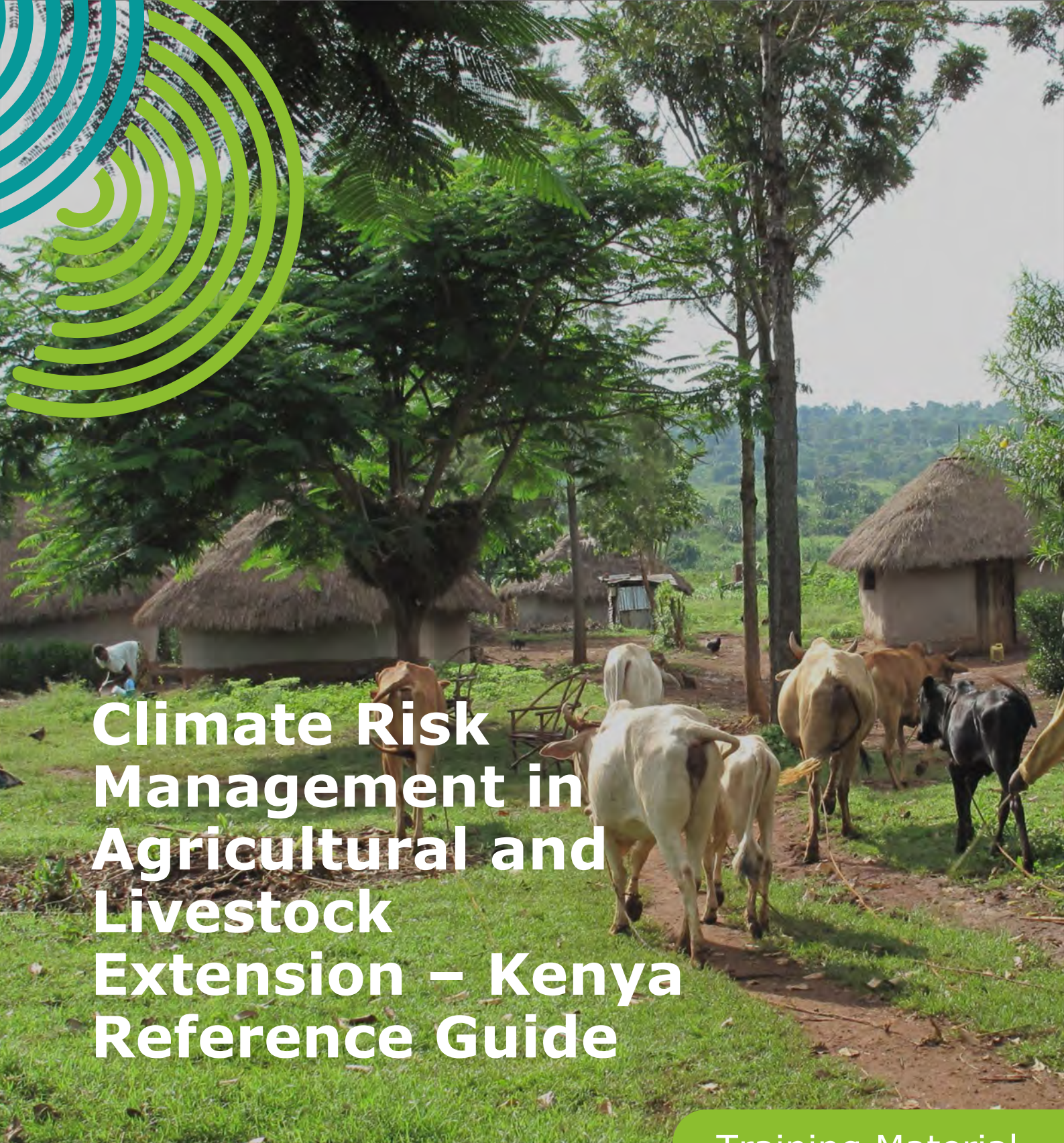




Climate Risk Management in Agricultural and Livestock Extension – Kenya Reference Guide

Training Material



**KENYA METEOROLOGICAL
DEPARTMENT**



**Ministry of Agriculture &
Livestock Development**



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About AICCRA Reports

Titles in this series aim to disseminate interim research on the scaling of climate services and climate-smart agriculture in Africa, in order to stimulate feedback from the scientific community.

Cover Photo

ILRI/Charlie Pye-Smith

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About AICCRA



Accelerating Impacts of CGIAR Climate Research for Africa (AICCRA) is a project that helps deliver a climate-smart African future driven by science and innovation in agriculture. It is led by the Alliance of Bioversity International and CIAT and supported by a grant from the International Development Association (IDA) of the World Bank. Explore our work at aiccra.cgiar.org

FOREWORD

The natural eco-systems continue to be threatened by climate change and global warming, affecting food production across the globe. This has resulted in food insecurity for countries relying on mainly on rain-fed agriculture, which Kenya falls under. Most of Kenya agricultural production is subsistence in nature and is rain-fed. The evolving climate change has brought forth the need to create awareness to make sure the natural eco-systems are made resilient. The resilience will be achieved by mainstreaming climate information in all spheres of life.

One of the ways to mainstream climate information is by ensuring that climate information is properly communicated. The National Meteorological and Hydrological Services (NMHS), Kenya Meteorological Department being one of them, produce weather and climate information for use by different sectors. The information is supposed to inform the decisions at all levels including policy and at the lowest level in food production.

To optimally utilize the climate information produced by Kenya Meteorological Department (KMD), all stakeholders should be sensitized. The sensitization will ensure that climate information is well understood and applied in order to create resilient eco-systems. The agricultural sector specifically is gravely affected by climate change and requires deliberate interventions.

In support of mainstreaming climate information, besides the usual weather and climate forecasts, KMD engages stakeholders in co-production of sector specific products during National Climate Outlook Forums (NCOF) every rainy season. As one of the climate user interfaces, NCOF is then cascaded to county levels under the participatory scenarios planning workshops (PSP). These platforms link climate information producers and users up to the grassroot level. This activity is led by climate information producers and sector leads especially the agriculture extension staff. From these user platforms, it has been appreciated that there is gaps in skills and knowledge on climate information and therefore there is need for basic understanding of climate basics, including a shared vocabulary and knowledge of basic terminology and dynamics to both articulate and engage in meaningful collaborations and design of climate solutions.

It is for this reason, KMD partnered with IRI of the Columbia University, USA, to build climate information understanding of the sector leads and other users, through the curriculum of climate risk management in agricultural and livestock extension (CRMAL). The learnt skills will support climate adaptation and climate-informed agricultural decision-making on the ground. This partnership has been supported by the Accelerating Impacts of CGIAR Climate Research for Africa (AICCRA) project.

With adoption of the CRMALE curriculum, it is expected that the teaching and learning will enhance skills and knowledge in target population in order to continue to support understanding of climate information to inform resilient agricultural and livestock production.



DR. DAVID GIKUNGU
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KENYA METEOROLOGICAL DEPARTMENT

ACRONYMS

ACRE	African Climate Risks Enterprise
ADA	Agricultural Development Agency
AET	Actual Evapotranspiration
AICCRA	Accelerating Impacts of CGIAR Climate Research for Africa
APSIM	Agricultural Production Systems Simulator
ASDSP	Agricultural Sector Development Support Programme
CA	Conservation Agriculture
CABI	Centre for Agriculture and Bioscience International
CARE	Cooperative for Assistance and Relief Everywhere
CBC	Community Based Committee
CCAFS	CGIAR Research Program on Climate Change, Agriculture and Food Security
CE	Circular Economy
CIAT	International Centre for Tropical Agriculture
CIS	Climate Information Services
CLIVAR	Climate Variability and Predictability program
CRMAL	Climate Risk Management in Agricultural and Livestock Extension
CSA	Climate-Smart Agriculture
CTA	Technical Centre for Agricultural and Rural Cooperation
DEA	Data Envelopment Analysis
DMI	Dipole Mode Index
DSS	Decision Support System
DSSAT	Decision Support System for Agrotechnology Transfer
DVA	Disaster Vulnerability Assessment
ENACTS	Enhancing National Climate Services initiative
ENSO	El Niño-Southern Oscillation
FAO	Food and Agriculture Organization
GAIIIS	Global Agriculture and Insurance Information System

GCM	General Circulation Model
GESI	Gender Equality and Social Inclusion
GHACOF	Greater Horn of Africa Climate Outlook Forum
GHG	Greenhouse Gas
GM	Genetically Modified
IBLI	Index-Based Livestock Insurance
ICPAC	IGAD Climate Prediction and Application Centre
ICRISAT	International Crops Research Institute for the Semi-Arid Tropics
ICT	Information and Communication Technology
IDA	International Development Association
IGAD	Intergovernmental Authority on Development
ILRI	International Livestock Research Institute
IMTR	Institute for Meteorological Training and Research
IOD	Indian Ocean Dipole
IPCC	Intergovernmental Panel on Climate Change
IR	Infrared
IRI	International Research Institute for Climate and Society
IVR	Interactive Voice Response
JAS	July-August-September
KAIP	Kenya Agricultural Insurance Program
KALRO	Kenya Agricultural and Livestock Research Organization
KAOP	Kenya Agricultural Observatory Platform
KMD	Kenya Meteorological Department
KSA	Kenya School of Agriculture
KSh	Kenyan Shilling
KMFRI	Kenya Marine and Fisheries Research Institute
MOS	Model Output Statistics
MUAC	Mid-Upper Arm Circumference
NASA	National Aeronautics and Space Administration

NCOF	National Climate Outlook Forum
NDMA	National Drought Management Authority
NDVI	Normalized Difference Vegetation Index
NMHS	National Meteorological and Hydrological Services
NMS	National Meteorological Service
NOAA	National Oceanic and Atmospheric Administration
PET	Potential Evapotranspiration
PICSA	Participatory Integrated Climate Services for Agriculture
POE	Probability of Exceedance
PSP	Participatory Scenario Planning
RCM	Regional Circulation Model
RCMRD	Regional Centre for Mapping of Resources for Development
RCOF	Regional Climate Outlook Forum
RP	Risk Premium
RUFORUM	Regional Universities Forum for Capacity Building in Agriculture
SD	Standard Deviation
SMS	Short Message Service
SPI	Standardized Precipitation Index
SPPARCK	Strengthening Participatory Planning for Resilient Communities in Kenya
SSP	Shared Socioeconomic Pathways
SST	Sea Surface Temperature
SW	Surface Water
TLU	Tropical Livestock Unit
USAID	United States Agency for International Development
USD	United States Dollar
USSD	Unstructured Supplementary Service Data
WHC	Water Holding Capacity
WMO	World Meteorological Organization
WRSI	Water Requirement Satisfaction Index

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INTRODUCTION

Improvements in the weather and climate information available in Kenya provide new opportunities for agricultural extension personnel to help agricultural producers better manage the risks that they face, and to adapt recommended technology packages to local climatic conditions. This 2-week course aims to equip agricultural extension workers to access, understand and incorporate climate information into their professional work. It is designed to provide foundational knowledge on climate and agricultural decision making; and practical tools to analyze climate-related risks, use appropriate weather and climate information to support agricultural decisions, communicate complex climate information effectively with crop and livestock farmers, and integrate climate services into agricultural extension activities.

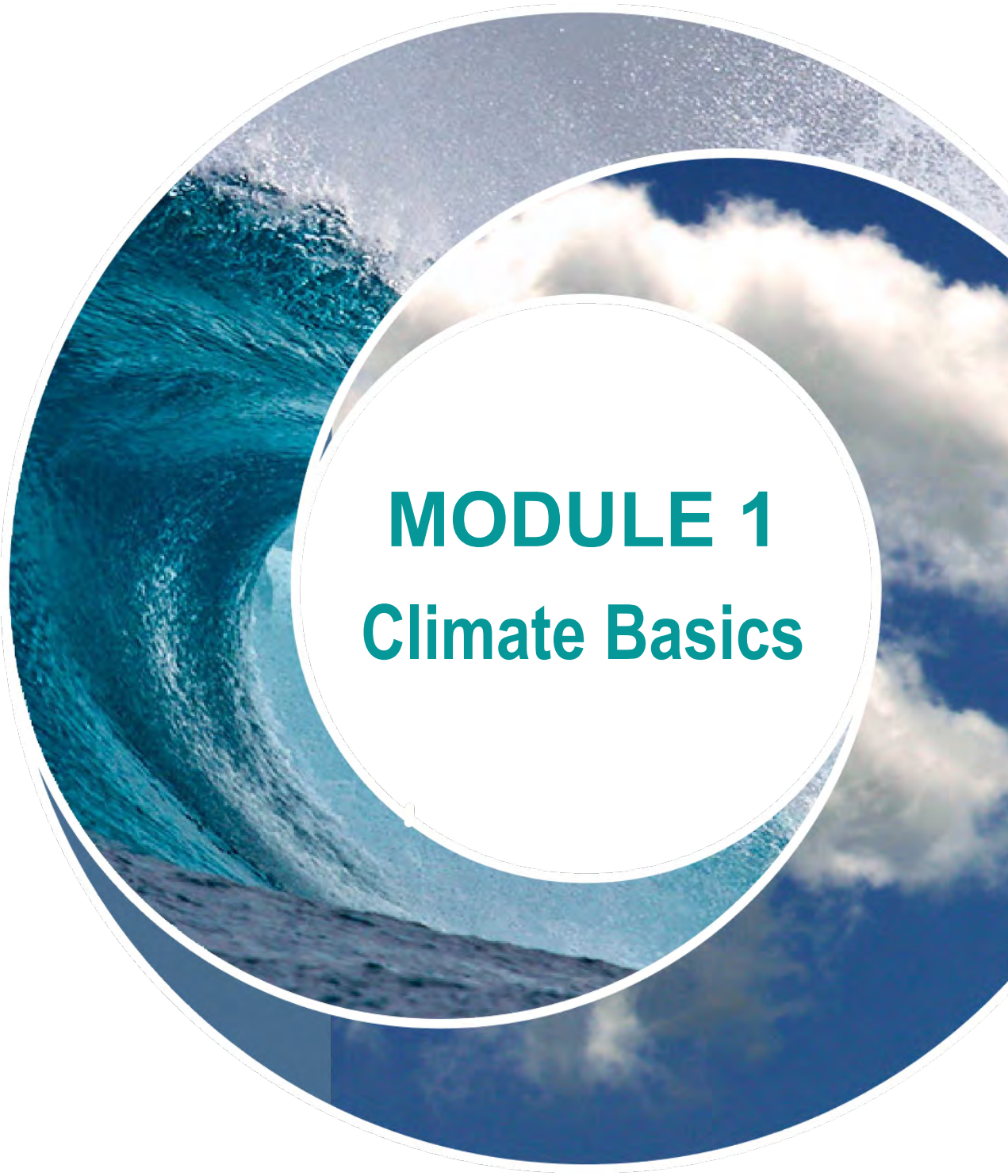
Module 1: *Climate Basics* provides foundational knowledge about climate concepts, data and common data analyses, and forecasts. A basic understanding of climate will provide necessary background and context for subsequent learning about the types and use of climate information to improve agricultural risk management. It also prepares participants to address client farmers' questions and concerns about weather and climate. The module includes probability concepts that are foundational for understanding and managing risk, and for interpreting and using climate information to support risk management.

Module 2: *Climate Information Available for Agriculture* provides an overview of relevant weather and climate information products and services that are, or will soon be, available through the Kenya Meteorological Department (KMD). It teaches participants how to navigate and use relevant historical, monitored and forecast information products available through KMD including the online Maprooms.

Module 3: *Climate-Sensitive Agricultural Decisions* strengthens participants' understanding of the interaction between climate and agricultural decision-making. It enables them to perform basic analyses of climate-sensitive production management decisions under uncertainty. A number of factors, in addition to crop and livestock productivity, influence agricultural production decisions, particularly at seasonal and longer time scales. To equip participants to provide appropriate support and guidance to their client agricultural producers, the module builds understanding of factors that lead to different management decisions by different producers and under different climate conditions.

Module 4: *Integrating Climate Services into Agricultural Extension* equips participants to bring climate services into the services that they provide their client producers. Building on learning from the other three modules, Module 4 equips them to lead producers in a participatory seasonal planning workshop, informed by historical and seasonal forecast information.

This course is designed for agricultural extension professionals who actively support crop and livestock producers with information, advice and other services. It targets extension agents working at the ward and sub-county levels within Kenya's public sector agricultural extension service, and non-government extension and advisory service professionals with a comparable background. Course activities require working knowledge of web browsers, Microsoft Word, Excel and PowerPoint.



MODULE 1

Climate Basics

MODULE 1 | CLIMATE BASICS

Module 1: Climate Basics provides a foundation of knowledge about climate concepts, processes, data, forecasts, and probability. A basic understanding of climate will provide necessary background and context for subsequent learning about the use of climate information to improve agricultural risk management. It also prepares participants to address client farmers' questions and concerns about climate. The module includes probability concepts that are foundational for understanding and managing risk, and for interpreting and using climate information to support risk management.

