather events, have significant implications for crop production and posing serious challenges for farmers to ensure productivity. Thus building climate resilient crop production system is very crucial. The first section of this module outlines the impacts of climate change on crop production. The second section describes climate-smart crop production practices and technologies and demonstrates how the practices are "climate-smart" by definition. The practices include the introduction of stress-tolerant crop variety, change in cropping system on the environment-friendly and economic manner, and managing input resources (water, soil, fertilizers, pesticides, etc.) in an effective way to reduce losses and emissions (GHG) discussed. The module also includes case studies on how to adapt to climate change and contribute to its mitigation. This will help the trainees understand and relate to the applicability of climate smart crop production in their circumstances.

Chapter objectives

By the end of the chapter the trainee should be able to:

- Describe the impact of climate change on crop production
- Explain what is climate smart crop management and its key characteristics
- Identify practical examples of CSA practices that are location specific
- Describe and explain climate smart crop management practices in their locality

Time needed **6hrs**

Session II. Impacts of climate change on crop production

Climate change affects crop production in a multitude of ways. Past climate trends have been observed to have an impact on crop production in several regions around the world (Porter et al., 2014), with negative impacts outnumbering positive ones (figure 36). Crop production is becoming increasingly vulnerable to the risks posed by new and evolving climatic changes. It has already had a negative impact on wheat and maize yields. Over the period of 1980 to 2008, there was a 5.5 percent drop in wheat yields and a 3.8 percent drop in maize yields globally, compared to what they would have been had climate remained stable (Lobell, Schlenker and Costa-Roberts, 2011). Recent results have confirmed the damaging effects of elevated tropospheric ozone on yields, with estimates of losses for soybean, wheat and maize in 2000 ranging from 8.5 to 14 percent, 3.9 to 15 percent, and 2.2 to 5.5 percent respectively (Porter et al., 2014). Several other possible impacts of climate change on the functioning of ecosystems – such as the balance between crops and pests, and effects on pollinators – are difficult to assess and are generally not taken into account by the models used to make projections of crop yields.

Generally, climate change impacted both negatively and positively to field crops, horticultural crops, pastures, and forestry in different ways including

- Rising temperatures and shifting rainfall patterns causes soil erosion, make growing more difficult for many crops, and shorten growing seasons;
- Droughts and increased desertification as a result of climate change reduce crop land productivity
- Increase in extreme weather events such as floods, droughts, cyclones, and heat waves adversely affects crop productivity and reduce crop yields in the rain-fed areas due to changes in rainfall pattern during monsoon season and increased crop-water demand. Capabilities of flowering and fruit setting in many crops reduced due to climate change.
- Quality of fruits, vegetables, tea, coffee, aromatic, and medicinal plants affected. The perennial fruit crop production may suffer problems in dormancy, acclimation, flowering and fruit production from altered seasonal conditions and climate variability;
- Vegetable crops also suffer from climate change. As these crops are mostly succulents and usually have shallow root systems, they are more vulnerable to climate extremes. Fluctuations in temperature causes bolting (pre-mature flowering) in many vegetable crops and increase rate

of respiration leading to less distribution of assimilates to reproductive sinks. This lead to smaller sized fruits with low market value;

- Rising temperatures are expected to create more favorable conditions for crop diseases and pest infestations that are detrimental to yield production and quality. Incidence of pest and diseases of crops increases because of more enhanced pathogen and vector development, rapid pathogen transmission, and increased host susceptibility. For instance, the change in rainfall patterns impact migration of desert locusts in which can become major devastating pests for agronomic and other crops in Ethiopia;
- Reduced precipitation restricts water availability as irrigation demand increases and reduced soil moisture, all results crop productivity loss;
- Agricultural biodiversity is also threatened due to the decrease in rainfall and increase in temperature, sea-level rise, and increased frequency and severity of droughts, cyclones and floods
- In some area, crop production increases through carbon dioxide "fertilization"

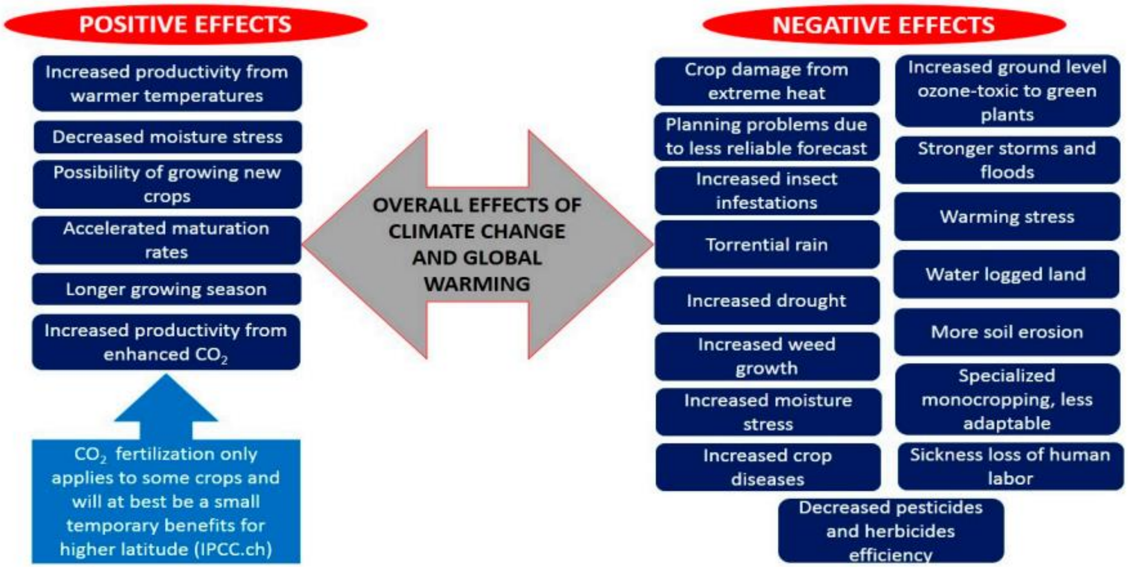


Figure 37. Negative and positive effects of climate change on crop production

The precise future effects of climate change on crop yields are very difficult to predict and will depend on many parameters. These include: physical ones, such as temperature, precipitation patterns and CO_2 fertilization; changes in agroecosystems (e.g. through loss of pollinators and increased incidence of pest and diseases); and the adaptive responses of human systems.

Many Ethiopian smallholder farmers cultivate slow-maturing, high-yielding "long cycle" crops that require two rainy seasons to mature and are thus more vulnerable to seasonal rainfall changes. The majority of crops grown by small-scale subsistence farmers are still heavily reliant on rainfall (only 1% of all cultivated land is irrigated) and are highly sensitive to temperature variability and water availability. These are environmental variations that pose significant challenges to farmers in addition to those encountered 'normally.' Temperature rise has complicated effects on crop growth and yield. Warmer temperatures and more frequent droughts are likely to be the most significant climate impacts for agriculture and food security. Drought intensity and frequency can have a direct impact on food availability (e.g., reduced crop yields) as well as indirect effects on livelihoods and income, which have consequences for food accessibility.

Session III. Climate smart crop management practices

Climate smart crop production strategies should meet the three basic CSA criteria: increasing yield on a sustainable basis, improving system resilience through increased adaptive capacity, and mitigating GHG emissions or climate change. The impact of relevant crop management systems on productivity, resilience, and mitigation would be elaborated with location-specific case studies in the following sections of this chapter.

1. **Conservation Agriculture:** The three main characteristics of conservation agriculture (CA) are reduced tillage, residue retention, and crop diversification. It is "climate-wise." It ensures long-term crop yield by providing adequate nutrients and water, and it makes it easier to use high-yielding varieties. Simultaneously, applying residues to the field (organic matter/carbon addition) gradually improves soil carbon and nutrient status, reducing fertilizer use and thus GHG emissions. Furthermore, by promoting natural biological processes, the CA helps to reduce the degradation of natural resources (soil, water, and energy) and maintain ecological balance. The CSA not only reduces GHG emissions but also aids in carbon sequestration in soil, thereby mitigating climate change. In California, crop diversification with deep-rooted crops or legumes could break subsoil compactions and provide additional nitrogen to soil and plants.
2. **Agro-Ecosystem based Approaches with Stress-Tolerant Cultivars:-** Crop smart management practices based on agro-ecosystems are primarily based on local resource availability, ecological niche, and farmer vulnerability. Traditional and stress-tolerant cultivars with low input requirements are the primary criteria for selecting crop varieties

and cropping systems in this approach. It places a greater emphasis on ecosystem resilience and farmer adaptability. With modified agronomic practices, potential abiotic stress-tolerant rice, wheat, and maize varieties are found promising all over the world.

3. **Integrated farming:** The growing and maintenance of compatible crops (field, horticulture, grasses, etc.) and animal (including fish) components together is referred to as an integrated farming system (IFS). The IFS is a symbiotic system that combines crop, livestock, aquaculture, and agro-industry. IFS's fundamental principle is resource recycling. That is, waste from one process/component becomes input for another. The IFS was designed with the idea of combining site-specific crop + animal components to reduce system risk, increase system productivity, reduce external input use, and recycle bio-resources and crop residues. IFS's broad goals are to ensure stable income, maintain agro-ecological balance, reduce fertilizer and pesticide use, maximize organic resource utilization within the farm boundary, and conserve natural resources for long-term environmental protection. IFS are perfectly matching with the three objectives/pillars of CSA (productivity enhancement, system resilience, and climate change mitigation). The IFS is a climate proof technology that has given the systems intrinsic climate resilience (the second pillar of CSA). The benefits of IFS that increase system resilience are as follows:
    - i. it provides diversified products and reduces the risk of market fluctuations of a single product;
    - ii. it improves soil chemical (organic carbon, fertility), physical (aggregation, porosity, infiltration rate), and biological (microbial population and functions, enzymatic activities) processes;
    - iii. encourages less dependence of external inputs (pesticides, fertilizers, energy, feeds);
    - iv. assures labor supply even in crisis as it mostly uses family labor for the basic component of maintenance of the system; and
    - v. ensures a higher net return from diversified income sources by providing a buffer against price-fluctuations, trade-inconsistencies, and climatic-vagaries;
4. **Participatory Watershed Management and Soil-Water Conservation:-** Participatory watershed management is an excellent CSA practice. In Africa's degraded hilly regions, the approach has been extremely successful. It is a natural resource-based rehabilitation of degraded land/ecologies with active local participation. This approach's three primary interventions are rainwater harvesting and water resource development, catchment

treatment/rehabilitation, and increased agricultural productivity (both crop and animal component). Rainwater harvesting in small water harvesting structures (WHS)/ponds or check dams; contour/graded bunding; diversion drains or runoff-drainage-network; contour/stagger trenching and afforestation in the catchment; spurs in torrents; introduction of climate-stress-tolerant high-yield varieties on command area; real-time nutrient management of crops; and infrastructure maintenance through watershed management committee are all components of watershed management (WMC).