By the end of this module, you will be able to:

- Understand the concepts of weather, climate and climate change.
- Characterize the climate of the country.
- Understand climate data, climate information and their limitations.
- Apply statistical concepts in climate.
- Interpret seasonal climate forecasts.

Session 1.1. Basic Climate Concepts

This session defines key terms that are essential for any discussion of climate. It introduces the main parameters that define weather and climate.

By the end of this session, you will be able to:

- Identify whether the problem at stake or information provided relates to weather, climate variability or climate change.

Time scales

In Climate Science, it is customary to distinguish between three concepts: weather, climate and climate change. *Weather* is the state of the atmosphere at a given time and place with regard to important atmospheric variables including temperature, precipitation, humidity, air pressure, wind, cloudiness and sunshine. The term “*weather*”:

- is generally restricted to conditions over short periods of time (two weeks or less);
- includes whatever is happening outdoors at a given place and time;
- can change a lot within a very short time;
- is what we learn about on TV/Radio and other news daily.

Climate is the statistics of weather at any place over some specific period of time. The term “*climate*”:

- includes mean and variability of relevant quantities of certain variables (e.g., temperature, precipitation, wind) over a period of time, (i.e., months and years, not days or weeks);
- includes the cycle of seasons (e.g., dry vs. rainy seasons);
- includes the characterization of extreme weather events (floods, cyclones);
- informs on the typical conditions in a specified location and time of year;
- is often reflected in the vegetation or agricultural/other economic activities.

A reference period, or climatology, is often used to denote a fixed period over which the statistical summaries of the weather, such as those mentioned above, are calculated. The WMO recommends a 30-year period for climatologies, known as “*climatological normals*,” and these are updated every 10 years.

Climate Variability is defined as differences from the average state of the climate, or climatology, across temporal and spatial scales. According to the WMO, climate variability refers to “deviations of climate over a given period of time (e.g., a month, season, year, or even decade) when compared to long-term statistics for the same calendar period. Climate variability is measured by these deviations, which are usually referred to as *anomalies*.”

Climate Change refers to changes in the characteristics of climate over long periods of time. It is important that these changes occur not only in the mean conditions but also in the variability. More information about climate change will be provided farther in this session.

Dimensions of climate

Climate and its characteristics vary from one location to another as well as from one period to another. It is customary to conceptualize climate as having spatial and temporal dimensions and present climate characteristics in both dimensions. Figure 1.1-1 shows different representations of climate in its spatial and temporal dimensions: Figure 1.1-1a shows a map - spatial dimension - of rainfall amounts received on average in one year in different locations; Figure 1.1-1b shows the amount of rainfall that fell each month in Taita between January 1981 and December 2021, thus the temporal dimension of climate; Figure 1.1-1c shows the rainfall that falls on average in Taita in each month of the year – another representation of temporal dimension of climate; Figure 1.1-1d shows how many times the annual rainfall recorded in Taita between 1991 and 2021 fell in each category of less than 500mm/year, between 500 and 600mm/year, 600-700mm/year etc. This is yet another way to represent the temporal dimension of climate.

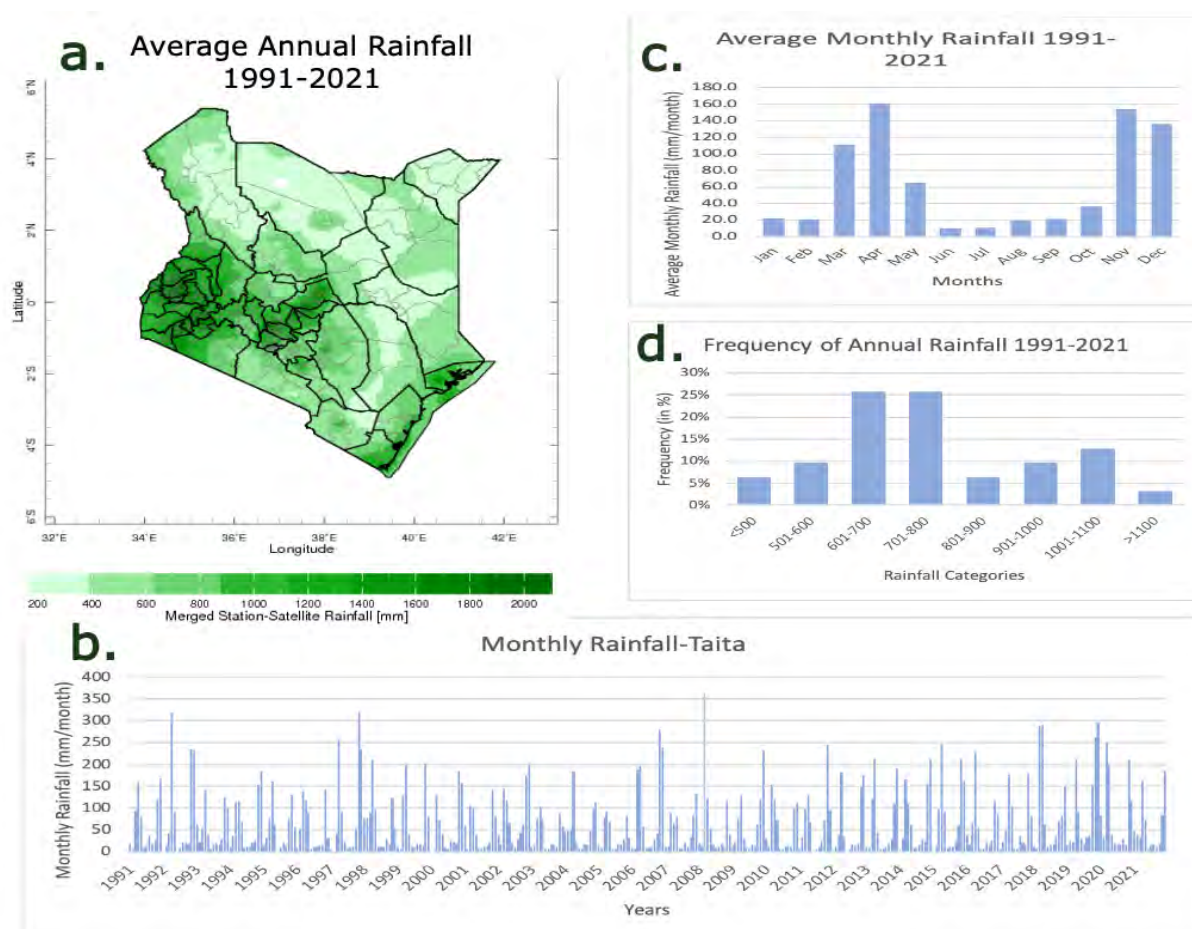


Figure 1.1-1. Spatial and temporal distribution of climate characteristics. a) map of annual rainfall, expressed in mm/month; b) time series of monthly rainfall over Taita, January 1981- December 2021 (in mm/month); c) average seasonal cycle of rainfall over Taita (in mm/month); d) number of years annual rainfall was in a given range (in mm/year).



Exercise

- Working individually or in small groups answer the following questions:
- Identify the areas of highest and lowest rainfall on the map (Figure 1.1-1 a). What type of vegetation or crop do you think grows in these areas?
- Can you identify a systematic pattern in the time series of monthly rainfall (Figure 1.1-1 b)? What changes the most from one year to another?
- In the seasonal cycle of rainfall (Figure 1.1-1 c), identify the month of highest rainfall. Identify the months with no rainfall. What are the months of the rainy season? What are the months of the dry season?
- Based on Figure 1.1-1 b and c, do you expect the rainfall in the wettest month to always be 250 mm?
- Figure 1.1-1 d shows the distribution of the total amounts of rainfall that fell in different years of the period 1981-2021.
 - ♦ Identify the amount that fell most frequently; in how many years was such amount recorded?
 - ♦ What was the smallest range recorded? In how many years?
 - ♦ What was the highest range? In how many years?

Main components of weather and climate

The components of climate are the weather variables which make up a climate over a period of time. The components which make up the climate for a given location include:

- temperature;
- precipitation;
- humidity;
- atmospheric pressure;
- wind;
- sunshine / cloudiness; and
- air quality.

Some of the main variables are described in the remainder of this session, along with the typical units and methods of measurement.

Temperature

Temperature measures how hot or cold a substance is, which is an indication of the internal energy of the substance. Routine measurements for weather and climate focus on air temperature, although water temperature, especially that of ocean, lakes and small water

bodies, can also be of interest. For agronomic applications, soil temperature is sometimes needed. Temperature captures how much energy the surface of the Earth receives and is an important limiting factor for plants and fish growth.



Exercise

- *Working individually or in small groups answer the following questions:*
- *Based on your experience, when is the hottest temperature of the day, when is the coolest?*
- *In which months do you experience the hottest temperatures, in which months the coolest? Which of the seasons is hotter: rainy season or dry season? Why?*
- *Where are the coolest places in Kenya? Why? Do you know where the hottest place is?*

Temperature is measured using a *thermometer*, in most of the countries using the Celsius scale ($^{\circ}\text{C}$) where 0°C and 100°C correspond to the freezing and boiling of water respectively¹. For the purposes of weather and climate, temperature frequently refers to air temperature or sea-surface temperature (SST). Meteorological Services record the hottest and the coolest temperature of the day – T_{max} and T_{min} respectively. Average temperature of that day (T_{mean}) is the average of these two numbers.

Precipitation

Precipitation is the water that falls to the ground as rain, snow or hail. Water is critical for many economic activities, from domestic use to hydropower generation; a critical limiting factor for plants growth in the tropics; and is closely monitored by meteorological and hydrological services.

Rainfall is measured using a *rain gauge* which is typically a plastic or metal receptacle with graduated markings denoting the depth of accumulated precipitation while the amount of water contained in snow will be estimated from the depth of the snow layer. The units used most often are millimetres (mm). Unlike temperature, water can accumulate in the soil or lake thus rainfall can be measured as cumulative amount over different lengths of time such as

¹ Occasionally, the Fahrenheit scale is used, mostly in the USA and associated territories. In that scale water freezes at 32°F and boils at 212°F . To convert to degrees Celsius $T_{\text{C}} = 5/9(T_{\text{F}} - 32)$. In some scientific applications degree Kelvin may be used. Water freezes at 273.15K and boils at 373.13K . $T_{\text{C}} = T_{\text{K}} - 273.15$. A simple rule of thumb to recognize that non-Celsius scale is used: if air temperature values are systematically somewhere between 20 and 90 degrees, Fahrenheit degrees are being used. If they are above 200 degrees, Kelvin is used.

daily, weekly, dekadly (10-day), monthly or annually. In Kenya, rainfall cumulated over past 24 hours is recorded at 08:00 AM daily.

On the weather scales, precipitation strongly varies in time and space. It can start and stop raining within minutes, and it can also rain on one side of a town or valley, and not on the other. Temperature, on the other hand, tends to vary less on those scales. Unless there is a change in elevation (e.g., from the bottom of the valley to the top of the mountain), in vegetation (e.g., from prairie to forest) or in proximity to a water body, temperature is unlikely to change within a kilometre or so (spatial dimension) or within minutes (temporal dimension).

On climate scales, seasonal cycles or year-to-year differences (temporal dimensions) for variables such as temperature and rainfall behave very differently between tropical and temperate regions (spatial dimensions), as Figure 1.1-2 illustrates.

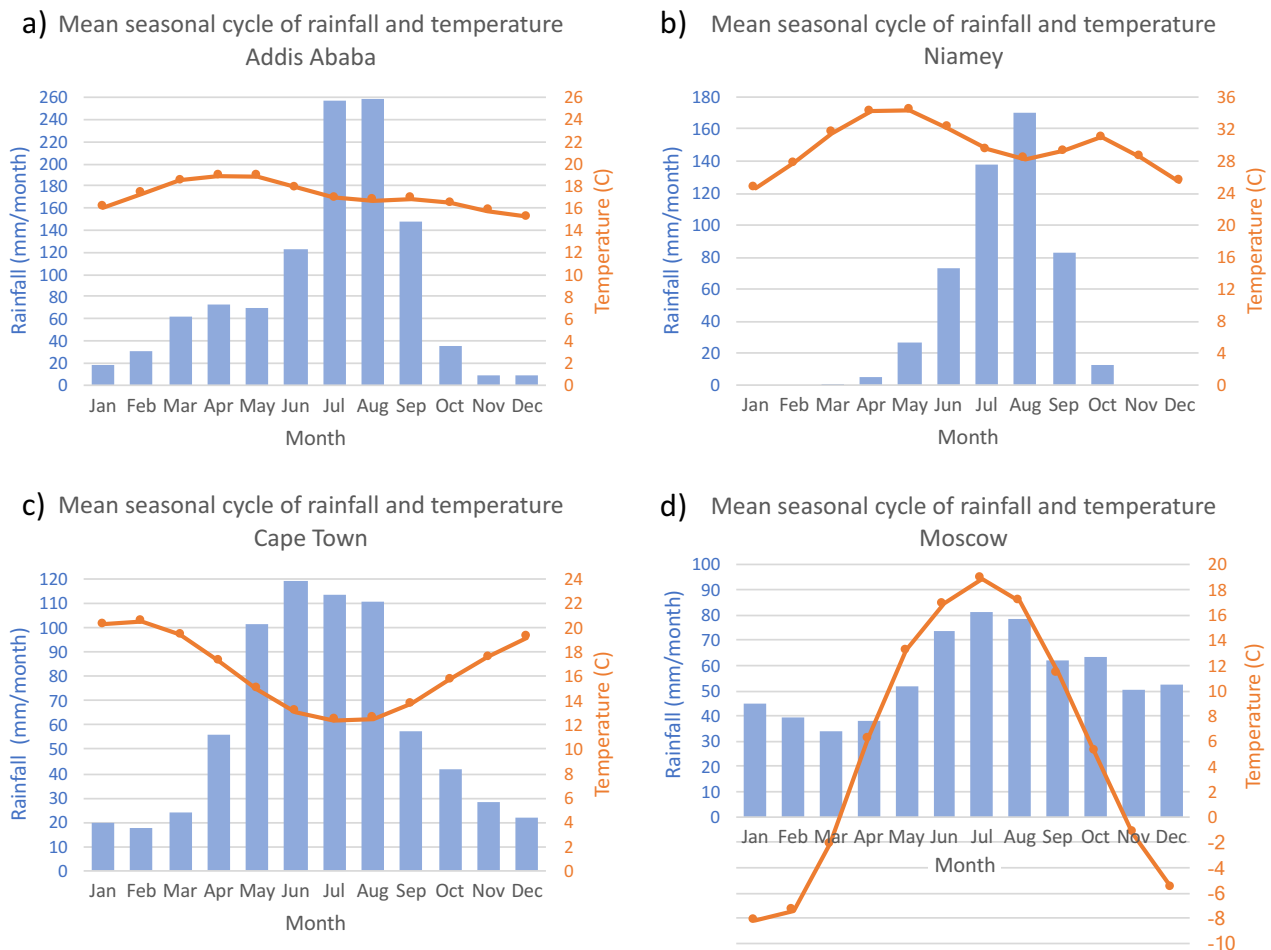


Figure 1.1-2. Mean seasonal cycle of precipitation (blue) and temperature (orange) in four locations, a) Addis Ababa [8.98° N, 38.76° E], b) Niamey [13.51° N, 2.12° E], c) Cape Town [33.92° S, 18.42° E] and d) Moscow [55.75° N, 37.62° E].

Tropical climates, with the exception of equatorial regions, often show large contrasts in precipitation during the year with temperature showing relatively small variations. Tropical climates are characterized by monthly average temperatures of 18°C, or higher, year-round,

with little variations between months. Conversely, with the exception of equatorial regions, precipitations can show large contrasts between the dry and the rainy seasons.



Exercise

- *Working individually or in small groups, answer the following questions based on Figure 1.1-2:*
- *What is the maximum average monthly precipitation in Addis, in which month does it occur? What is the minimum average monthly precipitation in Addis? In which month? What is the annual amplitude (the difference between the maximum and minimum, the seasonal contrast) of the average monthly precipitation in Addis?*
- *What is the maximum average monthly temperature in Addis, in which month does it occur? What is the minimum average monthly temperature in Addis? In which month? What is the annual amplitude of the average monthly temperature in Addis?*
- *Locate all the four cities on a map of the world.*
- *What are the value and the month of maximum average monthly precipitation in each city? What are the value and the month of the minimum monthly precipitation? What is the annual amplitude of rainfall? Which city receives the most rainfall in one month? Which city has the longest dry season? Which city has the shortest or none?*
- *What are the value and the month of maximum and minimum average monthly temperature in each city? What is the amplitude of the seasonal cycle of temperature? Which city has the coldest months? Which city is the warmest year-round?*
- *How do maxima and minima in precipitation and temperature relate to each other in a given city?*
- *When do you think is the main crop growing season in each of the locations? Why?*

In mid-latitudes, precipitations vary relatively little, while temperature shows large contrasts. A class of mid-latitude climates called 'temperate' or 'oceanic' encompasses areas where the monthly average temperatures is above 0°C but below 18°C. In 'continental' mid-latitude climates temperature in cooler months can drop below 0°C. Thus, in the tropics availability of water is the main limiting factor for agricultural activities while in mid-latitudes low temperatures are the main barrier to crops. Perennial vegetation in mid-latitudes goes dormant during the cold season.