5. **Integrated Nutrient Management (INM)**:- Integrated Nutrient Management refers to "an approach of the site-specific application of organic manure, inorganic fertilizer, and biological amendments to increase nutrient use efficiency and sustain crop productivity." Simultaneously, it reduces nutrient losses by adjusting crop demand to soil nutrient availability. The three key components of INM are;
    i. making the best use of available nutrient sources (inorganic, organic, biofertilizer, crop residues, etc.) to maintain soil health;
    ii. matching soil nutrient supply with real-time crop demand to maximize crop yield; and
    iii. increasing nutrient use efficiency and reducing pollution by reducing losses.

    So, in general, INM addressed all three pillars of CSA, namely increased productivity, resilience, and climate change mitigation (Fig. 7.5). The overall benefits of INM are as follows:
    i. Increase crop yield and quality;
    ii. Reduce nutrient losses (major and minor), increase NUE (nutrient use efficiency), and optimize fertilizer use;
    iii. Utilize natural organics (manure, bio-fertilizers, organic-soil amendments, etc.) and improve the use efficiency of native soil-nutrients, recycle crop residues, and maintain soil health;
    iv. It mitigates problems such as soil salinity, soil alkalinity, soil acidity, and soil compaction, which impede crop productivity, and thus imparts resilience to the soil-plant system and also slows soil degradation;
    v. Reduces GHG emissions, increases carbon sequestration, and improves soil quality.

vi. Mitigate GHG emission, increase carbon sequestration, and minimize energy consumption;
vii. Sustain ecological balance and economic viability of the production system

6. **Agroforestry**:- Agroforestry is a paradigmatic example of Climate-Smart Agriculture (CSA). It is the integration of crops, trees, and shrubs as part of agricultural systems. It promotes water infiltration, soil aggregation, and erosion prevention, as well as mitigating the negative effects of climate change. It meets all three CSA requirements: sustaining food security, system resilience, and climate change mitigation.
   i. It primarily improves crop/tree/fodder system productivity through balanced water and nutrient supply (via N-fixing leguminous trees such as Faidherbia albida, etc.); providing necessary energy; and improving soil fertility and crop yields.
   ii. Second, it makes the system more resilient to climatic fluctuations by diversifying production (trees/crops/shrubs/livestock) and acting as a weather buffer. Tree shades, for example, protect animals from heat stress and increase productivity. Trees also help to prevent soil erosion and land degradation, provide high-quality forage for livestock, reduce overgrazing, and restore ecosystem balance.
   iii. Third, agroforestry contributes significantly to the reduction of GHG emissions, carbon sequestration, and climate change mitigation.

   Agroforestry provides the following ecosystem services [21, 58, 63] and socioeconomic benefits;

   - Crop/tree yields are less volatile due to increased soil water retention.
   - Soils are protected from erosion caused by water and wind.
   - Increased income stability through diversification of farm products.
   - In hillslopes, agroforestry is a viable alternative to slash-and-burn systems.
   - It reduces pressure on forests, thereby preventing forest degradation/deforestation and contributing to the reduction of GHG emissions and climate change.
   - It reduces direct N2O emissions from the system because lower N-fertilizers are used and are typically deeply embedded in the soil.
   - Agroforestry has enormous potential as a carbon sink due to its above- and belowground biomass.

Case studies

1. Use of improved potato varieties (tolerance to heat, drought, and disease)
    a. Productivity: Increased yield and income (due to lower fungicide application costs);
    b. Adaptation: Bridges the gap in food security during shortage months and/or when other crops are not mature; and
    c. Mitigation: Reduces the intensity of emissions per unit of product.
2. Use of superior seed varieties (tolerance to heat, drought, and pests)
    a. Productivity gains in yield and income;
    b. Adaptation gains in responsiveness to unpredictable weather patterns. Local varieties may be more resistant to diseases and heat stress; and
    c. Mitigation reduces the intensity of emissions per unit of product.

Chapter self-evaluation question

1. What are the effects of climate change on crop production?
2. What is climate-smart crop production and its key characteristics?
3. How does climate-smart crop management contribute to adaptation, mitigation and food security?
4. What makes climate-smart crop management different from current practices?
5. What climate smart crop management commonly practiced for increased productivity applicable in their locality?
6. What are the role of indigenous knowledge in climate-smart crop management?

Reading materials

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Chapter Five: Climate-smart livestock and fishery Management

Session I. Chapter overview

Climate change has been found to have a significant impact on livestock and fishery. Temperatures above the tolerable limit increase livestock mortality and exacerbate the spread of various pathogens, vectors, and parasites. Furthermore, the livestock sector will face challenges of fodder, land, and water scarcity in the near future, which will be exacerbated by changing climatic conditions. Changing climatic parameters may cause sudden disease outbreaks and introduce new types of diseases, pests, and pathogens in a specific area, making livestock more vulnerable. Livestock production is expected to decline due to poor adaptive response, requiring a resilient sector and management to ensure food security. The first section describes the impact of climate change on livestock and fishery, and identifies adaptation and mitigation needs. The second section of the chapter highlights the main climate-smart strategies for the sector. Few of them are construction of shed and water sources in low cost to minimize the heat stress to animal, keeping high-quality breeds in lesser number, introduction of micro- and drip irrigation systems in pastures, and construction of water harvesting structures. This will help the trainees understand and relate to the applicability of climate smart livestock and fishery management in their circumstances.

Chapter Objectives

By the end of the chapter, the trainee should be able to:

- Describe the impact of climate change on livestock and fishery production
- Explain what is climate smart livestock and fishery management and its key characteristics
- Identify practical examples of CSA practices that are location specific
- Describe and explain climate smart livestock and fishery management practices applicable in their locality

Time needed 6hrs

Session II. Climate change impact on the livestock and fishery sector

Climate change has an impact on livestock production in a variety of ways, both directly and indirectly. The direct effects include rising temperatures, changes in photoperiod, and precipitation, while the indirect effects include reduced feed quality and quantity, less water availability, and increased disease susceptibility (figure 38). The most significant effects are on animal productivity, animal health and biodiversity, feed quality and quantity, and pasture carrying capacity. The following impacts of climate change on livestock production have been observed;

- Increasing variability in rainfall leads to shortages of drinking water, an increased incidence of livestock pests and diseases, and changes in their distribution and transmission;
- Change in temperature and rainfall affects availability of feed through affecting species composition of pastures, pasture yields and forage quality;
- Higher temperatures cause heat stress in animals, which has a range of negative impacts including reduced feed intake and productivity, lower rates of reproduction, higher mortality rates and lowers animals' resistance to pathogens, parasites and vectors;
- Climate-related stresses causes excessive heat and lower nutritional intake which have severe impacts on the animals' biological coping mechanisms;
- Variability in temperatures result in pronounced impacts on reproductive performance of animals such as decreased fertility, conception rate, and longevity
- Higher temperatures experienced because of climate change have caused the animals to reduce their food intake;
- Areas suitable for grazing and availability of forage has declined due to dry spells and droughts, leading to reduction in livestock production;
- Rangelands that are persistently affected by drought produce inadequate pasture which is deficient in nutrient content to sustain livestock production;
- Heat stress in poultry can reduce egg production and slow the growth rate of the birds;
- Affect fisheries and aquaculture systems due to its impact on water temperatures, oxygen deficit, sea-level rise, decreased pH and changes in productivity patterns.

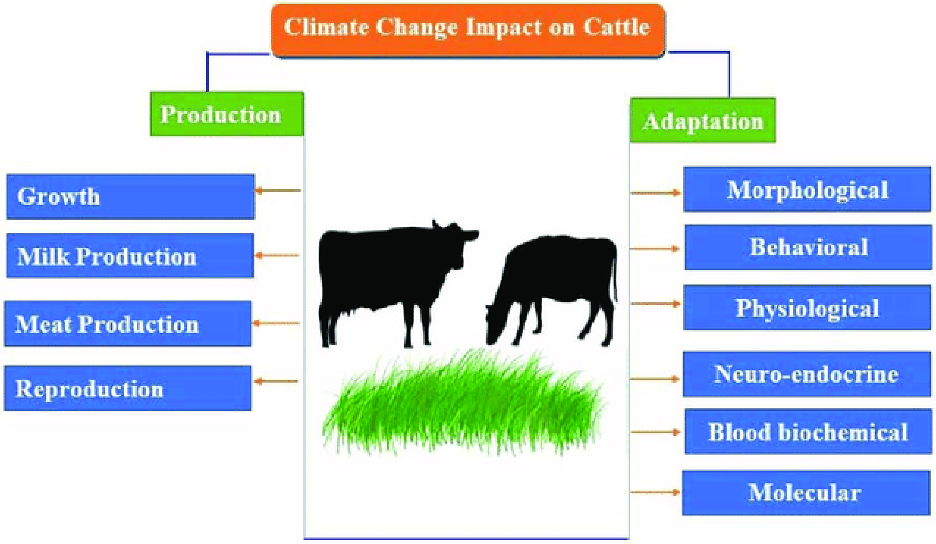

Figure 38. Negative impacts of climate change on livestock

Extreme weather events endanger coastal communities, cause infrastructure damage, and reduce the productivity of flood-prone river belts. Furthermore, post-harvest processing, transportation, and distribution would be hampered, affecting livelihood and food security. The overall effects of climate change on livestock, aquaculture, and fisheries are described in table 4.