Exercise

Total annual precipitation in Niamey is around 500mm/year while in Moscow it is around 600mm/year. The difference is in the order of 20%. Figure 1.1-3 shows natural vegetation around Niamey and Moscow in early summer.

- Working individually or in small groups answer the following questions:
- Would you expect these differences?
- How can climatic and other factors explain such differences?

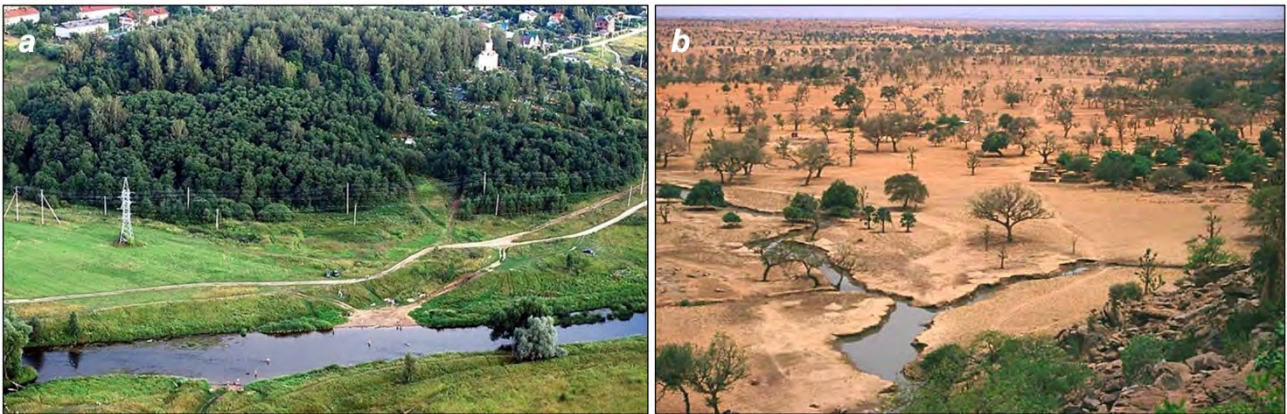


Figure 1.1-3. Natural vegetation around (a) Moscow and (b) Niamey in early summer.

Humidity

Humidity measures how much water vapor is in the air at a given time. There are two standard measurements of humidity:

1. *Absolute humidity*, a measure of the amount of water vapor in a given parcel of air and is typically measured in mass/volume or volume/volume units.
2. *Relative humidity*, a measure of the amount of water vapor in the air at a given time relative to the maximum amount of water vapor a parcel of air can retain called *saturation level*. It is typically expressed in percentages (of saturation).

Saturation level strongly depends on temperature – the warmer the air, the more water vapor it can contain. If saturated air cools (e.g., at night), water will condensate and create fog or precipitation. Note that the same level of absolute humidity in two locations in Kenya may produce very different results. In the hot lowlands, the amount of water contained as vapor may not be enough to produce a high relative humidity and precipitation. However, in the cool highlands, that same level of absolute humidity may be close to or over the saturation point and may be accompanied by fog or rain. Both absolute and relative humidity tend to be

correlated with precipitation with drier regions and seasons experiencing lower humidity than wetter regions and seasons.

Solar radiation and cloud cover

The existence of nearly all life on Earth is fuelled 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/m^2 , 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.

Wind

Winds are an important component of the climate system as they move around air masses with different properties (temperature, humidity). They can bring moist or dry air to an area or, conversely, blow away humid air generated locally through evaporation and evapotranspiration. It is not uncommon that the arrival of the rainy season is preceded by a change in prevailing winds and the new winds bring moisture that fuels rainfall from nearby oceanic or rainforest areas. The rainy season often ends with a change of wind direction that ceases to supply moisture to the area and also influences evaporation.

Atmospheric pressure

Atmospheric pressure is a measure of the force or weight of the overlying air per unit area on the surface. Winds can be driven by differences in atmospheric pressure, usually blowing, in the tropics, from areas with higher pressure towards areas with lower pressure. Lower atmospheric pressure tends to occur, with a few exceptions, over areas experiencing warmer temperatures than their surroundings and high pressure is often located over cooler areas. Warmer air in low pressure areas will rise and, if it contains enough humidity, the rising motion may lead to rainfall as the humid air cools at higher altitude and cannot hold the same amount of water vapor. In high pressure areas, air often descends and will be relatively dry, as it comes from upper, cooler atmospheric layers, containing less moisture. Deserts, however, are an exception to this rule as, usually, higher pressures overlay hot surfaces. This is related to moist processes in the air as well as general circulation patterns and diurnal cycle of temperature.



Self-Check

1. Recall the differences between weather, climate and climate change.
2. What are the two dimensions of climate. How do weather and climate differ in those two dimensions?
3. Recall three main variables used to describe climate in a given location.



Exercise

The elements above are the most important variables, necessary to describe current atmospheric conditions as well as predict their evolution in the near future, from 24 hours to a few weeks. They impact plants and crops in different ways.

- *Working individually or in small groups answer the following questions:*
- *What was the last or the most impactful weather or climate event that you remember having and adverse effect on crops?*
- *Was it weather- or climate-related?*

Session 1.2. The Climate of Kenya

In this session, students will use the basic concepts acquired in the previous session to describe different types of climates experienced in Kenya, based on rainfall and temperature.

At the end of this session, you will be able to:

- Describe different climates of the country and related limitations on agricultural activities.
- Interpret climate variability in Kenya.
- Explain the impact of El Niño/La Niña on seasonal climate.

Main features of Kenya climate

Spatial distribution of climates

Kenya has a complex mosaic of natural vegetation closely following the distribution of climates (Figure 1.2-1). Global climate classification such as the one shown in Figure 1.2-1 are based on annual total rainfall and temperature since they capture the most important parameters for plants. Cooler temperate climates are mostly found in extratropical regions of Europe, Asia and the Americas. Their presence in Kenya is linked with cooler temperatures in the highlands.

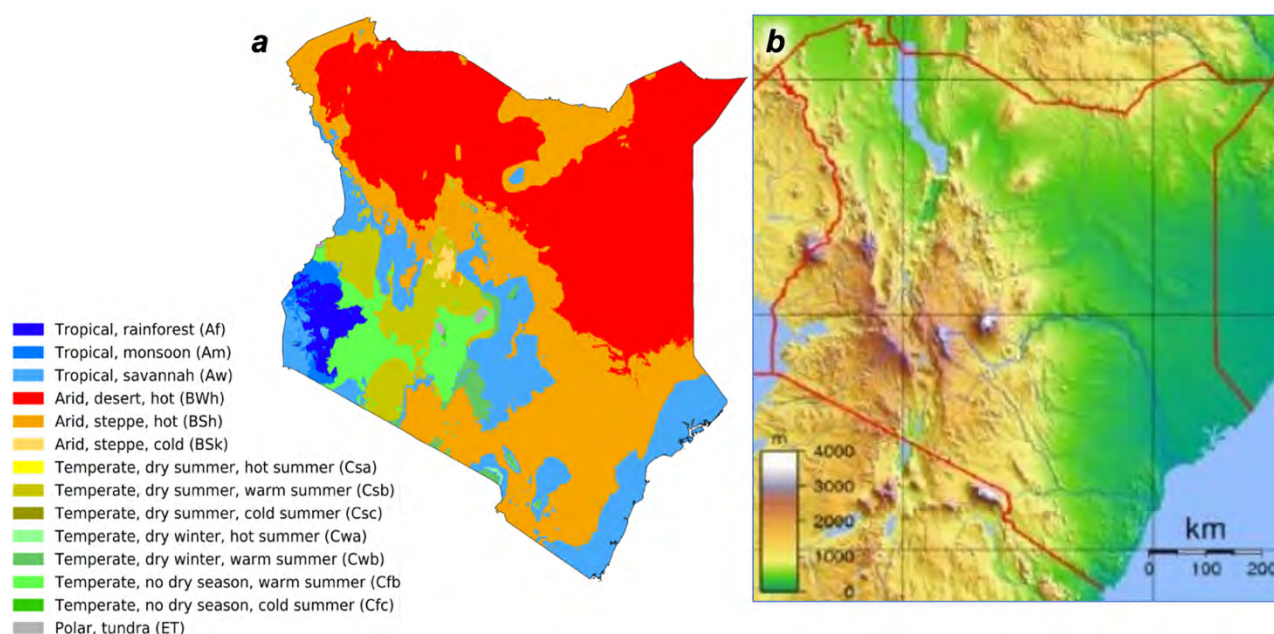


Figure 1.2-1. Spatial distribution of (a) climates and (b) topography. Source: topography: <https://www.mapsland.com/africa/kenya/detailed-topographical-map-of-kenya>; Köppen-Geiger climate classification map: https://commons.wikimedia.org/wiki/File:Koppen-Geiger_Map_KEN_present.svg, accessed 20 Oct 2025.



Exercise

- Working individually or in small groups answer the following questions:
- What are the main types of climates in Kenya? describe their approximate location.
- Climates in several areas are classified as 'temperate'. Did you expect temperate climates in Kenya? Why are there temperate climates in Kenya?
- There are variants of the temperate climates in Kenya, what are the differences?

Figure 1.2-2 allows to explain some of the features of the climate mosaic in Kenya. It is easy to see how temperature follows the topography (Figure 1.2-2a and b) and defines temperate climates. However, not all the areas experiencing high maximum temperatures (above 30°C) are arid or semi-arid. Rainfall also plays an important role in defining different types of tropical climates. In Kenya, rainfall distribution is also closely related to the topography, and the highest amounts of annual rainfall are observed over the western highlands. Higher rainfall values can also be observed over the coastal areas.

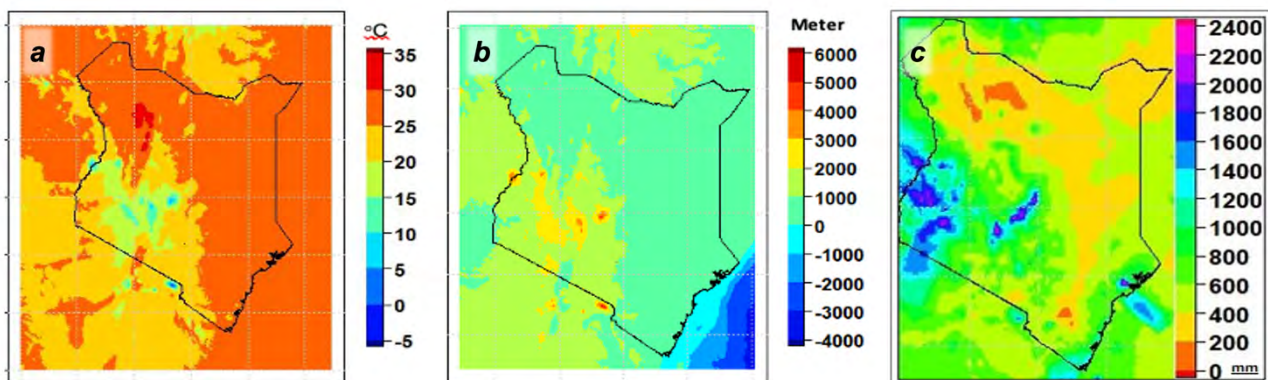


Figure 1.2-2. Spatial distribution of (a) annual average maximum temperature, (b) topography, and (c) average annual rainfall in Kenya.

Temporal characteristics of climates in Kenya

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 1.2-3 shows regions in Kenya experiencing different seasonal cycles of rainfall.



Figure 1.2-3. Different types of seasonal cycles of rainfall and temperature across Kenya.

The northern and eastern parts of Kenya are characterized by two distinct seasons (March to May, and October to December). The northern parts receive higher rainfall amounts during the March to May season, while rainfall amounts for eastern region of Kenya are very similar for the two seasons. The two seasons are not very distinctive for western and southern areas. The western parts of Kenya receive rainfall throughout the year. The southern parts also receive rainfall during the most part of the year.

Main factors determining climate of Kenya

The climate of Kenya is influenced by a complex interplay of local and global factors, resulting in the observed weather patterns across the country. Understanding these key factors is essential for grasping the characteristics of Kenya's climate.

Global factors

Energy balance refers to the equilibrium between incoming solar radiation absorbed by the Earth and outgoing thermal radiation emitted back into space. This balance regulates the planet's temperature and drives atmospheric and oceanic circulation, shaping global climate patterns. Global energy balance factors influencing local climate include solar radiation, which affects temperature and weather patterns, and the distribution of heat via atmospheric and oceanic circulation. These factors determine the overall climate dynamics, including temperature and precipitation patterns. Latitude defines how much solar energy per m² a given location receives and this amount decreases from the equator to the poles. These differences fuel the ocean and atmospheric circulations in the climate system.

The revolution of the Earth around the sun. Because Earth's axis is tilted, polar regions receive very different amounts of energy, depending on the season. During the winter of the northern hemisphere, northern polar regions don't receive any sunlight and mid-latitudes receive less solar radiation within shorter days than their southern counterparts. During the southern winter, the North Pole and northern mid-latitudes receive more solar radiation than their

southern counterparts. The variation in the energy received in the tropics due to seasonal cycle is much smaller.

Seasonality refers to the variations in climate and weather patterns that occur regularly over the course of a year, driven by the Earth's tilt and orbit around the Sun. It influences temperature, precipitation, and daylight hours, resulting in distinct seasons such as dry and wet seasons.

The distribution of ocean- and land-masses. Water, land surface and atmosphere have different capacities to store and distribute energy. Those differences define atmospheric circulations between land masses and oceans.

Figure 1.2-4 schematically presents those global factors and the resulting circulations, in the absence of local factors.

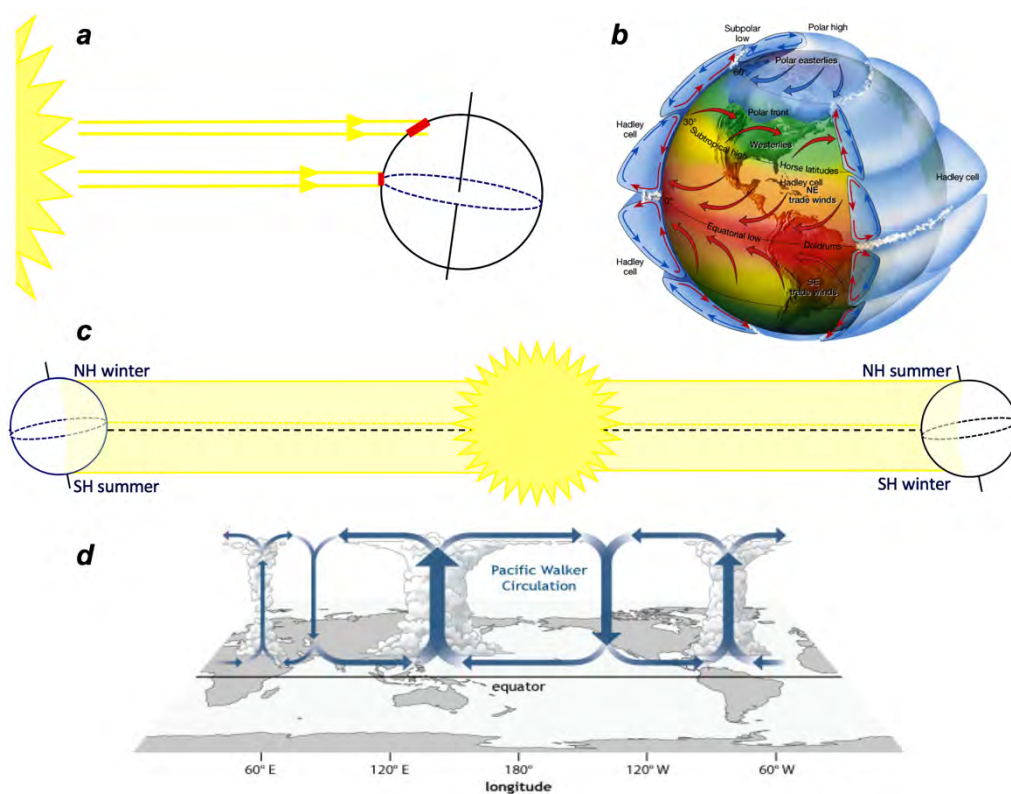


Figure 1.2-4. Schematic representation of the main global factors influencing local climate: differences in energy received by latitude (a); resulting atmospheric circulations, in the absence of land-masses (b); the seasonal cycle (c); and the distribution of land-masses and oceans (d). Sources: <http://www.ux1.eiu.edu/~cfjps/1400/circulation.html>, <https://www.climate.gov/news-features/blogs/enso/walker-circulation-ensos-atmospheric-buddy>



Exercise

- Working individually or in small groups answer the following questions:
- Note the circulations in the vertical dimension on Figure 1.2-4b. Where is the air rising, where is it sinking? Note the complex circulation pattern in the vertical dimension. Identify the equator. The cells immediately north and south of the equator are called Hadley Cells and define the extent of the tropics. Note the winds on the surface of the Earth in the tropics. In which direction are they blowing? They are called Trade Winds.
- Under the effect of the seasonal cycle depicted in Figure 1.2-4c, the system from Figure 1.2-4b is not symmetrical and shift towards the south and towards the north respectively. So does the zone of rising air near the equator. Do you expect the zone of rising air to be north of the equator or south of the equator during June-September i.e., during the Northern Hemisphere summer?
- Which of the global factors above can best explain the differences in the seasonal cycle of temperature noted in Figure 1.1-2?
- In Figure 1.2-4d identify the land-masses and oceans. Name the main continents. In this Figure, vertical arrows represent rising and sinking motions. Rising moist air is likely to generate rainfall. Where is the region of strongest rising motion (called 'convection')? Is the air rising or sinking over Southern Africa? Which way blow the winds over South Africa?