Table 4. Climate change impact on the livestock and fishery sector

Factor	Impact
Water scarcity	Climate change causes water scarcity scenarios, which affect fodder production, pasture yield, and the quantity and quality of drinking water for the livestock sector.
Temperature variability	Variability in temperatures result in pronounced impacts on reproductive performance of animals such as decreased fertility, conception rate, and longevity
Quantity and quality of feed	Climate change alters crop and fodder land uses, affecting the quantity and quality of livestock feed, particularly for marginal farmers. The growing season of feed changed due to temperature and rainfall variations, affecting fodder productivity and harvest index. Increasing temperature alters the decomposition of plant material and the digestibility of feed, reducing livestock production and farmer income.

Livestock health	Heat stress and humidity alter the physiology of livestock, making animals more susceptible to disease and stress. More vectors spread in colder regions (malaria and livestock-borne diseases shift to higher elevation) or warmer regions. Changes in rainfall patterns aid in the spread of vector attacks and the occurrence of disease (Rift Valley fever virus). Temperature and humidity change the pattern of helminth infection. Heat-related stress causes an increase in animal mortality.
Changing sea level	The water level in bodies of water, drought, and flood events cause a shift in fish species, which affects fish reproduction and nursery fish production. Global warming has an impact on the behavior of pests, pathogens, and disease transmission in fish and aquaculture.

Session III. Climate-Smart livestock and fishery management

Many adaptation and mitigation measures are to be adopted to make the livestock and fishery sector more resilient under changing climatic scenarios and make it climate smart. The most commons are

1. **Improved Livestock Breeds:** One of a key CSA technology in livestock production is improving the genetic potential of cattle, poultry, pigs, sheep, and goats to produce livestock that grow larger and faster while remaining stress resistant (e.g. water, heat , diseases stress etc). This can be accomplished through cross-breeding or upgrading the desirable traits of exotic breeds with the hardiness and disease resistance of local breeds. The goal of cross-breeding is to improve local breeds in terms of production (e.g., meat, milk, and eggs), maturity time, stress resistance, and feed resource use efficiency to reduce GHG emission. Livestock keepers can increase their earnings by selling more livestock products and byproducts.
2. **Improved Feeds:** Improved feeds include pastures and concentrates made from agricultural byproducts (molasses, brewer's waste, maize/rice/wheat bran, oilseed cake). These feeds can be modified to improve digestibility and provide essential nutrients. Feed additives can also be used to improve feed digestibility and nutritive value. Such Feed enhancements aim to reduce methane (CH4) emissions. Climate change mitigations result from more efficient nutrient absorption, which reduces gaseous losses and allows for comparable amounts of dairy and meat to be produced with fewer animals. Feed supplements are needed in small amounts but are extremely important in increasing livestock productivity. Examples of feed supplements are urea–molasses multi-nutrient blocks, low bypass protein, lipids, and calcium hydroxide. Succulent plants can offer an alternative source of water as well as feed to grazing animals especially during the dry season.

3. **Livestock Improved Feedings:** To improve livestock productivity, improved feeding strategies such as cut and carry, rotational grazing by paddocks, fodder crops, and grassland restoration and conservation may be implemented. This includes storing animal feeds (stover, grass, grain) and making better use of feed (by combining different types of feed), growing grass varieties that are specifically suited to the agro-ecological zone, and a variety of other practices such as fodder conservation and animal fattening. The strategies also include managing paddocks and/or pastures to ensure adequate fodder for livestock feeding at home, particularly under zero grazing conditions. Keeping livestock in paddocks and under zero grazing aids in improving manure management practices.
4. **Pasture and Grazing Land Management**
    - **4.1. Pasture Management:** Pasture management is the practice of growing healthy grass and related plants in order to profitably sustain forage availability and livestock production while protecting the environment. Pasture management has the potential to provide significant benefits such as increased forage yields, lower feed costs, and improved livestock performance. Good pasture management reduces carbon emissions into the atmosphere. The key to lowering GHG emissions is to keep pastures healthy and of high quality. High-quality feed results in greater feed efficiency and nutrient absorption by the animal. High quality forage influences animal consumption (e.g., cattle), increasing digestion efficiency and reducing the amount of time required to graze. Methane production is reduced as digestion speeds up and feed efficiency improves. Improved pastures also have numerous indirect benefits in terms of lowering GHG emissions from animal production. Perennial forages use their extensive root systems to trap atmospheric CO_2 and store it meters below ground. Grasses and alfalfa not only improve soil by increasing organic carbon, but they can also absorb excess water, lowering the water table and assisting in the control of soil salinity. Reducing soil moisture also reduces the risk of N losses due to de-nitrification, lowering the amount of nitrous oxide (N_2O) produced. Pastures also provide soil cover, which prevents erosion and helps to maintain or improve water quality.
    - 4.2. **Grazing Land Management:** Depending on indigenous knowledge of natural resource management, human and animal diseases, and their environment, different methods can be used to manage grazing land. Grazing lands can be managed using both traditional and improved grazing land systems. Communities control resource use patterns and conservation

under the traditional grazing land management system by using traditional knowledge of the ecosystem and biological diversity of the areas.

5. Efficient livestock management include (i) construction of shed and water sources at low cost to minimize heat stress, (ii) keeping high-quality breeds in a lesser number will lead to resource conservation and lower greenhouse gas emission, (iii) Introduction of micro- and drip irrigation systems, and (iv) construction of water harvesting structures
6. Crop and animal diversification: Production system incorporating agriculture and forestry production systems together and optimizing the timing of various field operations. The system is more tolerant to temperature and water stress and also to pest and disease attacks
7. **Agroforestry:-** A systems with an optimum combination of trees, crops, and pastures would improve crop production, protect the environment, and favor carbon sequestration. An integrated crop-livestock-based system would be a better measure to improve food security.
8. **Livestock Management Systems and Mitigation Measures:-** In three ways, the livestock production system contributes significantly to greenhouse gas emissions, namely, (i) enteric fermentation, (ii) manure/waste generation, and (iii) fodder production. The livestock production system indirectly influences land-use changes and, in some cases, promotes deforestation due to pasture production. As a result, better feeding and manure management are required to reduce greenhouse gas emissions from livestock. Increasing livestock efficiency in converting energy from feed and reducing waste and biogas production could also help to mitigate climate change. Systematic grazing at specific locations may be more effective at lowering GHG emissions and storing more soil carbon.
9. **Climate-Smart Aquaculture Management Systems**: The main elements of climate change that could potentially impact fishing and aquaculture production are mostly associated with water level changes in water bodies and temperature fluctuations. These adaptation options are broadly classified as diet based adaptation options, genetic and biotechnological approaches, Management approaches such as pond aquaculture/fish ponds, integrated aquaculture and cage culture, and Relocation of farm.

Case studies

1. Feed and feeding systems improvement
    a. Productivity: Increases milk and meat production and income;
    b. Adaptation: Increases efficiency in the management of natural pastures. Increases pasture/forage availability during extreme weather conditions; and

c. Mitigation Productivity increases reduce GHG emissions per product unit Methane (NH_4) emissions from enteric fermentation are reduced.

Chapter self-evaluation question

1. What are the effects of climate change on livestock and fishery production?
2. What is climate-smart livestock and fishery management production and their key characteristics?
3. How does climate-smart livestock and fishery management contribute to adaptation, mitigation and food security?
4. What makes climate-smart livestock and fishery management different from current agricultural practices?
5. What climate smart livestock and fishery management commonly practiced f in their locality?
6. What are the role of indigenous knowledge in climate-smart livestock and fishery production?

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Chapter Six: Climate-smart Natural Resource Management

Session I. Chapter overview

Climate change and variability have a variety of effects on natural resources. For example, in changing climatic scenarios, intense and erratic weather events cause increased erosion by water and wind, increased runoff loss, decreased groundwater recharge, and a lack of soil moisture for plant growth. Furthermore, reduced or erratic rainfall and significant drought periods cause soil moisture stress, limiting plant water and nutrient availability. Furthermore, rising soil surface temperatures promote mineralization of organic matter, reduce carbon sequestration capacity, increase salinization, and increase evaporation rates, all of which limit plant growth. Soil salt accumulation limits plant growth and reduces agricultural productivity. Climate change is also closely related to the hydrological cycle and leads to significant changes in regional water systems. Thus, there is a need to adopt adaptation and mitigation measures to climate change. Climate-smart natural resource management could create optimal physical, chemical, and biological conditions for sustaining natural resources and maintaining soil health. Thus, the six chapter of the training deals with the natural resource management for CSA which includes soil and land management as well as water and biodiversity management practices under CSA. This will help the trainees understand and relate to the applicability of climate smart livestock and fishery management in their circumstances.

Chapter Objectives:

By the end of the chapter, the trainee should be able to:

- Describe the impact of climate change on natural resource
- Explain what is climate smart natural resource and its key characteristics
- Identify practical examples of natural resource CSA practices that are location specific
- Describe and explain climate smart natural resource management practices in their locality

Time needed 8hrs

Session II. Impacts of climate change on natural resource

Impact on soil

Soil organic carbon (SOC), the foundation of soil health, is expected to decline in both tropical and temperate regions of the world under projected climate change scenarios. The reduction in SOC status would have a negative impact on soil health and quality. Furthermore, under predicted climate change conditions, the plants will be exposed to progressively higher atmospheric CO_2 levels, resulting in plant litter with a higher C: N ratio. The incorporation of plant biomass with a higher C: N ratio into the soil will result in greater carbon immobilization. As a result, increased SOC immobilization reduces soil nutrient supply to crop. At the same time, higher nitrogen mineralization due to high soil temperature and a quick wet-dry cycle, combined with lower supply, would reduce crop productivity, which is a possibility in future climate change scenarios. Aside from that, rapid nitrogen (N) mineralization frequently results in higher losses to the atmosphere, either through volatilization (as NH3) or denitrification (as N_2O emission), both of which contribute to positive feedbacks to climate change.

Climate change and global warming have a complex impact on soil processes and properties, which are influenced by a variety of direct and indirect factors. Weather events with intense and erratic rainfall due to climate change, resulting in increased erosion by water and wind, increased runoff loss, reduced groundwater recharge, and a lack of soil moisture for plant growth. Furthermore, decreased or erratic rainfall, as well as significant drought periods, cause soil moisture stress, limiting plant water and nutrient availability. Furthermore, rising soil surface temperatures increase mineralization of organic matter, reduce carbon sequestration capacity, increase salinization, and increase evaporation rates, limiting plant growth. Increased soil salt accumulation would also limit plant growth and reduce agricultural productivity. The major impacts of climate change on soil and soil sustainability could be listed in seven points as follows:

- Reduction of quality and quantity of organic matter, in general, and soil organic carbon, in particular, in tropical and sub-tropical areas;
- Reduction in rate of decomposition of added crop residue with a higher C:N ratio than expected to generate in higher quantity at elevated CO_2 concentration in the atmosphere;
- Addition of crop residues with a higher C:N ratio would reduce nutrient mineralization (increased immobilization) in the soil in anticipated climate change scenarios;
- Nitrogen, phosphorus, and potassium mineralization may increase in higher temperature but their availability would decrease due to higher losses by the processes of denitrification and volatilization;

- Soil erosion may increase as the intensity of rainfall would be expected to increase, although total precipitation may be unchanged or decreased;
- Distribution and frequency of rainfall and wind intensity could enhance water and wind erosion leading to soil degradation.
- Sea-level rise may lead to salinity ingression in the coastal productive lands and turning them to less productive agriculture

Impact on water

The climatic system is complex and governed by the interactions among the atmosphere, water bodies, land system, snow dynamics, and ocean. Climate change is closely related to the hydrological cycle and leads to significant changes in regional water systems. Freshwater challenges include: having too much water, having too little water, and having too much pollution. Climate change has the potential to exacerbate each of these issues. Observational data and climate projections show that freshwater resources are vulnerable and could be severely impacted by climate change, with far-reaching consequences for human societies and ecosystems. Observed warming over several decades has been linked to changes in the large-scale hydrological cycle such as: increasing atmospheric water vapour content; changing precipitation patterns, intensity and extremes; reduced snow cover and widespread melting of ice; and changes in soil moisture and runoff. Changes in the distribution of precipitation, with longer periods between rainfall events and more intense precipitation leads to increased occurrence of extreme weather events, including floods and droughts. Dry spells, the short periods of rainfall, reduced soil moisture and the productivity of rain-fed crops and results increased the risk of increased frequency of crop failures. The impacts of climate change on different elements of water cycle are presented in table 5.

Table 5. Climate change impacts on the different components of water cycle

Elements of water cycle	Climate change impacts
Annual precipitation	Increased and expected to increase globally during the 21st Century, with potentially great spatial variations.
Soil moisture stress (droughts)	Moisture stress to generally increase as a result of increasing variability of rainfall distribution (longer periods without rain) and increasing temperatures.

Floods	Increased as a result of increasing frequency and intensity of extreme rainfall events
Snow and glacier melt	Rising temperatures lead to accelerated snow and glacier melt with initial increases in river flow followed by decreases
River discharge	Increased variability as a result of changes in rainfall patterns. Changes in snow and glacier melt induce changes in seasonal patterns of runoff. Changes in annual runoff expected to vary from region to region
Groundwater	Varies as a function of changes in rainfall volumes and distribution. Impact is complex, with floods contributing to increasing recharge, and droughts leading to increased pumping
Evapotranspiration	Increases as a function of temperature increases
Water quality (in rivers, lakes and aquifers)	Reduced water quality due to temperature increases and erosion
Salinity in rivers and aquifers	Increased where sea water level rise combines with reduced runoff and increased withdrawal

Climate change have a significant impact on the water sector, causing problems in many other sectors such as agriculture, health, industry, and urban development. However, the agricultural sector will bear the brunt of the effects of the water sector disruption. This is a major concern for Ethiopian scientists and policymakers because climate change reduced rainfall, further stressing water availability in these already dry areas. As a result, the overall effect of climate change on water resources is an intensification of the water cycle, resulting in more extreme floods and droughts on a regional and global scale. The growing population necessitates more food, but traditional crop production practices necessitate more water in order to produce enough food to feed the growing population. This jeopardized by increased competition for water among sectors (agriculture, industries, domestic, and infrastructure) and diminishing water resources as a result of climate change.

Impact on forest

Climate change and climate variability threaten the provision of a range of crucial goods and environmental services from forests. They include the delivery of a clean and reliable water supply, protection against landslides, erosion and land degradation, provision or enhancement of the habitats of aquatic and terrestrial animals, provision of a range of wood and non-wood products for household use or sale, and the generation of employment. Higher temperatures and changes in precipitation are increasing tree mortality through heat stress, drought stress and pest outbreaks. Forests have experienced biomass productivity declines that have been attributed to warming-induced drought. Warming and drying, coupled with productivity decline, insect disturbance and associated tree mortality, also favour greater fire disturbance. Generally, the major impacts of climate change on forests are:

- Species composition and density of many forest species reduced due to combined effects of climate change and habitat fragmentation;
- Loss of forest ecosystem and reduced provision of forest ecosystem services, and other non-wood forest production
- Water scarcity due climate change affects forest growth
- Soil moisture depletion reduces the productivity of major forest species, increases fire risk, and changes pest and disease patterns

The majority of Ethiopians rely on forests for various goods (wood and non-wood) and ecosystem services, either directly or indirectly. For these people, especially those who live in rural areas, forests are an important natural resource. Forests help to stabilize the climate by producing oxygen and reducing CO2, ensuring a clean and sustainable water supply, regulating ecosystems and protecting biodiversity, protecting land from degradation and soil erosion, and providing timber, fuel wood, food, and habitat for wildlife. Climate change is clearly contributing to a decline in tree productivity, dieback from drought and temperature stress, increased frequency of forest fires, landslides and avalanches, increased storm damage, increased wind and water erosion, inundation and flood damage, saltwater intrusion, sea-level rise, pest and disease outbreaks and changes in the composition of plan and changes in the composition of plants. Climate change and subsequent forest degradation will have a significant impact on these people's livelihoods. They will be the most affected and vulnerable by climate change. Because forests are so important in maintaining the biological diversity of various ecosystems, it is extremely difficult, if not impossible, to recover biodiversity once it has been eroded. That is, a threat to forests is a threat to the very existence of various biological organisms. Climate change is likely to have a negative impact on Ethiopia's already vulnerable forestry sector. The most likely consequences will be reduced forest area, decreased productivity, changes in species composition, biodiversity loss, increased flood risks, dam silting, and so on.

Session III. Climate-smart natural resource management practices

Climate-smart soil management practices

Soil is one of the major terrestrial carbon pools, contains approximately 2344 Gt of organic carbon globally. According to current estimates, soils contribute 37% of GHG emissions from the agricultural sector on a global scale. Agricultural soils, on the other hand, have the potential to significantly contribute to GHG mitigation through soil organic carbon (SOC) sequestration. Because the amount of carbon stored in soil is much greater than the amount of carbon stock in living vegetation and the atmosphere combined, any minor change in soil organic carbon can result in a significant change in CO_2 concentration in the atmosphere. Soils are thought to have a high potential for carbon sequestration globally, which can be achieved by adopting appropriate land uses and best soil management practices. Land-use change (LUC) and/or soil management have a significant impact on GHG emissions. Surface SOC layers are also affected by changes in management practices. As a result, careful monitoring and management of LUC provide a viable opportunity to reduce atmospheric GHG concentrations. Now, in order to make soil management practices more sustainable, the basic ecosystem functions performed by soil must be maintained or improved without compromising those services or biodiversity.

Principles of Soil Management for CSA

Climate change and variability have a variety of effects on soil health. Weather events would be more intense and erratic in general under changing climatic scenarios, resulting in increased erosion by water and wind, increased runoff loss, reduced groundwater recharge, and a lack of soil moisture for plant growth. Furthermore, decreased or erratic rainfall, as well as significant drought periods, would cause soil moisture stress, limiting plant water and nutrient availability. Furthermore, rising soil surface temperatures will increase mineralization of organic matter, reduce carbon sequestration capacity, increase salinization, and increase evaporation rates, limiting plant growth. Increased soil salt accumulation would also limit plant growth and reduce agricultural productivity. As a result, soil management practices should emphasize increasing the organic carbon content of the soil. The practices should aim to reduce chemical input to the soil while maintaining productive, carbon-rich soil. CSA integrated soil management practices should aim to create optimal soil physical, chemical, and biological conditions, with a particular emphasis on soil resilience.

Principles and practices of some management practices are as follows:

- I. No or minimum tillage system with retention of crop residue would lead to minimizing soil disturbance and the protection of soil organic carbon;
- II. Burning of crop residues must be avoided to maintain optimum soil physical and biological conditions;
- III. In an intensive agriculture system, nutrient supply should be regulated from combined inputs of organic (mulch, compost, crop residues, green manure) and inorganic sources;
- IV. Management practices that inhibit the rapid mineralization of carbon and nitrogen in the soil are to be adopted;
- V. Application of biochar, which is a carbon-enriched form of charcoal, with high stability, porosity, and surface area (produced by pyrolysis, that is, heating of biomass like rice husks, sugar cane bagasse, municipal wastes, and animal manure, etc., with little or no oxygen) could enhance the SOC sequestration potential in soils. Conversion of rice straw into biochar is a potential strategy for controlling GHG emissions.