Local factors

While global factors play a significant role in shaping Kenya's climate, local factors are equally important in determining the specific climatic conditions experienced across the country. The theoretical circulations linked with global factors interact with local factors such as mountain ranges, inland water bodies, types of vegetation, and soil. These local elements modify temperature, precipitation patterns, and wind flows, creating microclimates and unique weather phenomena. The effects of local factors are schematically represented on Figure 1.2-5

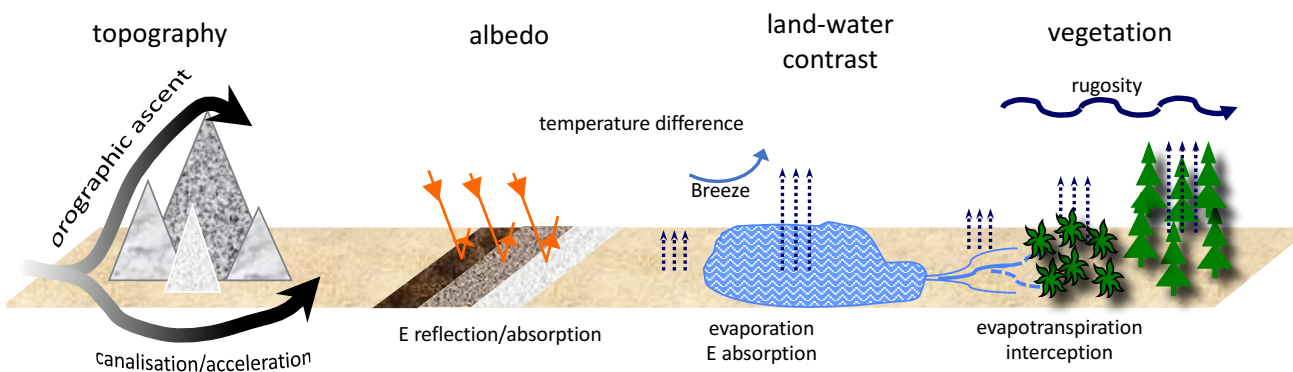


Figure 1.2-5. Schematic representation of local factors influencing local climate.

Topography. The effects of topography on the climate of any given region could be very significant. Mountain ranges create barriers that alter wind and precipitation patterns,

Topographical features such as narrow valley channel and amplify winds. The orientation of mountains to the sun may create distinct microclimates in some areas. Mountains play an important role in precipitation and temperature patterns in Kenya, which evident from Figure 1.2-2.

Land breeze prevails during night. The land surface cools to lower temperatures than the temperatures over adjacent water surface. A low pressure is developed over water surface and high pressure is developed over land surface. Due to this pressure gradient between land and sea, air moves from land to sea. Land breeze is developed along the sea coast.

Sea breeze prevails during day time. During day time land surface warms to temperatures higher than nearby water surface temperatures. Therefore, a low-pressure area is developed over the land surface and high pressure is developed over water surface. Air moves horizontally from sea (water surface) to land along the pressure gradient between sea and land. This movement of air from sea to land is called as sea breeze.

Vegetation is an indicator of the climate of an area. Because of this, climate zones are defined by distribution of vegetation types: hot desert flora, tropical rain forest, boreal forest, temperate deciduous forest and tundra. Vast forest canopies and grassland have a cooling effect on the environment. Forest soils also absorb large amounts of energy, which affects the weather and climate. Vegetation affects climate because it influences the reflection of solar energy from the Earth's surface and the amount of water vapor in the atmosphere.

Exercise



- *Working individually or in small groups answer the following question:*
- *Which local factors do you think are the most important in defining the climates in Kenya?*

Climate Variability in Kenya

Climate variability is defined as differences from the average state of the climate, or climatology, across temporal and spatial scales. According to the WMO, climate variability refers to “deviations of climate over a given period of time (e.g., a month, season, year, or even decade) when compared to long-term statistics for the same calendar period. The succession of the seasons occurs on a regular basis but with small deviations from one year to other: the rainy season can be more or less rainy, more or less long, the temperature can be a little warmer or cooler than the year before etc. Those variations are usually small and for the most part socio-economic systems are well adapted to withstand them, within a certain range. They aren't however without consequences on crop productivity and animal and human wellbeing. Part of

climate science focuses on understanding and predicting those variations that occur from one to another.

Based on the elements seen so far it is easy to understand that a small change in the seasonal wind pattern, such as stronger winds from the Kalahari or the change in the timing of direction switch in the winds from the Atlantic Ocean can delay the rainy season and make it shorter. Similarly, less humidity brought by the winds can make the season less rainy. It is easy to imagine numerous combinations of those variations. In addition to those factors in the direct vicinity of Kenya, variations in places as remote as the tropical Pacific Ocean can also affect climate in Kenya, by disrupting the cells established between the land- masses and the oceans and depicted in the Figure 1.2-4d. Two main remote phenomena have profound impact on the interannual variability of climate in Kenya: El Niño-Southern Oscillation and Indian Ocean Dipole

El Niño-Southern Oscillation

El Niño-Southern Oscillation (ENSO) is an interaction between the ocean and the atmosphere in the equatorial Pacific region. In neutral conditions, trade winds push warm waters into the western equatorial Pacific, resulting in a lot of evaporation and rainy condition in southeastern Asia. In the western equatorial Pacific, surface waters are cooler and the atmosphere is drier, leading to dry conditions on the west coast of tropical South America (Figure 1.2-6a). Periodically, these conditions are relaxed, and warmer waters and rain-producing systems spread eastward and can cause torrential rains on the coast of South America (Figure 1.2-6b). This is an El Niño episode. During the opposite episode, La Niña, the atmospheric circulations and contrast in oceanic temperatures strengthen (Figure 1.2-6c). El Niño/La Niña mostly occur around December-January and draw their name from their co-occurrence with Christmas (El Niño, Spanish for the baby boy, referring to baby Jesus).

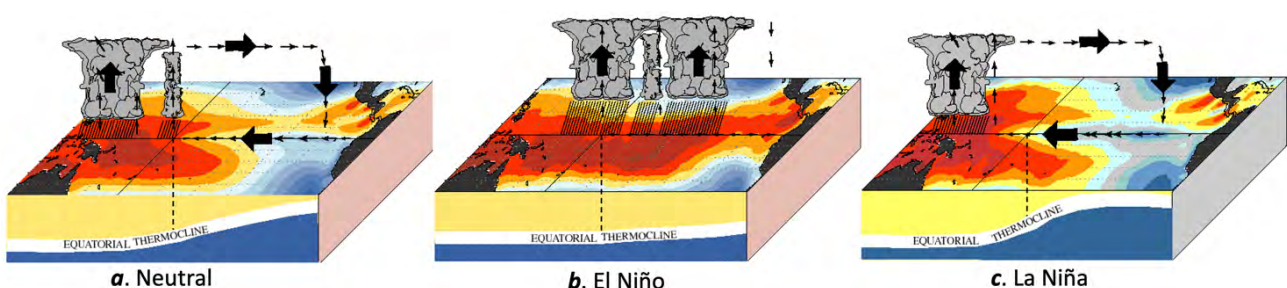


Figure 1.2-6. Schematic representation of (a) Neutral, (b) El Niño and (c) La Niña conditions in the Equatorial Pacific.

Exercise



Working individually or in small groups answer the following question:

- *Locate the circulation in Figure 1.2-4d that is disrupted by the El Niño/La Niña phenomenon. Which other circulation it can disrupt?*

The anomalies in the atmospheric circulation and rainfall in the equatorial Pacific propagate around the world through connections in the atmosphere and atmospheric waves, and can generate climate anomalies in various regions of the globe. Figure 1.2-7 shows the main climate anomalies in El Niño and La Niña phases respectively. While these figures are global, in a nutshell, El Niño tends to maintain moist air in the southern parts of East Africa, thus enhance rains in the Kenya, particularly during the October-to-December season. La Niña tends to have opposite effects with drier season, particularly during March-to-May season. Figure 1.2-8 shows the time evolution of sea surface temperature anomalies in the equatorial Pacific associated with El Niño/La Niña events.

You can see more precisely the impacts of ENSO on climate of Kenya in the dedicated maproom in the Climate Analysis section of the maprooms, described in module 2. KMD's Maproom can be used to assess the probability of seasonal rainfall being normal, or dryer/wetter than normal during different ENSO phases: El Niño, La Niña, and neutral. By analysing historical data, this maproom can show how ENSO variations affect rainfall distribution (e.g., Figure 2.2-7). Understanding these probabilistic patterns could be helpful for mitigating the adverse effects of climate variability and enhancing the region's preparedness for extreme events.

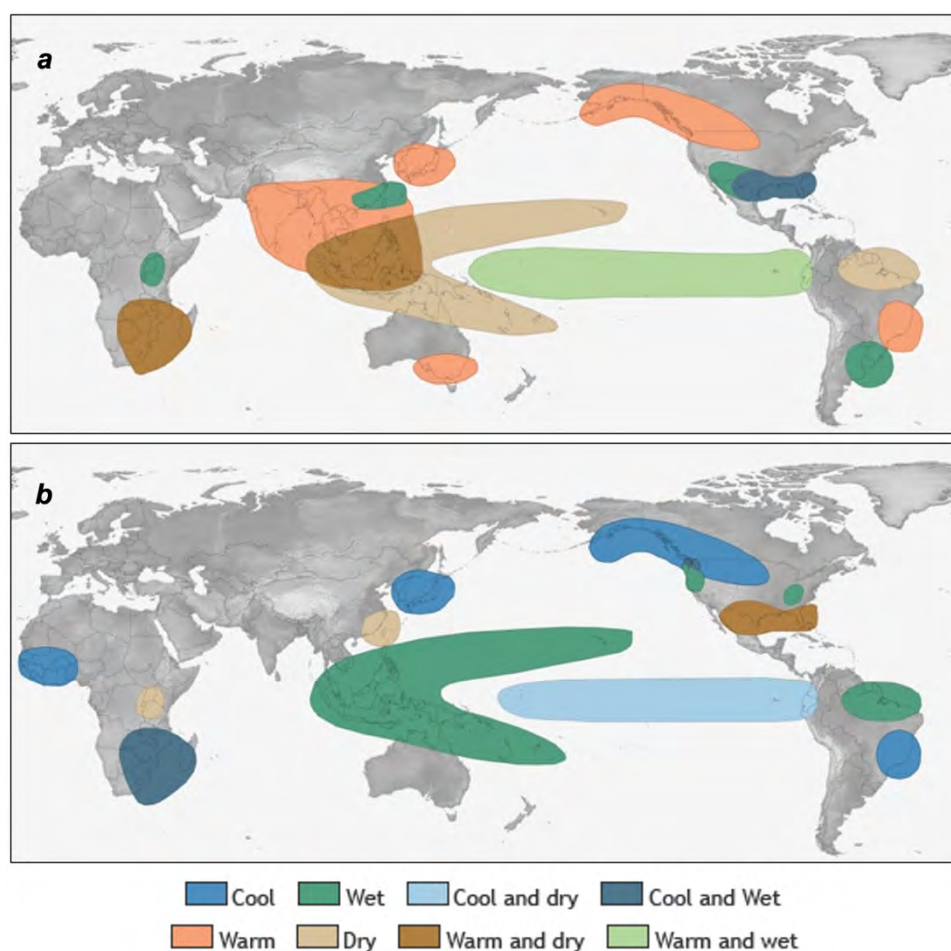


Figure 1.2-7. Impacts of (a) El Niño and (b) La Niña on temperature and rainfall around the globe in the December-February season. Source: NOAA, <https://www.climate.gov/news-features/featured-images/global-impacts-el-niño-and-la-niña>, accessed 8 Feb 2021.

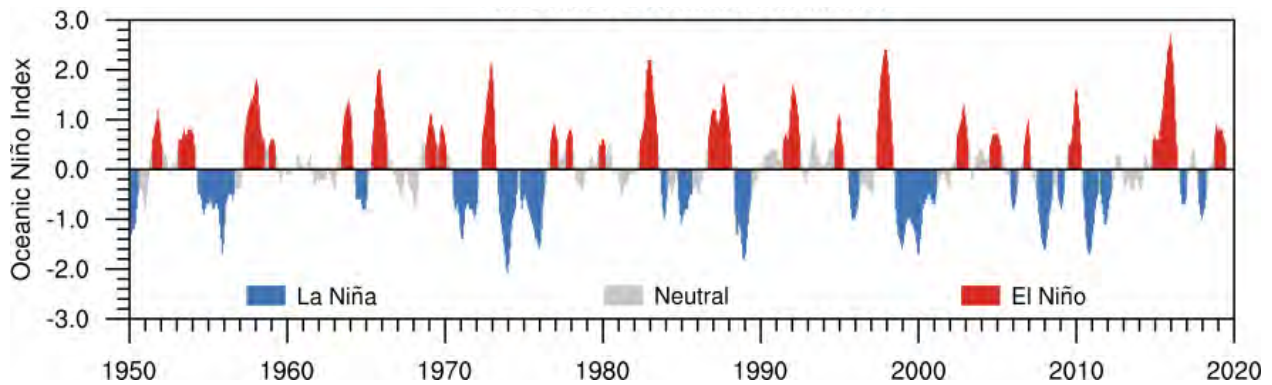


Figure 1.2-8. Time series of SST anomalies in equatorial Pacific over the period 1950-2020. Source: <https://fews.net/el-niño-and-precipitation>, accessed 8 February 2021.

Indian Ocean Dipole

Indian Ocean Dipole (IOD) is another ocean-atmosphere phenomenon that influences rainfall and temperatures in East Africa. Figure 1.2-9 displays a schematic view of the IOD and Figure 1.2-10 displays the time evolution of associated sea surface temperatures anomalies. More precise impacts of IOD on your country can be found in dedicated maprooms in the Climate Analysis section of the maprooms. Several maprooms, introduced in Module 2, provide information on how ENSO and IOD impact Kenyan climate.

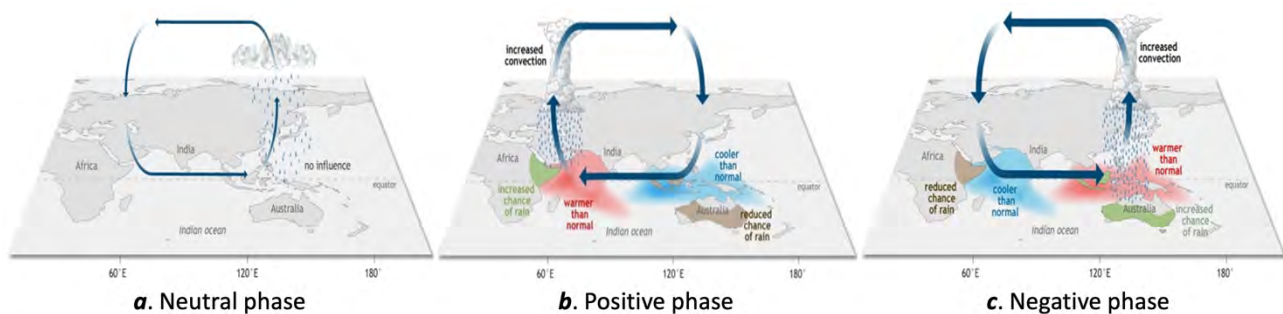


Figure 1.2-9. Indian Ocean Dipole. Neutral (a), positive (b), negative phases (c) and their impacts. Source: NOAA, <https://www.climate.gov/news-features/blogs/enso/meet-enso-s-neighbor-indian-ocean-dipole>, accessed 8 Feb 2021.