There are several soil management practices to cope up with climatic stresses (adaptation) and some of them also help to reduce agricultural GHG emissions (mitigation). The practices could enhance food security and climate change mitigation (Table 6)

Table 6. Description of Climate-smart soil management practice

Climate-smart soil adaptation practices	Climate-smart soil mitigation practices
1) Integrated soil fertility management	
1) Maximizing nutrient supply through organic sources such as compost, green manure, etc. to enhance soil organic carbon builds up; 2) Enhancing nutrient and water use efficiency through suitable intercropping, mix-cropping, crop rotation, leguminous nitrogen-fixing crops; 3) Minimizing inorganic nutrient inputs and reduction of nutrient losses	(i) Reducing the input of synthetic nitrogen fertilizers will reduce nitrous oxide emissions (ii) Use of controlled release fertilizers, or fertilizers with urease and/or nitrification inhibitors to reduce N2O emission (iii) Modification of time, method, and rate of manure application to reduce GHG emissions
Biochar application	

i) The application of biochar promotes soil biological activity and improves nutrient use efficiency (ii) It increases carbon sequestration (iii) The addition of nitrogen fertilizer with biochar could control organic nitrogen mineralization	(i) Reduces greenhouse gas emission by increasing recalcitrant and labile carbon pools ratio
Conservation agriculture	
(i) Conservation agricultural-based practices protect the soil from erosion, reduce evaporation, and promote nutrient conservation (ii) Water and nutrient conservation leads to increasing use efficiency and increased crop production (iii) Conservation agriculture increases the resilience of the soil ecosystem	(i) Conservation agriculture reduces carbon dioxide emissions from mechanization due to lower energy requirements for farm operations (ii) It reduces carbon dioxide emissions resulting from different tillage operations (iii) Conservation agriculture has a high potential to sequester soil organic carbon. It has been reported that maximum rates of sequestration are achieved in the first 5 to 20 years after the implementation of carbon-enhancing changes in land management. Sequestration rates then decrease until soil organic carbon stocks reach a new equilibrium after 20 to 30 years
Agroforestry	
These systems integrate crops with trees and thus help to restore soil organic carbon and nitrogen	Perennial crops and trees can sequester substantial amounts of C in long-lived stable pools than annuals in the biomass

Climate-smart water management practices

Climate change is a multidimensional phenomenon, which makes the adaptation to it a complex task. Various sectors affected by climate change are closely interlinked (water, agriculture, industries) with each other; there exists a large-scale spatial variation (local, regional, national); and the type of adaptation measures (physical, technological, policy interventions) also varies with the different climatic zones (dry land, mountains, polar and arctic regions). As a result, water-efficient technologies and practices are viable options in such a situation, and they can be considered water-smart because water-smart technologies use water effectively and efficiently. This practice aids in reducing yield loss caused by extreme weather conditions. Rainwater harvesting, drip irrigation, solar-powered irrigation, water harvesting/collection tanks, drainage management, cover crops, mulching, flood/drought-tolerant varieties, direct-seeded rice, alternate wetting and drying, sprinkler irrigation, and other methods are examples. Some of the common practices are:-

1. **Solar-based irrigation system:_** One of the critical CSA technologies that enables farming communities to irrigate crop fields even during the dry season is the solar-based irrigation system. Solar irrigation has aided smallholder farmers in transitioning from traditional rain-fed subsistence agriculture to high-value crops and marketing by forming groups and cooperatives. In the following ways, the solar-powered irrigation system contributes to the CSA pillars:
    a. Adaptation:- Year-round availability of water, allowing farmers to cultivate rice and vegetable crops on time, regardless of weather.
    b. Mitigation:- This system emits no GHGs and can significantly reduce GHG emissions caused by diesel pumps.
    c. Food security: Increased crop and vegetable productivity as a result of guaranteed irrigation facilities. y Increased cropping intensity by growing multiple crops in a year as opposed to leaving land fallow after the summer crop.
2. **Rainwater harvesting:-** Rainwater harvesting is one of the appropriate practices in which naturally occurring rainwater is collected either in large community-managed ponds or in smaller ponds or tanks practiced in mid and high hill areas. Rainwater harvesting reduces surface runoff and can be used for irrigation during the dry season. Furthermore, during the rainy season, water is collected from the roof of the house and stored in a water collection tank, which is a common practice in Ethiopia. In the following ways, rainwater harvesting systems contribute to adaptation, mitigation, and production (food security).
    a. Adaptation: Increase farmers' access to water during dry periods in order to cultivate high-value (vegetable) crops. It also helps to reduce soil erosion. Larger ponds for collecting rainwater reduce societal exposure to climate change such as population displacement, habitat abandonment, and so on.
    b. Mitigation: Year-round crop cultivation aids in carbon sequestration and thus reduces GHG emissions:
    c. Food security: Boost and secure crop production, especially of vegetable crops. Farmers can earn more money and secure their food supply.

3. **Drip irrigation:-** Drip irrigation is a water-saving technology that is regarded as one of the most important technologies for climate change adaptation. It is made up of plastic pipes with outlets through which water slowly drips from the system. Because drip irrigation irrigates plants only in the root zone, it saves water and reduces weed infestation in the field, resulting in lower intercultural operation costs. It also helps to reduce soil erosion, especially on sloped land. Furthermore, disease incidence is low because the majority of the soil and foliage remain dry. Drip irrigation contributes to the three CSA pillars in the following ways:
   a. Adaptation: through efficient water use and minimal water loss Weed infestation in the field is minimal.
   b. Mitigation: Because weeds are reduced, the use of weedicides is reduced, which reduces greenhouse gas emissions.
   c. Food security: Increased productivity of high-value crops (vegetables) results in higher income, allowing farmers to better secure their food and livelihood.

Chapter self-evaluation question

1. What are the effects of climate change on natural resources?
2. What is climate-smart natural resource management practices and their key characteristics?
3. How does natural resource management contribute to adaptation, mitigation and food security?
4. What makes climate-smart natural resource management different from current agricultural practices?
5. What climate smart natural resource management commonly practiced f in their locality?
6. What are the role of indigenous knowledge in climate-smart natural resource management?

Reading materials

1. Climate-smart agriculture source book, Module 4 (2013) Soils and their management for CSA, pp 134. https://www.fao.org/climate-smart-agriculture-sourcebook/en/
2. Paustian K, Lehmann J, Ogle S, Reay D, Robertson GP, Smith P (2016) Climate-smart soils. Nature 532(7597):49–57
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5. FAO, Joosten K, Grey S (2017) Integrating climate change adaptation and mitigation into the watershed management approach in Eastern Africa: discussion paper and good practices booklet, pp 66
6. Sikka AK, Islam A, Rao KV (2018) Climate-smart land and water management for sustainable agriculture. Irrig Drainage 67(1):72–81

Chapter Seven: Socio-Economic and Gender Perspectives in Climate-smart Agriculture

Session I. Chapter overview

Climate change is a global challenge that has affected many lives and livelihoods; however, women and children are arguably the most affected. Women make an important role in the agricultural sector as they are more involved in farming besides household chores. In developing countries, 43% of the agricultural labor force are women with considerable variation across regions and within countries (FAO, 2011). It is utmost that the information, services, resources, technologies etc. are provided to the women farmers so as to increase the efficiency of the workload and bring about transformational changes in agricultural sector. This chapter tries to examine the impact of climate change on socio-economy and describe how climate change is affecting women. Moreover, it provides an overview of the interconnectedness of women with agriculture and climate change. In addition, it looks at gender specific vulnerabilities and how to manage them through a gender-responsive approach in climate smart agriculture.

Chapter Objectives

By the end of the chapter, the trainee should be able to:

- Describe socio-economic consequences of climate change
- Discuss how gender gap affects adaptation to climate change in agriculture;
- Understand the gender responsive interventions in CSA

Time needed 6Hrs

Session II. Impact of climate change on Incomes and livelihoods

The effect of climate change on the production and productivity of the agriculture sectors will translate into mostly negative economic and social impacts, with implications for all four dimensions of food security. Climate change can reduce incomes at both the household and national levels. Given the high dependency on agriculture of hundreds of millions of poor and food-insecure rural people, the potential impacts on agricultural incomes – with economy-wide ramifications in low-income countries that are highly dependent on agriculture – are a major concern. By exacerbating poverty, climate change would have severe negative repercussions on food security as described bellow;

- Unpredictable weather leading to poor agricultural yields, reduced crop varieties and pastures, poor animal health, rangeland related conflicts, food insecurity, and reduced incomes leading to poverty;
- Increase in floods, droughts, and landslides leading to increased loss of lives, crops, animals, and property, destruction of infrastructure, increase in water related conflicts, and reduced access to clean water;
- Changes in the climate increased disease outbreaks for humans, animals, and plants, as well as an increase in disease vector population, resulting in loss of life and health-related expenses;
- Increased tree cutting and deforestation, increased charcoal use, and increased soil erosion all add to household expenses.

One way the reducing agricultural yield due to climate change consequences is going to increase food availability and then food costs. Higher food cost leads to higher prices and reduced purchasing power of huge low-income consumers globally. On the other way, the higher food prices decline consumer demand that not only reduce energy intake (calories) but also likely to lead less healthy diet globally. Less healthy diet refers to lower intake of protein and micronutrients (zinc, iron, manganese, etc.) to a huge number of populations in lower and middle-income countries that would increase diet-related mortality.

Session III. Women, agriculture and climate change

Women and agriculture

Climate change has a different impact in each sector. Ethiopian agriculture, on the other hand, is more affected due to its high exposure to nature and reliance on weather conditions. Furthermore, the effects of climate change on agriculture are more important to women because of the increased role of women in Ethiopian agriculture as a result of ongoing socioeconomic and demographic changes in rural areas due to male outmigration. Women in Ethiopia contribute up to 40-60% of labor in the production process. Despite women's significant role in agriculture, there is still a significant gender gap in access to and control over resources, which reduces agricultural productivity and disempowers women farmers. Furthermore, the unequal gender roles defined by Ethiopian society expose women to climate change and limit their ability to respond to its effects. Climate change adaptation in agriculture and other sectors will be less effective unless these gender dynamics and differential impacts are understood and gender needs and priorities are integrated into relevant policies and programs. As a result, women-responsive, climate-smart, and transformative agricultural systems, technologies, practices, and approaches are critical to improving food and nutrition security by increasing and sustaining agricultural productivity and livelihoods, as well as contributing to broader development outcomes by addressing the interconnected challenges of gender inequality and climate change resilience.

Climate change and women work burden

Men and women are all affected differently by climate change. Agriculture and women are inextricably linked. As farmers, workers, and entrepreneurs, women play an important role in agriculture. Women farmers are more vulnerable to climate risks than men for many of the same reasons that male farmers have lower farm productivity—women have fewer endowments and entitlements, less access to advisory information and services, financial capital, and they are less mobile and have limited control over farm labor. In most cases, women are excluded from decision-making and may be denied access to technologies and practices that could assist them in adapting to new climatic conditions. There is international agreement that gender differences in the capacity to adapt to and mitigate climate change must be considered in the design and implementation of climate change response strategies and projects. Gender differences in time use, access to assets and credit, treatment by formal institutions, which can limit women's opportunities, limited access to policy discussions and decision making, and a lack of sex-disaggregated data for policy change are key factors that account for the differences in women's and men's vulnerability to climate change risks. Factors like overburdening, poverty, lack of education, skills and income also constrain women’s access to information and exploration of diversifying livelihoods options within agriculture and off-farm sectors. As a result, in order for climate-smart agriculture interventions to be more effective and sustainable, they must address gender inequalities and discrimination against vulnerable people.