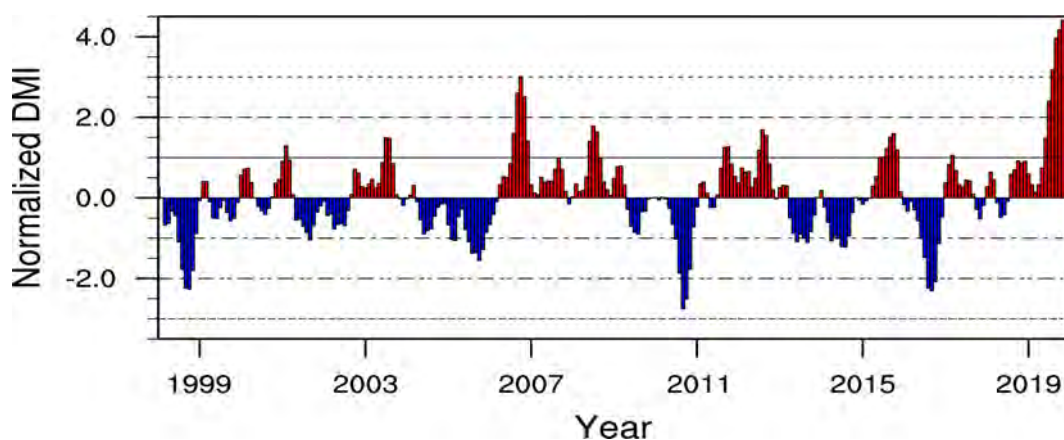


Figure 1.2-10. Yearly changes in the Dipole Mode Index (DMI) - DMI is defined as the sea surface temperature anomaly difference between tropical western Indian Ocean and the southeastern Indian Ocean. Positive DMI values (red) point to a positive IOD year, and negative values (blue) to negative IOD years. Image credit: Dr. Saji N Hameed. Source: <https://watchers.news/2019/09/17/indian-ocean-dipole-iod-2019-strongest-on-record/>, accessed 8 Feb 2021.



Self-Check

1. What are the two main classes of factors that define the characteristics of climate in Kenya? Cite three elements in each class.
2. Which local factor is the most important in Kenya. Cite two-three ways it impacts climate in Kenya.
3. What are the three main regions of Kenya with respect to the seasonal cycle of rainfall? Which class of factors is the most important for the seasonal cycle of rainfall?
4. ENSO is a phenomenon in tropical Pacific. Explain the mechanism by which it affects



Exercise

- *Work individually or in small groups. Looking at the time series of ENSO (Figure 1.2-8) and IOD (Figure 1.2-10), answer the following questions:*
- *How often do El Niño/La Niña events occur?*
- *How often do positive/negative IOD events occur?*
- *In what years did the two strongest El Niño and two strongest La Niña events occur?*
- *Do you recall their impact on crop production?*
- *For the strongest El Niño and La Niña events after 1999 what was the status of the IOD?*

Session 1.3. Climate Data and Climate Information

An important distinction needs to be made between weather and climate *data* on one hand and weather and climate *information* on the other hand. Data refer to arrays of measurements of weather and climate variables from which information that is more useful in everyday life is distilled or that are ingested in applications such as crop or hydrological models. Weather and climate information are based on various analyses of data made with specific objective in mind. Most people need weather and climate information, not data, for their every day and professional activities. However, there are different types of data and they influence the type and the quality of climate information that is possible to derive from them.

At the end of this session, you will be able to:

- Identify different types of meteorological and climate data, their strength and weaknesses.
- Identify some statistical aspects of climate.
- Describe and interpret climate information provided.
- Explain different climate dimensions and scales.
- Interpret some statistical aspects of climate in terms of their relevance to agricultural decisions.

While often used interchangeably an important distinction exists between climate data and climate information:

- *Climate data* are a collection of values/measurements of the variable of interest (temperature, air pressure, wind, humidity, cloudiness, precipitation etc.). They are an array of values and usually not very useful for non-specialists.
- *Climate information* is analysed or interpreted data for a specific objective, e.g. average over a county, frequency of rainfall above certain events, duration of the rainy season. Different types of climate information can be obtained from the same data. With different analyses. For example, the frequency of extreme rainfall and the length of the rainy season are both extracted from the same daily rainfall data. Most of the decisions in agriculture do not require data but information that has been prepared for a specific

purpose. This can only happen if a sustained dialogue is established between climate information producers and users. Finally, such extraction adds value to the initial data.

Types of Climate Data

Our understanding of weather and climate, their variability and long-term evolution under climate change relies on the analysis of data pertaining to the variables listed in Session 1.1 and collected on a routine basis by various devices and organizations, from Meteorological stations managed by the Meteorological Services, to data collected high up in the atmosphere by radars and planes or in the middle of the ocean by ships and buoys. For the past 40 years, meteorological conditions have also been observed by satellites orbiting around the earth. Figure 1.3-1 portrays various data sources contributing to our knowledge.

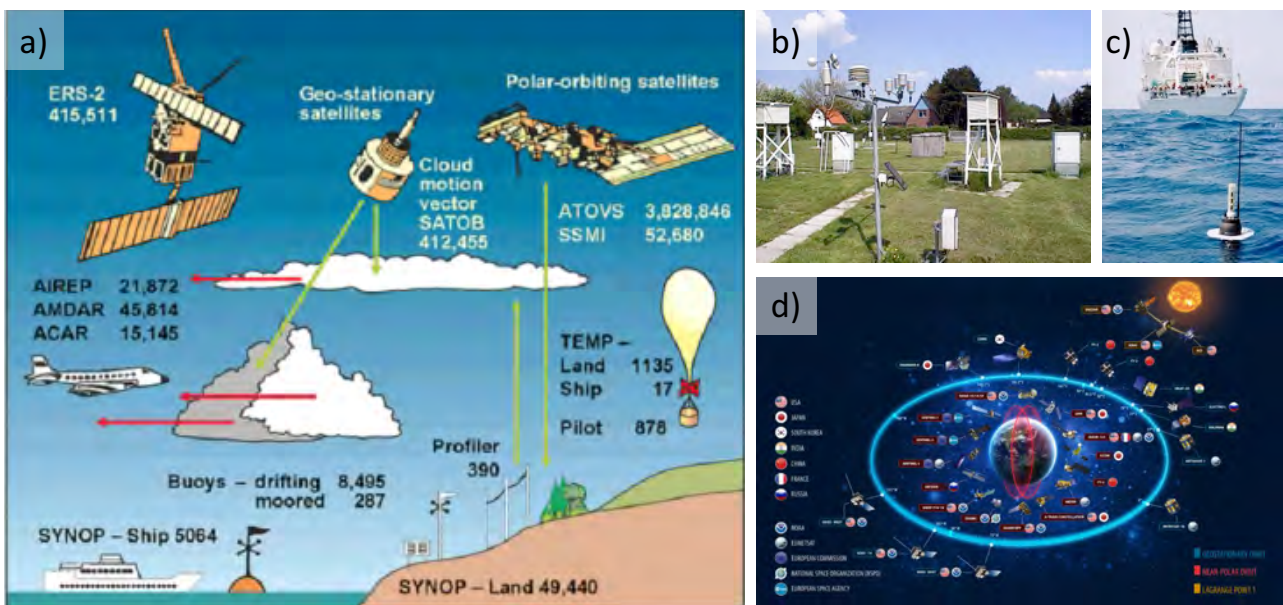


Figure 1.3-1. Illustration of various sources of weather and climate data. a) schematic representation of various devices measuring weather variables. b) a picture of typical meteorological station; c) ship and buoy – main sources of measurements over the oceans; d) the constellation of various satellites orbiting around the Earth.

Exercise



- Working individually or in small groups answer the following question:
- Take a moment to identify different ways of measuring weather and climate variables in Figure 1.3-1a. Which platforms are used to collect data at the surface of the earth, which in the atmosphere and which above earth's atmosphere?

These measurements lead to three types of data:

Station data are measurements in a given location, mostly at the surface of the Earth, although radar and stationary balloons also record information about the atmosphere above. However, there are regions of the globe with very few stations making the measurements. Figure 1.3-2 shows the distribution of meteorological stations that reported collecting data on June 1st, 1997.

Exercise



- Working individually or in small groups, analyse Figure 1.3-2:
- Identify regions with a lot of stations and those with few stations.
- What do think are the reasons for having fewer stations?
- What consequences it can have on the quality of weather and climate information in the areas with few stations?

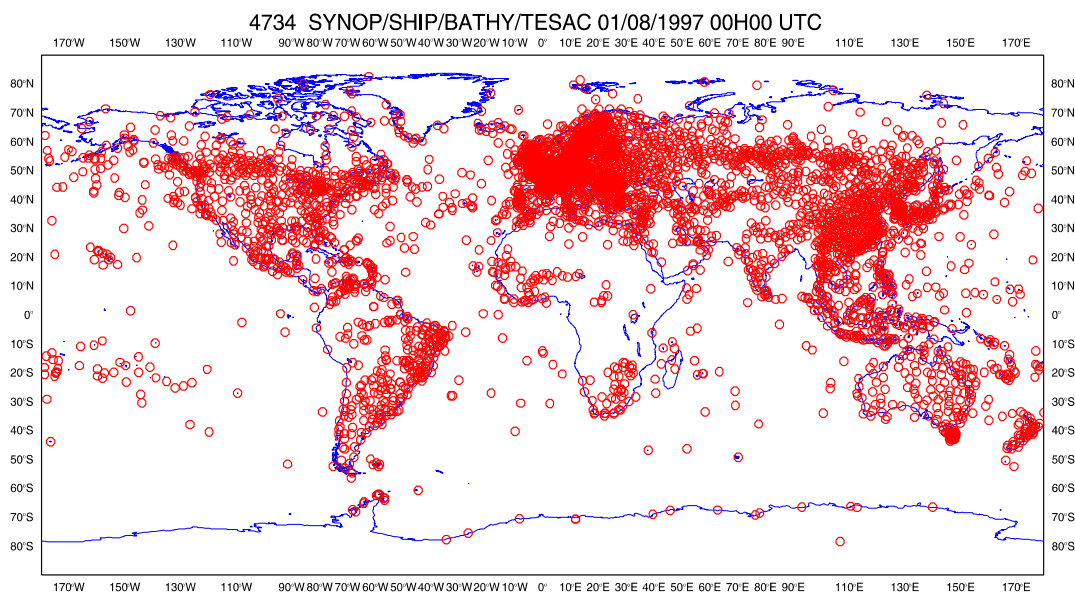


Figure 1.3-2. Location of the meteorological stations that reported collecting data on 1 June 1997. Each red circle represents one station.

Gridded station data are station data that have been interpolated, or mathematically filled in, to create a continuous dataset with values on a uniform grid across a region, instead of only at exact locations where observations were taken. Interpolation partitions Earth's surface in small squares and attributes a value of a weather/climate variable to each square. In this way Earth's surface is evenly covered with values, even in places where there is no observation. The way in which the values in places without observations are derived depends on the dataset and its specifics and ranges from a simple mean of closest observed values to more complex methods that include, for example, the elevation. The advantage of such datasets is that there are no

areas without values which helps with a lot of analyses. Most of such datasets are also global. However, there are limitations on how well data in places with no observations represent the reality. Currently, the resolution of gridded datasets – the size of the squares – ranges from a few km² to a few hundred km².

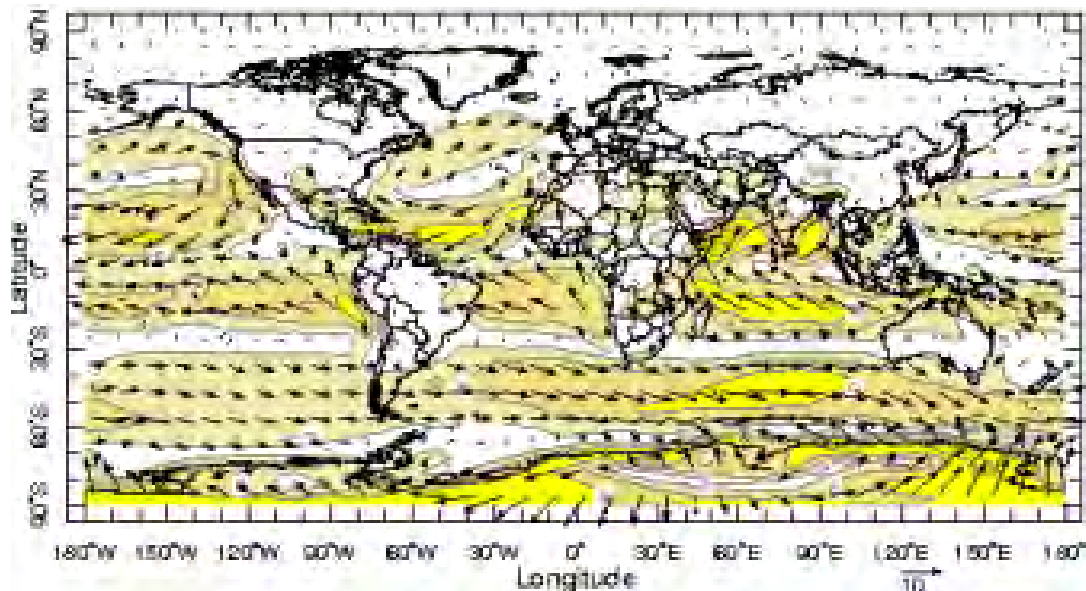


Figure 1.3-3. Map of winds close to the oceanic surface (arrows) and of a measure of their convergence (colours) based on gridded data.

Satellite data are a special class of gridded data. Satellites can observe vast swaths of Earth and atmosphere, even in remote, hard to access oceanic areas. However, they too have some issues: First, there are different types of satellites – some orbit around the Earth and pass over the same place approximately every 15 days. This means that they measure weather/climate variables every 15 days. Some are stationary over a given place, which means that they observe every minute the conditions in that place and a circle of several kilometres around but there is not enough of them to have measurements covering the entire globe. Second, satellites make

Exercise



- *Working individually or in small groups:*
- *Compare Figures 1.3-2 and 1.3-3 in terms of data over oceans.*
- *Say, a gridded dataset fills missing observations with the average of neighboring observed values. There are stations measuring rainfall and temperature in two valleys separated by a mountain range with no observations. The dataset derived the values corresponding to the mountain range as an average between the observations in the valleys.*
- *How well do you think the gridded values represent the conditions in the mountains? What aspects will be well represented? What aspects will be less well represented?*
- *What error do you expect for temperature? What error do you expect for rainfall?*

observations from a very long distance and the measurements can be affected by what is going on between the satellite and Earth's surface. For example, on a cloudy day they don't 'see'

Earth's surface thus cannot measure surface temperature. Similarly, they will have difficulties having exact values of temperature if there is a lot of pollution or smoke. Finally, some variables are not measured directly but values are calculated from measurements that reflect the variable. Rainfall, for example, is such an indirectly measured variable. As mentioned above, satellites cannot measure what is hidden to them by clouds. Clouds and rain are indissociable; therefore, satellites cannot measure the rain that hits the ground. They make estimates of how much it rains below the clouds based on how tall the clouds are – the taller the clouds the more intense the rainfall. The height of the clouds is estimated from the temperature of their top – the taller the cloud the coldest the temperature. Measurements of rain from stations on the ground are then used to associate cloud's temperature with the rainfall that is effectively observed. This method is not without flaws as some local characteristics, such as mountains, lakes or even vegetation can influence how much rain will be produced by a cloud of the same height. Therefore, we talk about 'satellite rainfall estimates.'

In summary, satellites add a great deal of information, particularly for remote areas, but this information is not the 'ground truth' and satellite data often need to be corrected using observations, where these are available, in a process called 'merging'. The merged datasets have the advantage of even spatial coverage and are closer to the truth on the ground than satellite-only dataset. An important merged dataset in Kenya is the rainfall and temperature high resolution dataset developed under *ENACTS* – Enhancing National Climate Services. Its current resolution is 4km x 4km and it spans the period 1982-present. It is the basis of numerous maprooms that will be discussed in Module 2.

Model Data refer to data generated by Numerical models. Such models - General or Regional Circulation Models (GCM or RCM) - are 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. The GCMs will be explained more in details in the session about forecasting. 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 more physically coherent gridded datasets and are particularly in favour with climate scientists, especially the dataset called 'Reanalysis', but may suffer from systematic biases, similar to those of gridded datasets.

The type of data used to generate given information should be provided with the information (as a caption or description) and it is very important to pay attention to the data used.



Exercise

- *Working individually or in small groups:*
- *List the advantages and disadvantages of the different types of data.*
- *What precautions one needs to take while using station data?*
- *What precautions when using gridded or model data?*

Measuring Surface Climate

Measuring instruments

At meteorological stations around the world, there are a number of instruments used to measure atmospheric variables “in-situ” meaning in place or directly. Weather parameters are measured using a wide range of instruments. Each instrument is designed to measure a specific parameter. Common meteorological instruments include: thermometer, rain gauge, barometer, anemometer, wet-bulb thermometer/hygrometer (Figure 1.3-4).

A *thermometer* measures temperature. Because the thermometer is intended to measure the air temperature, it is important that it is shaded not only from direct sunlight, but also from radiant heat from the ground and from other surrounding objects. Older thermometers (like the one shown in Figure 1.3-4) were typically made with mercury, which is liquid at most temperatures observed on Earth and which expands in a predictable way at higher temperatures. Newer thermometers are typically digital, and for various reasons indicate slightly different temperatures than more traditional methods. Temperature measurements are some of the longest available climate data, but for climate analysis great care has to be taken to account for changes in instrumentation, changes in location, and changes in the immediate environment (e.g., the land surface).

A *rain gauge* measures rainfall accumulation. As with the thermometer, older instruments, like the one shown Figure 1.3-4, were manual and measurements were typically made only once a day. More modern instruments are automatic, and give measurements every hour or even more frequently. Rain-gauge design can have quite a strong impact on the amount of rainfall measured, as can changes in the environment, such as the construction of new buildings, or even the growth of nearby trees. These problems are compounded by the highly localized nature of rainfall - even just a few meters away, the intensity of rain can be quite different. Measuring snow depth brings additional challenges. As a result, care again has to be taken to account for the effects of changing instrumentation, location, and environmental setting. Nevertheless, because of the importance of rainfall, especially in the tropics, rainfall climate datasets are amongst the best developed of all climate variables.

A *barometer* measures atmospheric pressure. All barometers require a pressure sensor or a compressible liquid (typically mercury or water) to measure atmospheric pressure. Older barometers often displayed pressure readings in a circular dial, but newer barometers are digital. Air pressure measurements are relatively insensitive to changes in instrumentation, location and environmental setting, and so there are some good-quality air-pressure datasets suitable for climate analysis.



Figure 1.3-4. Common manual meteorological measurement instruments: mercury thermometer (a), rain gauge (b), barometer (c), anemometer (d). Sources:

<https://www.homesciencetools.com/product/thermometer-plastic-back/> (accessed 25 Feb 2022), https://www.123rf.com/photo_100212071_meteorology-with-rain-gauge-in-garden-measurement-of-precipitation.html (accessed 25 Feb 2022), https://www.flinnsci.com/barometer-metric/ap5070/?gclid=Cj0KCQjw94WZBhDtARIsAKxWG-ksMsWzA9vwfxyJ5vhK-UCMsqH28Sb0S9vsaaa0YFxxPGIVGM9gYaAh5DEALw_wcB (accessed 14 Sep 2022), <https://www.baranidesign.com/wind-sensors> (accessed 25 Feb 2022).

An *anemometer* measures wind speed and direction. There are very few wind climate datasets, in part because of the highly localized and temperamental nature of wind.

A *wet-bulb thermometer* or *hygrometer* is used to infer humidity. A standard (usually mercury-based) thermometer's bulb is covered with a water-soaked cloth and the evaporative cooling of the water from the cloth cools the wet bulb thermometer's temperature. At 100% relative humidity, the wet-bulb temperature and the regular (or "dry-bulb") temperature are the same. As the relative humidity decreases, the difference between dry-bulb and wet-bulb temperature grows. Because humidity measurements are based on temperatures, the data quality issues for temperature generally apply for humidity also.

What are weather stations?

Weather stations around the world generally include the instruments mentioned above, although some have fewer instruments and others have more (Figure 1.3-5). Different protocols exist for the calibration of meteorological instruments and the means of reporting the data. The site selected for the establishment of meteorological Observatory should satisfy some basic requirements recommended by WMO. The Meteorological Observatory (stations) are located at sites that have been selected to ensure the observations are representative of the wider area around the station and not unduly influenced by local effects. While many older weather stations require recording the values by hand, many newer weather stations are fully automatic and include a data logger that can transmit the recorded information to a meteorological service office. Automatic weather stations typically have a thermometer, barometer, rain gauge, anemometer, energy sensor, data logger and sometimes soil temperature sensor all mounted to the same apparatus (Figure 1.3-6). The readings from all the instruments are recorded digitally on the data logger and can be monitored remotely.



Figure 1.3-5: Traditional weather station site. This weather station includes a rain gauge, temperature gauge, relative humidity, barometer, anemometers, pyranometers, and pyrliometer with solar panels to power the sun tracker and some sensors. Source: <https://www.essearch.com/compact-weather-sensors-and-traditional-weather-sensors/>, accessed 10 Feb 2025.

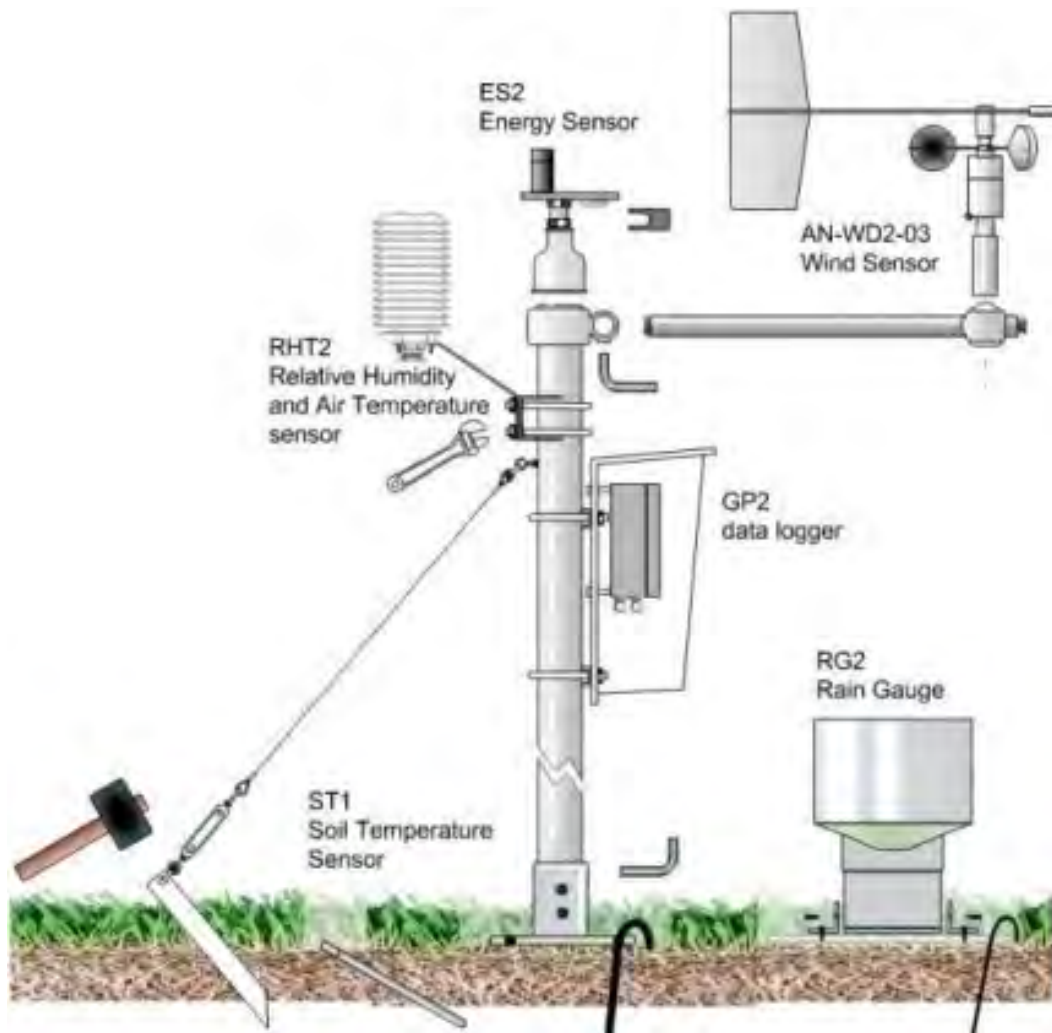


Figure 1.3-6. Weather station. Source: Alpha Omega Electronics (n.d.). *Advanced Automatic Weather Station System*. Source: <https://www.alphaomega-electronics.com/en/compact-stations-kits/1713-advanced-automatic-weather-station-system.html>, accessed 25 Feb 2022.

In order to measure atmospheric properties at different levels in the atmosphere, several of these same instruments may be mounted to an aircraft or placed below a weather balloon that tracks elevation through flight (Figure 1.3-7). A weather balloon is a type of high-altitude balloon that carries meteorological instruments to take measurements at high altitudes in the atmosphere. A radiosonde is a battery-powered instrument that measures atmospheric pressure, temperature, and humidity, usually aboard a weather balloon, and transmits them by radio to a ground receiver. A rawinsonde is a radiosonde that is used to measure wind in addition to the other parameters. A dropsonde is a meteorological recording device that includes several instruments (usually in a fully digital framework) and is designed to be dropped from an aircraft to the surface while making recordings throughout its fall. Note that, unlike weather stations, these platforms usually do not record atmospheric parameters continuously in time. Rather, they are released punctually for specific purposes.



Figure 1.3-7: Left: Launching a weather balloon with instruments attached. Right: a storm monitoring aircraft releasing dropsondes to record atmospheric conditions within a storm. Sources: <https://www.forbes.com/sites/marshallshepherd/2018/05/18/it-was-weather-balloon-georgia-not-a-bomb-5-questions-answered-about-them/>, <https://scied.ucar.edu/learning-zone/atmosphere/dropsonde>, accessed 10 Feb 2025.

Climate analyses

As mentioned before, most of the time climate information, i.e., data that have been analysed, are the most useful for many applications. In this session we will discuss the most common data analyses. Some of them apply to both spatial and temporal dimensions of climate, some to only one.

Mean

This is probably the simplest and the most common analysis. It consists of the sum of the values divided by the number of values. It gives us an overall idea of the values in the dataset, knowing that they are not all equal to the mean. It is convenient for comparisons of climate characteristics between locations. For example, average or mean annual rainfall in location 1 is 600mm/year while in location 2 it is 800mm/year. It can be computed in space, e.g. average rainfall over a district or a river catchment, or in time, e.g. average rainfall over 1991-2020 period. When computed over time, it is common practice to use at least 30 years of data for the mean to be representative of the climate. The mean of past 3 or 5 years, while still giving some information, may not be really representative of the climate since those years could have been exceptionally wet or dry or cold or warm. Meteorologists often refer to 'climatic normals', these usually span 30-year periods starting at the beginning of the decade and are updated every 10 years. The current normal is the normal of the most recent fully finished decade. Current climatological normal is 1991-2020.

Anomaly

The mean is a useful way of describing climate but it does not capture its variability, both in space and in time. It might be useful sometimes to know that part of the catchment or of the district receives more rainfall than another part or is cooler than another part. It might also be useful sometimes to tell that one year was cooler than the average or warmer than the average. Anomalies are calculated by subtracting the mean for each value in the spatial domain or in the time series. Certain values of the anomalies will be positive and certain negative. While the

variability can be seen from the raw values on a map or in the time-series, expressing it as anomalies describes it in terms of values 'lower than average' or 'higher than average', and allows to see more quickly where or when there were deficits in rainfall or heatwaves.

It may sometimes be useful to estimate what is the total range of variability or anomalies around the average value. This we can also say: annual rainfall total in a given location ranges between 950 and 1250mm/year, or: annual rainfall total in that location is 1100 +/- 150mm/year. The latter gives us a better overall sense of the amount of rainfall and adds the range of variability to it. If the values to estimate the range are the maximum and the minimum of the values on the record, the range is called *amplitude*.

Standard deviation

The standard deviation is another measure of variability around the mean. Instead of taking the maximum and the minimum values in the data, which, most of the time only occurred once on the record thus are exceptional, it may be interesting to figure out what is the 'average' range of anomalies. To do so a sum of squared anomalies is computed first to take into account the departures from the mean without their sign (so that they do not cancel each other), a square root of this sum is taken (to get back to the same units as the initial variable) and the value obtained is divided by the number of observations, to obtain the 'average' anomaly. The temperature or rainfall in a location will then be presented as mean +/- standard deviation. Note that the standard deviation will be smaller than the amplitude discussed earlier. Providing a measure of variability around the mean is important for understanding local climate and risks.



Exercise

- Working individually or in small groups:
- Compare two locations in terms of risks to the crops,
 - ♦ location A receiving on average 1250mm of rainfall per year with std=100mm and
 - ♦ location B receiving on average 1250mm/year with std=400mm
- Compare two locations in terms of risks to the crop,
 - ♦ location B receiving on average 1250mm of rainfall per year with std=400mm and
 - ♦ location C receiving 600mm/year with a std=400mm

Coefficient of variation and standardized anomalies

Mean and standard deviation are compact ways of presenting the climate as they capture the 'total' experience of climate – what is it on average and how much it can vary. While comparing averages is straightforward, the comparisons become more complicated when variability is also

included in the comparisons. Two additional manipulations make comparisons, and understanding climate easier: the coefficient of variation and standardized anomalies.

Coefficient of variation is the standard deviation divided by the mean. By expressing the 'average' anomaly as fraction of the average of the variable it gives us a sense of 'big' the variability is and a sense of its potential impact.

Standardized anomalies (sometimes called "*normalized anomalies*") are the anomalies on the record divided by the standard deviation. On some occasions looking at relative anomaly, rather than its value might be more important. This is the case when we want to know whether two locations co-vary (have anomalies of the same sign at the same time and their larger and smaller anomalies coincide) – we are less interested in whether the larger anomalies are 100 or 200mm but that they are large compared to the entire range of anomalies. Standardizing anomalies can also be useful when comparing anomalies between different variables for the same location or different variables for different locations. For example, to estimate the impacts of El Niño on rainfall in Nairobi one could look at the time series of standardized anomalies of sea surface temperatures in the key ENSO area and standardized anomalies of rainfall in Nairobi. A statistical procedure called 'correlation analysis' makes use of standardized anomalies to estimate how well variables co-vary, but is beyond the scope of this course.



Exercise

- *Working individually or in small groups:*
- *Compute the coefficients of variation for locations A, B, and C from the previous sub-section. In which location would you prefer to farm? Why?*

Frequencies, probabilities and extremes

The measures of variability above, while useful, still do not allow to describe climate with enough detail for a lot of applications. For example: how often do values close to the maximum or minimum occur? How often do values close to the mean occur vs close to the extremes? What are the values that occur with a certain frequency, of interest to the application (e.g., once every 10 years, once every 50 years)? How often is a certain threshold crossed (e.g., seasonal rainfall amounts necessary to grow certain crop, temperature or rainfall threshold linked with epidemic malaria outbreaks)? Frequency analysis and construction of probability density functions and probability of exceedance curves allow to answer those and similar questions (Figure 1.3-8). In those frameworks, long term changes in climate properties are represented as shifts in the distributions and allow to capture changes in the mean climate as well as in the variability.

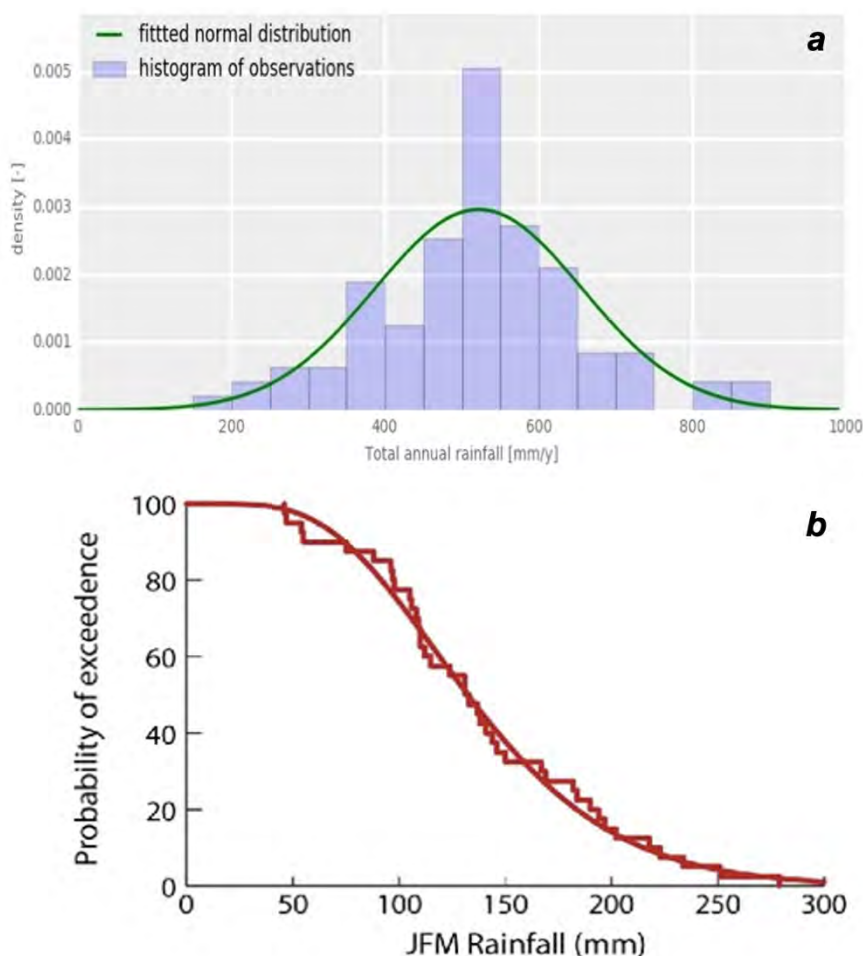


Figure 1.3-8. Examples of probability density function (a) and cumulative probability (b) for annual and seasonal rainfall values.