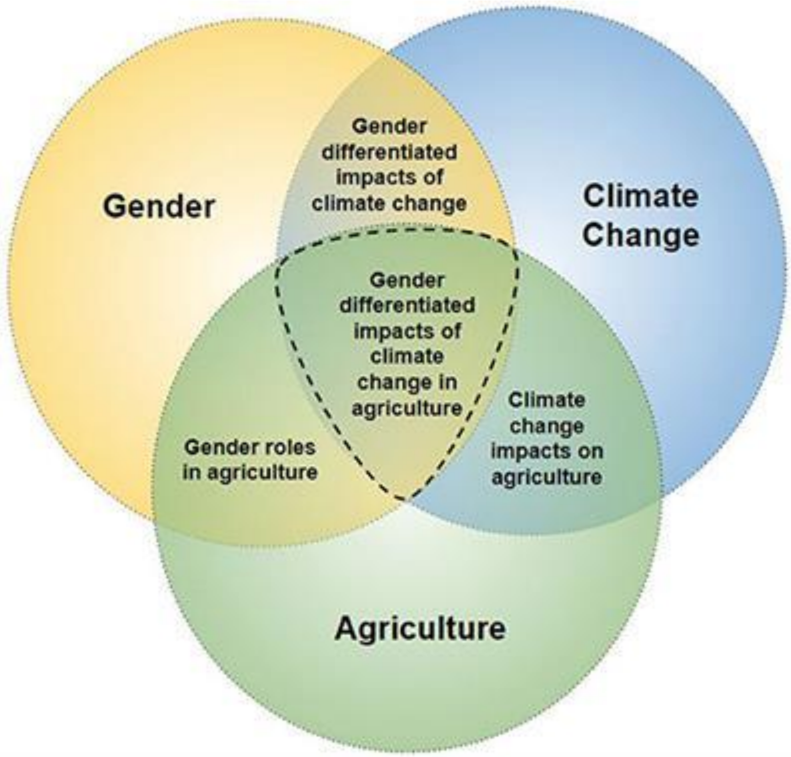

Figure 39. Conceptual diagram to define the gender-agriculture-climate change nexus.

Session III. Gender responsive planning, implementation and monitoring of CSA

The increase in women's workload has had a number of consequences for their health, income, safety, nutrition, violence against women, and, ultimately, their social, economic, and political empowerment. Climate change has exacerbated their existing marginalization and made it difficult for them to gain knowledge of adaptation, technologies, climate finance, and infrastructure. To incorporate gender into CSA, basic information on the status of gender inequality in specific project sites and communities should be considered, against which interventions should be planned, implemented, and monitored.

Considerations while planning CSA

- Gender analysis and role mapping: It is critical to understand how men and women engage in farming activities, as well as the differential impact of climate change in the local context. This analysis will provide a foundation for identifying and developing CSA interventions based on women's vulnerability status.
- Identification of CSA actions and interventions that improve women's conditions and positions: Identification of women-responsive technologies and practices appropriate for the local context will aid in improving women's conditions.

- Identifying targeted communication materials as well as specific training and capacity building requirements.

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Considerations while implementing CSA

- Because males and females have different capacities for understanding information, simple but effective communication methods for reaching women must be developed. Women's ability to comprehend and read knowledge products is not uniform. As a result, care should be taken when developing knowledge products aimed at women.
- Consider how the identified interventions benefit both men and women equally, and ensure that the identified CSA interventions do not harm women.
- Women and men may not access information in the same way or from the same location. As a result, it is critical to ensure that the appropriate time, location, and resource person are chosen for training in order to benefit both men and women equally.
- Eliminate all forms of gender discrimination while carrying out the CSA intervention. Consider how women are represented equally in the planning, design, testing, and implementation of CSA interventions

Considerations while monitoring and evaluating CSA

- Monitoring and evaluation for the effectiveness of CSA tools for women: After the selection and promotion of CSA tools and technologies, it is necessary to carefully monitor the effectiveness of the technologies and practices before we go for large-scale promotion.

To assure if climate-smart agriculture technologies and interventions implemented are gender-responsive, the following additional criteria and indicators can be used in CSA M and E framework.

Gender responsive CSA

- Gender responsive budgeting and coding is the key factor to translate the policy into actions. This budgeting category includes direct responsive, indirect responsive and neutral based on the level of targeted investment to reach out and benefit women as detailed out below:
- » Direct Responsive: if 50 percent or more budget directly reaches and benefits women
- » Indirect Responsive: if 20-50 percent of the budget directly reaches and benefits women
- » Neutral: if less than 20 Percent of the budget directly reaches and benefits women

Women responsive policies, strategies and mechanisms and its importance

- The availability of women responsive CSA tools and technologies only is not enough for the integration of gender in CSA. Supportive policy provisions are equally essential to help women use and benefit from climate-smart technologies. Harmonization among various policy frameworks and programme is equally essential to increase women's role in agriculture and make agriculture climate smart. There are several policies and strategies for gender, agriculture and climate change in Ethiopia. The section below highlights some key policies and strategies with their specific provisions in agriculture and climate change targeting women.

Strategies and interventions to mainstreaming gender in CSA

- Increase the participation of women and their access to input and services for high-value production and Agri-enterprises;
- Support for irrigation scheme demanded from women farmers' groups;
- Development of women technicians for better reach to women farmers;
- Formation and mobilization of women farmers' groups to deliver input and services;
- Gender disaggregated database and monitoring; y Gender Focal Desk and involvement in planning, monitoring, capacity building;
- Research and coordination with other actors on women-specific matters;
- Support for women's agro enterprise (high-value crop).

Chapter self-evaluation question

1. What are the effects of climate change on socio-economy?
2. Does gender matter in climate change adaptation?
3. Describe gender specific vulnerabilities to climate change and how to manage them through a gender-responsive approach in climate smart agriculture?
4. Explain gender responsive interventions in CSA

Reading materials

1. World Bank, FAO and IFAD. 2015. Gender in climate-smart agriculture: Module 18. Gender in agriculture sourcebook. World Bank Group and the Food and Agriculture Organization of the United Nations and the International Fund for Agricultural Development.
2. Nitya C, Chhetri AK, Pande K and Joshi R. 2018. Integrating gender into the climate-smart village approach of scaling out adaptation options in agriculture. InfoNote. Climate Change, Agriculture and Food Security (Available at https://cgspace.cgiar.org/bitstream/handle/10568/96274/http://Infonote_gender_CSV.pdf)

3. FAO & CCAFS. 2016. A gender-responsive approach to climate-smart agriculture; Evidence and guidance for practitioners. Rome: Food and Agriculture Organization of the United Nations; and Copenhagen: CGIAR Research Program on Climate Change, Agriculture and Food Security. (Available at http://www.fao.org/3/abe879e.pdf). FAO & World Bank. 2017. Training module: How to integrate gender issues in climate-smart agriculture projects. Rome: Food and Agriculture Organization of the United Nations. (Available at http://www.fao.org/3/a-i6097e. pdf).
4. Chanana N, Khatri-Chhetri A, Pande K and Joshi R. 2018. Integrating gender into the climate smart village approach of scaling out adaptation options in agriculture. CCAFS info note. Copenhagen: CGIAR Research Program on Climate Change, Agriculture and Food Security (CCAFS). (Available at https://cgspace.cgiar.org/ bitstream/handle/10568/96274/http://Infonote_gender_CSV.pdf)

Chapter Eight: Agricultural Extension and Knowledge management towards CSA

Session I: Chapter overview

Ensuring that agriculture becomes climate smart is a priority for meeting the demand for adequate, nutritionally balanced food for a growing and more demanding population in the face of resource constraints, climate change, and variability. Despite the recognizing the importance of CSA, the dissemination and uptake of climate smart technologies, tools, and practices remains largely an ongoing, difficult process. It is critical to adapt climate-related knowledge, technologies, and practices to local conditions, promote joint learning among farmers, researchers, and rural advisors, and widely disseminate CSA practices. Farmers, on the other hand, are facing challenges in reducing climate impacts on agriculture due to a lack of proper CSA knowledge. Furthermore, because CSA is knowledge-intensive, effective information dissemination is required to allow stakeholders and farmers to make informed decisions. As a result, agricultural extension and knowledge management for CSA is an important practice that provides farmers with knowledge, information, and predictions about weather conditions, agricultural practices, and the possibility of pest and disease infestation, as well as helping to build a climate resilient agricultural sector. Thus, this chapter discusses the dissemination and knowledge management relevance to CSA.

Chapter Objectives

By the end of the chapter the trainee should be able to:

- Describe types of agricultural extension approach for CSA;
- Explain the contribution of climate knowledge management and extension to the pillars of CSA; and
- Recommend areas for improving the dissemination of climate based information

Time needed **4hrs**

Session II: Agriculture extension for CSA

The important role of extension services

Climate-Smart Agriculture (CSA) is a success story that has been quickly adopted by the international community due to its ability to address the urgent needs of climate mitigation, adaptation and resilience, and food security. While a lack of location-specific tools, long-term experiences, and a favorable enabling environment are barriers to CSA implementation, a number of climate-smart technologies and practices are well-known and readily available. Unfortunately, few have demonstrated widespread adoption. The difficulty of sharing information and knowledge on effective CSA practices emerging from research is one reason for low uptake and implementation.

National agricultural advisory services can be thought of as synapses that connect research findings to the end users, namely farmers. However, in many developing countries, these advisory services suffer from chronic understaffing, limited operational funds, and weak links to other players, such as research. Evidence from Africa, for example, shows that each extension worker serves a very small number of farmers. This situation results in underperformance of extension systems, limited reach and impact, and is the primary barrier to CSA implementation. These systemic constraints can make it difficult to respond quickly to changing climatic environments with adaptation strategies, posing a threat to agriculture-based economies.