Exercise



- Work individually, in pairs, or small groups.
- By analyzing monthly rainfall in selected locations in Kenya using statistical and graphical methods, you will gain experience in climate data analysis, and in interpreting rainfall patterns and their implications. The analyses include:
 - ♦ Preliminary analysis of climate data into mean seasonal cycle of rainfall, annual total rainfall time series and anomalies
 - ♦ Annual rainfall frequency distribution, translation into probabilities, visualization as histogram and interpretation of the results.
 - ♦ Cumulative probability calculation and visualization
 - ♦ Probability of exceedance calculation, visualization and interpretation
 - ♦ Tercile Analysis
 - ♦ Alternative Probability of Exceedance Plot
- Instructions are in activity sheet, **A1-1 Annual rainfall analysis.docx**.
- Two versions are available: one using the Excel spreadsheet, **A1-1 Annual rainfall analysis.xlsx**, and one using a calculator and graph paper.

Standardized Precipitation Index

Drought is one of the most impactful climate anomalies as it can affect crop production and water availability and quality, thus food security and sanitation. Drought can be roughly defined as resulting from lower levels of precipitation than what is considered normal. Drought is therefore a phenomenon relative to local conditions, in space and time. The same rainfall anomaly will have different impacts in the Sahel and in the Amazon. Similarly, the same rainfall anomaly will have different impacts in the heart of the rainy season and outside of the rainy season. The same anomaly of monthly rainfall will have different impact if it is embedded in a multi-month deficit or is one of a kind. Rainfall deficits persisting over 1 to 6 months will affect soil moisture and agriculture while deficits persisting over 6 to 24 months will impact streamflow, reservoir and groundwater. Thus, different sectors will define drought differently and it is possible to experience drought on one time scale but not on another. *The Standardized Precipitation Index (SPI)* was designed to quantify precipitation deficits at multiple scales and relate them to normal conditions prevailing locally. The possibility of computing the index at multiple scales allows to detect different types of droughts that impact different sectors. The standardization makes it comparable between regions.

The SPI (Fig. 1.3-9) can compute drought intensity over any desired interval, e.g., one month, five months or 200 days. Technically, the SPI is the number of standard deviations that the observed value would deviate from the long-term mean, for a normally distributed random variable. Since precipitation is not normally distributed, a transformation is first applied so that the transformed precipitation values follow a normal distribution. Positive SPI values indicate greater than median precipitation and negative values indicate less than median precipitation. Because the SPI is normalized, wetter and drier climates can be represented in the same way; thus, wet periods can also be monitored using the SPI.

SPI has several strengths: It is designed to quantify the precipitation deficit for multiple timescales which correspond to the time availability of different water resources (e.g., soil moisture, snowpack, groundwater, river discharge and reservoir storage). It uses precipitation data only. Values are comparable across regions with different climates. SPI is relatively simple to calculate. SPI also has important limitations: As a measure of water supply only, the SPI does not account for evapotranspiration, and this limits its ability to capture the effect of increased temperatures (associated with climate change) on moisture demand and availability. It is sensitive to the quantity and reliability of the data used to fit the distribution; 30-50 years recommended. It does not consider the intensity of precipitation and its potential impacts on runoff, streamflow, and water availability within the system of interest.

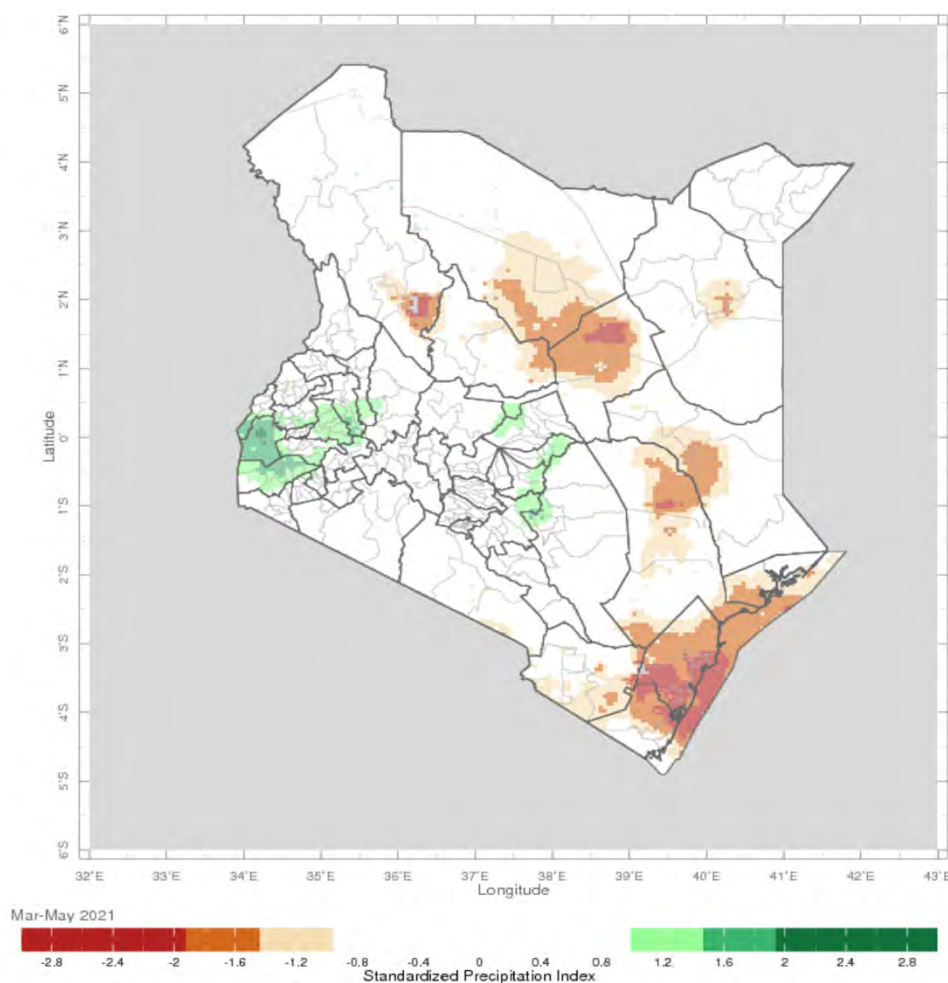


Figure 1.3-9. Example of a 3-months SPI for March to May 2021. Source: KMD Data Library, http://kmddl.meteo.go.ke:8081/maproom/Climatology/Climate_Monitoring/seasonalspi.html?T=Mar%202021%20-%20May%2020214, accessed 31 Oct 2024.

Exercise



- Working individually or in small groups:
- What is the magnitude of the three-month SPI in Figure 1.3-9?
- Which areas were the most affected?
- Do you know what caused the extreme SPI?
- Do you know what was the impact on crop production?



Self-Check

1. What is the difference between climate data and climate information. Give one example of each.
2. List the advantages and disadvantages of the different types of data. What precautions need to be taken when using information based on each type of data?
3. Read carefully the caption in Figure 1.3-10 below. What is plotted on the figure? Is it spatial or time dimension? Over what period of time? What data have been used? What analysis have the data undergone? What are the main types of variations presented?

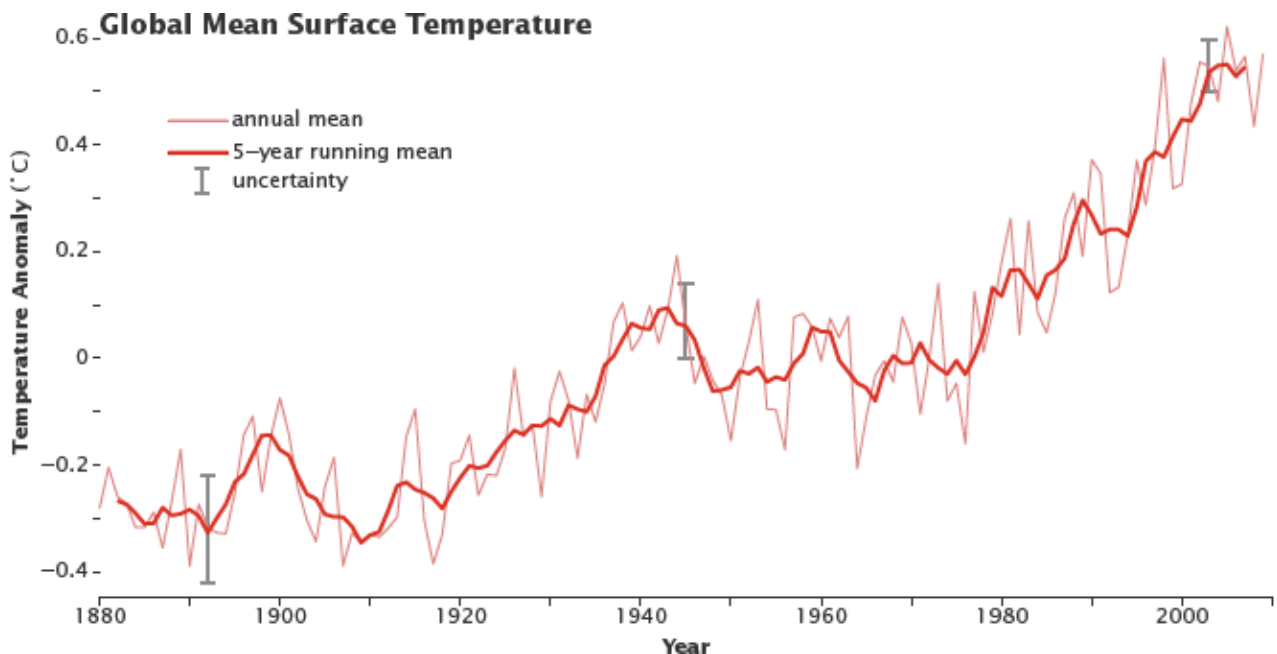


Figure 1.3-10. Anomalies of global mean surface temperature based on station data. Thin red line is the anomaly of annual mean, thick red line is the 5-year running average. Source: NASA figure adapted from Goddard Institute for Space Studies

<https://earthobservatory.nasa.gov/features/GlobalWarming/page2.php>, accessed 21 Feb 2021.

Session 1.4. Seasonal Climate Forecasting

The basis for seasonal forecasting lies in the slower evolution of temperatures of the oceans and phenomena such as ENSO or IOD, reviewed in Session 1.3. There are two main classes of methods to forecast the evolution of climate in the next season. This session presents a few basic concepts in seasonal forecasting. It is not intended to provide in-depth information on specific methods that are being used operationally, rather, it aims to provide basic understanding to support forecast interpretation and use.

At the end of this session, you will be able to:

- Identify different types of forecasts.
- Explain forecast uncertainty.
- Interpret probabilistic seasonal forecasts.

Basis for seasonal for seasonal forecasting

Seasonal climate forecasting is based on the understanding of large-scale climate patterns and their influence on weather and climate over entire seasons (usually 3-4 months), more particularly the influence on climate over land by slowly evolving SSTs (see previous session). The ocean and atmosphere are closely connected, constantly exchanging heat, moisture, and energy. Slowly evolving SSTs influence weather and climate by:

- *Heating the air:* The ocean absorbs heat from the sun and warms the air above it. When SSTs are high, more heat is transferred to the atmosphere, which can change air pressure and wind patterns.
- *Increasing moisture:* Warmer water evaporates more, adding more moisture to the air. This extra moisture can lead to more clouds and heavier rainfall when it condenses into precipitation.
- *Changing wind patterns:* Warm SSTs cause air to rise, creating low-pressure areas. This pulls in surrounding air, which can change wind patterns over large regions. These changes affect weather systems, like monsoons and storms.
- *Transporting moisture over long distances:* Winds can carry moisture-rich air from warm ocean areas to faraway places, including inland where it fuels most of the large rain-producing systems, such as monsoons.

Several methods are used to take advantage of the slow evolution of SSTs and its impacts on climate, with the main categories presented below.

Seasonal forecasting methods

Statistical methods

Statistical methods take advantage of historical climate records and establish statistical relationships between the variable of interest (predictand), like rainfall, number of rainy days or temperature anomalies during an upcoming season, and variable(s) that drive their variations (predictor), such as SST anomalies in key oceanic regions. The relationships, sometimes called “statistical models”, can be as simple as anomalies conditioned on SST anomalies or a linear regression between two indices, or can involve more complex spatio-temporal analyses, such as Canonical Correlation Analysis.

Statistical methods are simple to understand and to implement. However, they rely heavily on relationships between variables and selection of predictors that may not hold under all circumstances. For example, a strong IOD can interfere with the impacts of El Niño in East Africa. Special care needs to be taken to capture all the potential influences. However, it is easy to select too many predictors that are either redundant or show correlations that cannot be supported by plausible mechanisms explaining their influence on the region of interest. Therefore, it is recommended that predictors be always checked for co-variability and (at least hypothetical) mechanisms be proposed to explain the impacts of selected predictors on seasonal rainfall and temperature in your region, to avoid overfitting. Measures of uncertainty of the forecasts should also be provided (see section on *Uncertainty*, below).

Dynamical methods

Dynamical methods refer to the use of models based on physical equations that govern interactions between various components of the climatic system, called General Circulation Models, and similar to the models used in Numerical Weather Prediction. These models describe the evolution of each meteorological variables using physical equations. Figure 1.4-1 shows schematically (top) the main processes included in numerical weather and climate models and (bottom) the main processes and interactions described by the equations.

To describe the state of the atmosphere in different locations on the globe and through its height they partition Earth’s surface and the atmosphere above into small building blocks and computing changes in each weather and climate variable with time. Figure 1.4-2 schematically represents the partition of the atmosphere and the main variables computed at each step.

Such models capture our current knowledge of climate system and complex interactions within and take advantage of advances on computing technologies. They are used to predict weather and they are very good at predicting ENSO several months ahead as well as how ENSO will disrupt the circulations around the globe and impact climate in Kenya. However, they too have several caveats. The main caveat is the model resolution (horizontal size of the grid cell). Typical

grid cell size ranges from about 50kmx50km to 100kmx100km. The conditions are assumed uniform within the grid. Thus, the models have difficulty generating different values where there are inhomogeneities within a grid such as mountain ranges or water bodies. However, increasing the resolution (decreasing grid cell size) is not trivial as solving the equations requires a lot of computing resources which limits the number of grids we can partition the atmosphere into. Another major caveat is in our imperfect knowledge of the atmospheric conditions at the start of the forecast.