Extension services have traditionally been thought of as a mechanism for putting research-based knowledge to use, with a strong emphasis on increasing agricultural production. According to GFRAS (2012), new global challenges such as declining water availability, increasing soil degradation, and changing and uncertain climate and markets have significantly altered the role of extension systems today. Addressing these global challenges necessitates the creation, adaptation, and application of new knowledge, which necessitates interaction and support from a diverse range of organizations. These new challenges also imply that extension systems must address a wide range of objectives, including, but not limited to, the transfer of new technology. This includes the need to: connect more effectively and responsively to domestic and international markets (food, feed, fibers, etc., and/or carbon); reduce vulnerability and strengthen the voice of the rural poor; promote environmental conservation; build links between farmers and other agencies; and institutional and organizational development to support farmers' bargaining position, such as the formation of farmer groups (Davis, 2009; GFRAS, 2012). As a result, the new extensionist has evolved from a production-focused role to an integrated, cross-sectoral function of the extension ecosystem. Today, extension comes in "many sizes and shapes"

(FAO, 1998), and distinguishing between extension approaches (e.g., participatory training approach, training and visit approach) or the main underlying principles of advice (e.g., organic production, integrated production) is not absolute. However, all extension systems face the same challenge in determining how to best respond to climate change. This is exacerbated by the fact that CSA considerations in extension strategies are still relatively new. The need for a shift from a food security focus to an integrated view that considers both synergies and trade-offs between the three components of CSA is and will be a major barrier to CSA implementation, necessitating significant investments to develop knowledge and capacities at both the extension and farmer levels.

In many countries, agricultural extension has proven to be a high-return public investment. According to a review of 48 impact studies, 75% of extension projects produced significant positive results, with rates of return ranging from 13 to 500% (Birkhaeuser et al., 1991). A more recent review in Sub-Saharan Africa found similar results, with 71% of evaluated impact evaluations reporting positive impact (Taye, 2013). As a result, a functional, climate-smart, sensitive, and responsive extension system can be viewed as an efficient and cost-effective tool that can help address climate change.

The literature mentions several extension approaches, with the major categories being group extension, mass media extension, and individual/household extension. Extension approaches and methods have advantages and disadvantages, implying that there is no best way to extend. Among other things, the target audience, available resources, and facilitator capacity all influence the choice of an extension approach.

Types of agricultural extension services relevant for CSA

Different types of extension approaches are used in different parts of the world. Each approach reflects a distinct set of objectives, goals, and sociocultural context. State institutions, agricultural training institutions, advisory services, private sector agencies, nongovernmental organizations (NGOs), farmer organizations, and farming communities provide extension services. Extension services are provided not only by extension agencies, but also by farmers, scientists, commercial companies, and mass media organizations. The majority of extension services in developing countries are provided by public institutes. However, because most public extension systems are still top-down in structure, the private sector and civil society organizations are playing an increasingly important role in providing specific extension/advisory services.

Information, knowledge, and skills for CSA are delivered via three extension methods: mass communication, individual, and group. Different tools and approaches were used for each method. This could include technologies like radio, podcasts, mobile phones, and video programs, as well as methods of sharing new knowledge and skills with farmers like model farmers, farmer field schools, village information centers, or question-and-answer services. Many approaches have been used to promote agricultural development, including the market day approach, the teacher-student approach, the field school approach, the village level participatory approach (VLPA), adaptation (modification) for adoption, and radio and television. Some of these extension services have concentrated on providing farmers with information and training.

Generally extension approaches and methods related to CSA are divided into two categories:

1. **Traditional approaches for climate-smart agriculture**:- Traditional mass media extension methods include radio, print media such as newspapers and pamphlets, and audio visual aids.
2. **Innovative approaches for climate-smart agriculture**:- Demonstrations of agricultural practices, field days, farmer days, master farmer training, training workshops and meetings, study circles, exchange visits, and farmer field schools are all part of the innovative extension approach.

Session III. Contribution of agricultural knowledge management and extension to CSA

Climate-based agricultural extension and knowledge management are critical components of CSA, owing to the fact that adapting to climate change necessitates changes in knowledge, attitudes, resilience, capacities, people's skills, and extension systems. Agricultural extension contributes to the three pillars of CSA, either directly or indirectly. Climate information dissemination, technologies, and management information; capacity development; facilitating brokering and implementing policies and programs; coordination; infrastructure/institutions; training; use of practices and technology demonstrations; yield crop forecasting; and feedback role, according to Singh and Grover (2013).The contribution of agricultural extension services and knowledge management to CSA:

1. **Productivity:**- Climate information-based agricultural extension services that are effective are part of the enabling environment for the transition to CSA. Adequate and timely weather information extension can assist farmers in making decisions about the timing of agricultural activities, the types of crops to be planted, and the type of livestock to be raised, thereby

increasing productivity. Climate information serves as a foundation for adaptable planning to a variety of climate scenarios. It aids in deciding which options to invest in, as well as when and how much to invest. For example, given a good rainfall forecast, a farmer may decide to grow a high-yielding maize variety. In order to increase income, the farmer may decide to diversify and apply the value of the harvested maize to other projects such as poultry and piggery.

2. **Adaptation through risk management:-** Effective dissemination and use of climate information services contributes to resilience by allowing farmers to better manage the negative effects of weather-related risks during drought periods, while also taking advantage of average and better-than-average seasons. Understanding climate as a major influence on livelihoods, life, ecosystems, and development requires a climate information-based extension service. It enables effective adaptation, which entails creating a variety of adaptation options with the ability to switch from one strategy to another or combine strategies. It assists actors in adjusting their plans as climate stressors and shocks emerge.
3. **Mitigation:-** Climate information-based extension services can contribute to CSA by providing information that promotes more efficient fertilizer use in order to reduce greenhouse gas emissions into the atmosphere.

Chapter self-evaluation question

1. Describe types of agricultural extension approach for CSA.
2. How does climate based information management and extension contribute to adaptation, mitigation and food security?

Reading materials

1. FAO (2013) Climate smart agriculture Source book. Rome Italy Food Agriculture Organisation of United Nations, pp. 4-10.
2. Salas S, Kossi, R., David S edit (2014). Compendium of climate smart agriculture and extension, supporting agricultural extension towards climate smart agriculture: an overview of existing tools, pp. 5-43.
3. Singh I., Grover J. (2013). Role of extension agencies in climate change related adaptation strategies. International Journal of Farm Sciences 3(1): 144155, 2013, p. 145.

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Chapter Nine: Policies, Strategies and Institutions in CSA

Session I: Chapter overview

Climate change has exacerbated the difficulties that rain-fed agricultural systems face. As a result, there is a growing recognition of the need to balance environmental protection, investment in smallholder agriculture, and improving food production and productivity while reducing GHG emissions and vulnerability to climate change impacts. A paradigm shift that allows institutional arrangements and the creation of synergies focused on championing the components of Climate-smart Agriculture is required to achieve sustainable food production (CSA). While the Ministry of Agriculture is a major player in climate action promotion, there is frequently a disconnect between these sister institutions, as well as conflict between farmers and policymakers. Given the need for greater coordination and integration among institutions, a coordinated, legally binding institutional framework for the enforcement of CSA interventions is required. The instrument is intended to eliminate bottlenecks while ensuring a coordinated effort that maximizes existing synergies while minimizing trade-offs between institutions and actors. Furthermore, policies and strategies to transform agriculture and promote climate smart agriculture are required. This necessitates greater policy coherence, coordination, and integration between climate change, agricultural development, and food security. The integration of policies in these three areas will have a greater impact on agricultural production systems and GHG emissions. A lack of coherence, coordination, and integration can have a negative impact on the desired outcomes. This chapter highlights the CSA practices that can be used as entry points for the formulation of CSA policy and the governance of institutional arrangements.

Chapter Objectives

By the end of the chapter the trainee should be able to:

- Identify key institutions that can champion CSA and its implementation using existing policy instruments that recognise CSA as a technology for improving food security;
- Identify all existing entry points for CSA implementation and establish the capacity needs to improve the design and implementation of the programmes;
- Identify and list institutional arrangements that can be established in the implementation of CSA; and
- Recommend policy statements for input into the national CSA legal/policy framework.

Time needed 4hrs

Session II: Policies related to CSA

Enabling environments for CSA imply that there is encouragement and support for the adoption of CSA practices and technologies. Relevant policies, institutional arrangements, stakeholder involvement, supportive infrastructure, access to weather information, and farm services are examples of enabling environments. Agricultural transformation to CSA may also be aided by enabling environments that provide appropriate incentives, laws, and regulations. It may also include individual and institutional capacity building. Policy and strategy are required to transform agriculture and promote SCA. This necessitates greater policy coherence, coordination, and integration between climate change, agricultural development, and food security. The integration of policies in these three areas will have a greater impact on agricultural production systems and GHG emissions. A lack of coherence, coordination, and integration can have a negative impact on the desired outcomes. Every country has its own national climate change strategy and plan of action, while also contributing to regional and global agendas.

Ethiopia's government has put in place a number of policies to help with climate change adaptation and mitigation, as well as overall sustainable development. Ethiopia's policy responses to climate change challenges are numerous, though there is no direct mention of climate-smart agriculture. However, even before climate change became one of the most important factors in sustainable development, several of Ethiopia's development and sectoral policies and programs addressed the issue. The goals of climate-smart agriculture for sustainable development are already shared by the Climate Resilient Green Economy (CRGE) Strategy objectives and guiding principles, the productive safety net program (PSNP), and the sustainable land management program (SLMP). Early climate change actions enabled the country to plan for short- and long-term agricultural adaptation and mitigation actions that are tightly linked to national food security and nutrition policies. What remains is to raise awareness of the policies and promote their implementation at all levels. One approach could be to incorporate policies into agricultural extension and research. Furthermore, establishing a legally binding institutional framework for greater institutional coordination and integration, as well as synergy among programs/projects, is critical. Table 6 lists some of the key policy responses relevant to climate smart agriculture.

Table 7. Summary of key policies, laws and strategies relevant to Climate Smart Agriculture practice in Ethiopia

Policy	Year	Intention or goal
Environmental Policy of Ethiopia	1997	Overall guidance in the conservation and sustainable utilization of the country's environmental resources
Environmental Impact Assessment	Proclamation 2002	Ensure that the environmental implications are taken into account before decisions are made
National Adaptation Program of Action (NAPA):	2007	The NAPA represented the first step in coordinating adaptation activities across government sectors
REDD+ strategy	2008	This shows alternative mechanisms for financing forestry development in Ethiopia and enhancing the country's climate change mitigation potential.
The Comprehensive Africa Agriculture Development Program (CAADP) Compact	2009	One of the pillars of CAADP is extending the area under sustainable land management and reliable water control systems
Growth and Transformation Plan (GTP I)	2010	The GTP recognizes that the environment is a vital pillar of sustainable development
Agriculture Sector Programme of Plan on Adaptation to Climate Change/APACC	2011	The Agriculture Sector Climate Change Adaptation Plan
Ethiopian Programme of Adaptation to Climate Change (EPACC)	2011	More programmatic approach to adaptation planning
Climate Resilient Green Economy Strategy	2011	Carbon-neutral middle-income status before 2025
National policy and strategy on disaster risk management	2013	This is a framework for disaster risk management, which includes early warning and risk assessment, information management, capacity building, and disaster risk reduction integration into development plans. It is primarily concerned with droughts.
Ethiopia's climate-resilient green economy climate resilience	2015	This is a sectoral chapter of the CRGE's resilience strategy. It is concerned with water and energy.

strategy: water and energy		
Growth and Transformation Plan (GTP-II)	2015	GTP II is the second federal, 5-year national development plan
Agriculture and forestry climate change resilience roadmap	2015	This is a sectoral chapter of the CRGE's resilience strategy focusing on agricultural crops, livestock, forestry, food security, and disaster prevention as the agriculture and forestry sectors are transformed into services and industry.
Intended nationally determined contribution (INDC)	2015	This section contains information on emission reduction targets as well as general climate change mitigation and adaptation strategies. Agriculture (livestock and soil), forestry, transportation, electric power, industry (including mining), and construction are all included (including waste and green cities)
Ethiopia's climate resilient green economy national adaptation plan, Federal Democratic Republic of Ethiopia (NAP-ETH)	2019	NAP-ETH seeks to reduce vulnerability to the effects of climate change by increasing adaptive capacity and resilience. It aims to strengthen the holistic integration of climate change adaptation in Ethiopia's long-term development path, supported by effective institutions and governance structures, funding for implementation and capacity development, and strengthened disaster risk management and integration systems across sectors.
Climate Change Education Strategy of Ethiopia 2017-2030	2017	The goal is to strengthening the Integration of Climate Change Education into the Formal System of Education of Ethiopia
Ethiopia climate-smart agriculture roadmap	2020	The roadmap proposes key CSA actions that can be implemented at scale to ensure resilient food systems, to build enabling institutional environments that can promote such mainstreaming, to promote the centrality of gender and social inclusion in our agricultural systems, and to develop capacity that can strengthen Ethiopia's national efforts for adaptive, resilient, and transformative food systems and agricultural livelihoods.

Ethiopia is a signatory to a number of multilateral agreements that affect the country's efforts toward sustainable development. Ethiopia has signed and/or ratified a number of international climate change and land degradation conventions and protocols, including the United Nations Framework Convention on Climate Change (1994), the Convention on Biological Diversity (CBD), and the United Nations Convention to Combat Desertification (UNCCD).

Session III. Institutions related to CSA

It is a complex process to ensure long-term food security and development in changing climates while avoiding further depletion of natural resources and land degradation. More food production to feed the world's growing population will necessitate more water, deforestation, land degradation, and GHG emissions. To ensure sustainable food production with efficient use of natural resources and low GHG emissions, the agriculture sector must undergo significant transformation. This transformation necessitates greater collaboration among institutions such as academia (agricultural colleges, universities, and training institutions), agricultural establishments (agricultural research, agricultural extension, water management, plant protection, soil conservation, and so on), environmental departments, policymakers, and the country's financial institutions.

Climate change action in Ethiopia was previously mandated by the Environmental Protection Authority (EPA), which was established following the 2009 Climate Change Conference in Copenhagen. Following a reorganization of governmental institutions, the Ministry of Environment, Forestry, and Climate Change (MEFCC) was designated as the lead entity for the country's climate framework until 2021. Since 2022, the Ministry of Planning and Development has served as the overall coordinator of the country's climate-change-related activities.

The Ministry of Agriculture (MoA) is a key institution promoting CSA practices in the country, primarily through various projects and programs implemented by its various units, such as the Climate Resilient Green Economy (CRGE) Coordination Unit, the Sustainable Land Management Programme (SLMP) Coordination Unit, the Soil Information and Fertility Directorate, the Agricultural Growth Programme (AGP) Coordination Unit, and the National Agricultural Research System. CSA initiatives promoted by the MoA link to increased agricultural productivity and climate resilience, focusing on practices such as soil and water conservation, conservation agriculture, agroforestry systems, fodder production (cut and carry), and improved varieties. Aside from the SLMP, the Ministry also implements the Managing Environmental Resources to Enable Transitions to More Sustainable Livelihoods Coordination Unit, a World Food Programme-supported project that began in the 1980s and includes activities such as water harvesting, reforestation, seedling production, soil fertility management, and farmland terrace construction.

The Agricultural Transformation Institute (ATI) is tasked with improving the livelihoods of smallholder farmers. ATI implements four major programs that aim to improve: I smallholder farmers' agricultural production and productivity; (ii) processing and value addition in agribusinesses for improved market access; (iii) sustainable and inclusive growth for improved farmer resilience; and (iv) capacity building of agricultural institutions for project implementation and impact maximization. ATI has a diverse portfolio of CSA-related work, including training extension actors on CSA practices such as conservation agriculture, improving agricultural decision making through improved access to climate information and weather station installations, and supporting improved access to agrometeorological data.

In terms of research, the Ethiopian Institute of Agricultural Research (EIAR) and its regional research institutes, federal and regional research centers, and universities comprise Ethiopia's National Agricultural Research System (NARS), the primary goal of which is to generate and promote the adoption of information, knowledge, improved practices, and technologies that increase agricultural productivity. CSA-related research is also being conducted in the country by a number of international research institutes. CGIAR Centers such as CIAT, the International Crops Research Institute for the Semi-Arid Tropics (ICRISAT), the International Maize and Wheat Improvement Center (CIMMYT), the International Center for Agricultural Research in the Dry Areas (ICARDA), the World Agroforestry Centre (ICRAF), the International Livestock Research Institute (ILRI), and the International Water Management Institute (IWMI) are working on biogas from dairy waste management, soil and water conservation, agroforestry

Among other things, the Ethiopian Environment and Forest Research Institute (EEFRI) conducts research on agroforestry, forest product utilization, and climate change. Haramaya University (HU) is also established African Center of Excellence in Climate-Smart Agriculture and Biodiversity Conservation, which aim to produce skilled human capital on CSA for the Eastern and Southern Africa regions. National and local NGOs' work on CSA is primarily focused on increasing smallholders' climate resilience and food security in the face of climate-related hazards, particularly droughts. For international organizations, the Food and Agriculture Organization of the United Nations (FAO) has a long history of support for conservation agriculture and other climate-smart practices in Ethiopia.

Overall, the country has a clear institutional and policy framework in place to support climate change action in agricultural sector development. Through investments in research, capacity building for extension workers, and field demonstrations, the government, in collaboration with its development partners, has made progress in bringing CSA onto the policy agenda and within farmers' reach. As the number and scope of such efforts grows, coordination of interventions and alignment with existing policies will be critical for effective resource spending and value addition.

Session IV. Session Role of institutions in scaling up CSA

Policies and programs are unlikely to be effective unless they are implemented by credible institutions. In order to implement and replicate CSA strategies, institutional capacities must be strengthened. Institutions are critical to agricultural development and the realization of sustainable livelihoods. They are not only a tool for farmers and decision-makers, but also the primary channel for scaling up and maintaining climate-smart agricultural practices.

Session V: Effectiveness of Policies, Strategies and Institutions related to CSA

Significant efforts are being made in Ethiopia to develop climate change policies and strategies. These policies are also adequately incorporated into subsequent government plans, such as the GTP and Home Grown Economic Reforme. Under the strategic priority of environment and climate change, the GTP addresses climate change as a cross-cutting issue. Building a climate-resilient green economy is outlined as a strategic priority for the plan period of 2010 to 2015. A number of policy-supported development projects and programs have been initiated and implemented. The majority of the work was devoted to soil and water conservation, soil/land management for increased agricultural productivity, and reforestation practices.

The most recent climate change strategy is the CRGE, which was developed in 2011. Institutional arrangements are being developed for coordinating and implementing public policy responses to CRGE. The Ministry of Environment and Forests is in charge of coordinating CRGE planning. The CRGE Inter-Ministerial Committee, which reports to the Council of Ministers, oversees the CRGE process. Within the CRGE institutional arrangements, this Committee is the highest-ranking body. It is in charge of providing overall guidance to the CRGE process as well as approving financial decisions for the CRGE facility. State Ministers and senior officials from participating institutions make up the Committee.

The Ethiopian government is developing institutional arrangements to enable demand-driven articulation and implementation of CRGE investments. Outlining a role for implementing and executing entities, as well as the establishment of CRGE units within the implementing entities, are among the proposed arrangements. Furthermore, policies such as the Environment Policy are being operationalized through the preparation and implementation of District Environmental Management Plans in various districts. To achieve the desired results, forest, soil, and water conservation area enclosure activities have been implemented as primary actions. Despite the fact that policies are being implemented, more work needs to be done to ensure their effectiveness. Another issue is a lack of coordination and a relevant legislative framework, as well as consultations on climate change-related activities, projects, research programs, and responses currently being undertaken by various stakeholders, particularly between government NGOs and donor agencies. This could result in duplication of effort and inefficiency in project implementation.

Chapter self-evaluation question

1. Describe the role of policy and institutions to transform agricultural sector in Ethiopia towards CSA.

Reading materials

1. FAO (2013) Climate smart agriculture Source book. Rome Italy Food Agriculture Organisation of United Nations, pp. 4-10.
2. FAO (2016). Ethiopia Climate-Smart Agriculture Scoping Study. by Jirata, M., Grey, S. and Kilawe, E. Addis Ababa, Ethiopia