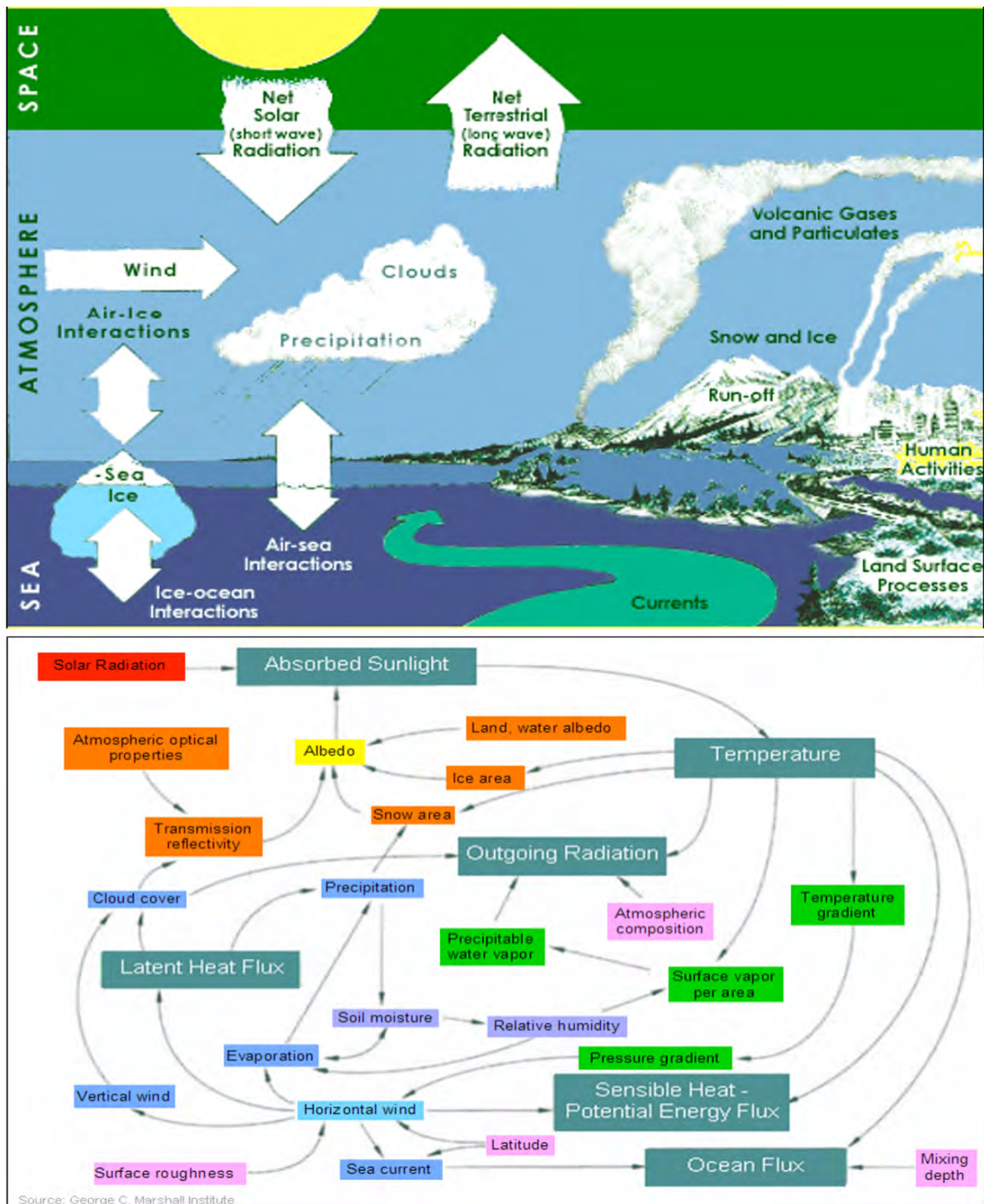


Figure 1.4-1. Schematic representation of the main physical processes in the climate system (top). Main processes and interactions captured by the equations in a GCM (bottom).

Weather forecast modeling

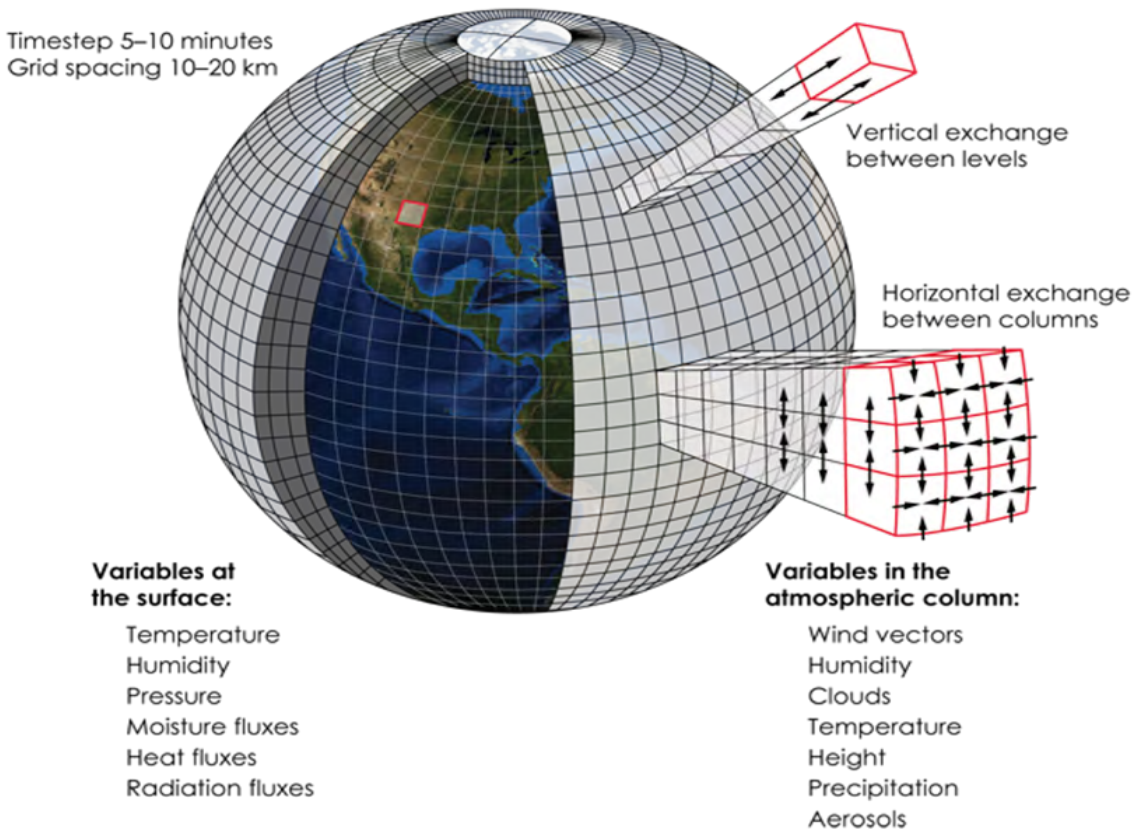


Figure 1.4-2. Schematic representation of a GCM, the partition into grid-cells and the main processes variables computed at the surface of the Earth and in the atmosphere.

Exercise



- Working individually or in small groups, explore the following:
- Assume that in a GCM the surface of the Earth is partitioned into 10,000 grid points and that the height of the atmosphere is partitioned into 20 levels. To predict the future state of the atmosphere the model needs to solve 100 equations in each cube. And it can only advance by steps of 15 minutes i.e., in order to predict the state of atmosphere in one hour it needs to solve the equations 4 times, advancing in time 15 minutes each time. Assume that the computer can solve 1 million equations per second.
- How long will it take the model to compute the state of the atmosphere in 24 hours from now? In one month? In 3 months? In one year?
- Assume you want your grid point to be smaller and cover half the distance in each direction (hint: there are three directions). How long will it take the model to compute the state of the atmosphere in 24 hours from now? One year from now?

Mixed methods

To take advantage of the objective forecasts allowed by the GCMs but correct some of their systematic biases, statistical treatments are sometimes applied to GCM (or RCM) outputs. Such treatments are often called *Model Output Statistics* (MOS). Climate Predictability Tool developed by IRI allows for such MOS corrections. Statistical treatments can also be applied to further downscale model outputs.

Formats of seasonal climate forecast

Uncertainty

Uncertainty is an inherent feature of predictions of future climate, from weather to climate change scales. The main categories of sources of uncertainty in the predictions are:

- Uncertainty on the initial conditions of the forecasting process, due to spatial gaps in the weather observing system (e.g., in oceanic and sparsely populated areas, such as deserts)
- Uncertainty on our representation of the system, e.g., a regression line is only an approximate representation of a scatter plot; GCMs only imperfectly capture local conditions due to their coarse resolution
- Uncertainty on the evolution of the system and of the main drivers, e.g. changes in SST over the period of seasonal forecast, changes in the emission rates for climate projections.

The relative importance of these factors depends on the horizon of the forecast, with the uncertainty on the initial conditions being most important for short term, weather forecast and the uncertainty on the evolution of the system and external drivers, for longer horizons such as climate change.

It is important to note that uncertainty can and should be evaluated and communicated to convey forecasters confidence in the forecast. Similarly, evaluation of the uncertainty should be an integrant part of forecast evaluation. Probabilistic formats are a convenient way to convey the uncertainty of the predictions.

Flexible format seasonal forecast

As demonstrated in previous sections, climate and its variability can be expressed as a probability distribution of historical values of the variable of interest, e.g., annual or seasonal rainfall, number of rainy days, monthly average temperature etc. Historical distribution gives us a first guess of the likelihood of a given value to occur or the be exceeded/not exceeded. Probabilistic forecast indicates potential shifts in those probabilities, as shown on Figure 1.4-3. This format of seasonal forecast allows the user to access shift in the probabilities for a value that is of interest to his decisions. Maprooms allow to visualize historical and predicted probabilities for a given location, like in Figure 1.4-3, as well as plot maps of probability of exceedance (or non-exceedance) of a user-defined value. In addition, maprooms allow to plot maps of probability of exceeding/not exceeding thresholds of interest.

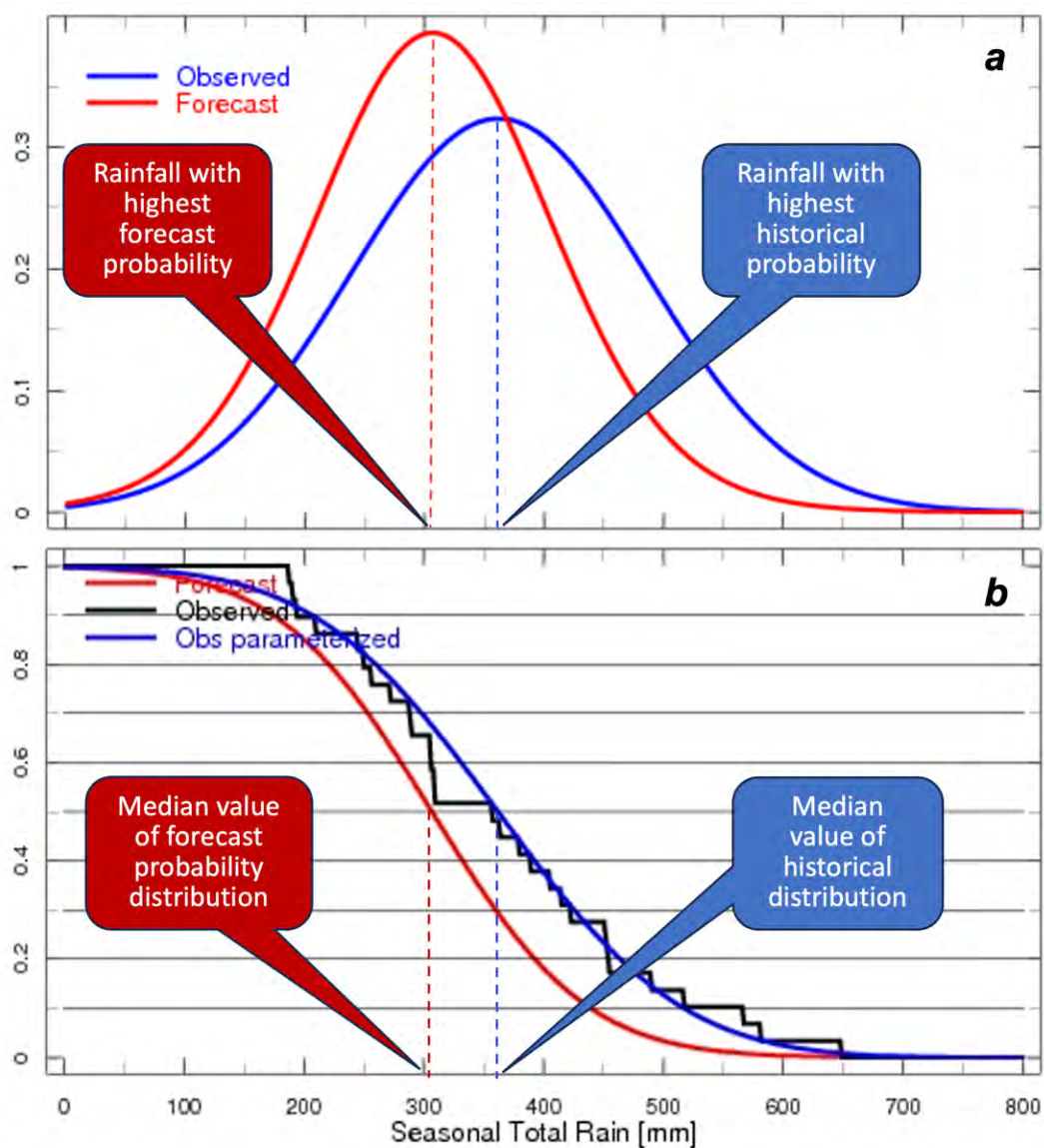


Figure 1.4-3. Predicted shifts in probabilities in the seasonal rainfall totals, predicted in September 2020 for Oct-Dec 2020 season, for the location 31.5E, 12.25S. a) shifts in ----the distribution of probabilities, b) shifts in the probabilities of exceeding rainfall threshold.



Exercise

Working individually or in small groups, answer the following questions:

- Looking at the Figure 1.4-3a:
 - ♦ What does the forecast suggest for next season's rainfall?
 - ♦ What is the most probable forecasted rainfall amount? What is the associated probability?
 - ♦ What is the most probable climatological rainfall? What is the climatological probability associated?
 - ♦ What is the forecasted probability for the amount from question b? is the shift in probability with respect to climatology large?
- Looking at the Figure 1.4-3b:
 - ♦ What is the meaning of the median?
 - ♦ What is the climatological rainfall related to median?
 - ♦ What is the forecasted rainfall amount related to 50% probability of exceedance? Is the shift in the predicted median large?

Tercile format seasonal forecast

Tercile format is an older format of the probabilistic forecast where the historical distribution was first divided in three equiprobable segments – the terciles – that had a nominal probability of occurrence of 33.3%. The forecast indicated predicted shifts from the expected 33.3% probabilities, as shown in the Figure 1.4-4.

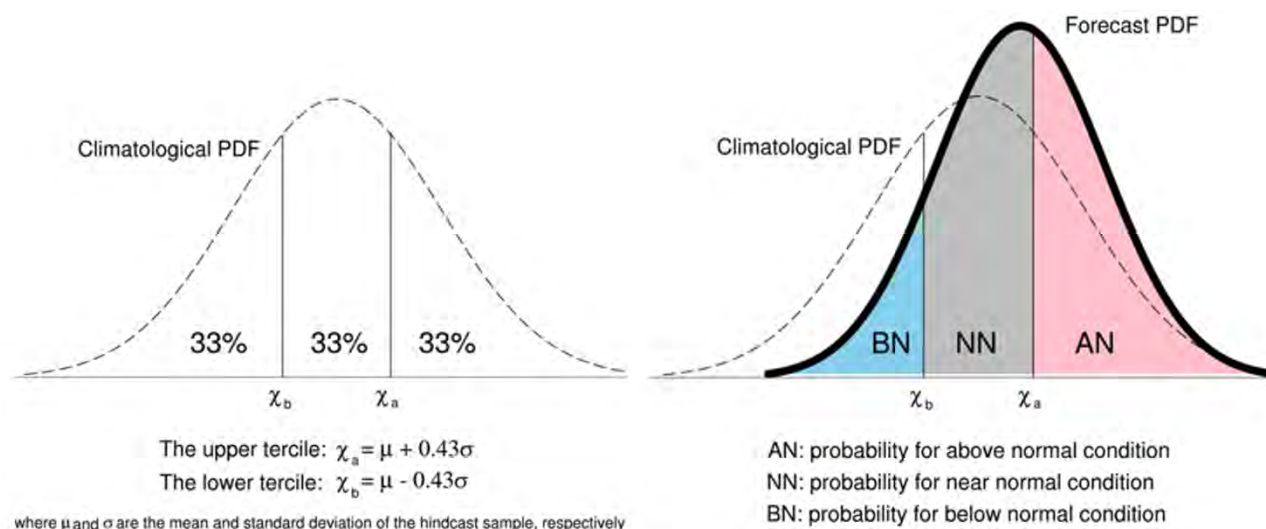


Figure 1.4-4. Schematic depiction of shifts in tercile probabilities in a tercile probabilistic forecast.

Maprooms display spatial distribution of predicted probabilities of individual terciles as well as summary maps. Tercile forecast format has the inconvenience of pre-partitioning the full

distribution into predefined segments that do not always correspond to thresholds relevant to decisions. However, due to historical reasons, a lot of forecasts are still presented in this format.

An example of a tercile forecast presentation, with a downscaled forecast for Meru County, from the Kenyan Meteorological Department, is shown in Figure 1.4-5. In line with the decentralization strategy, KMD established County Meteorological Offices in September 2012, headed by a County Director of Meteorological Services, CDMS. In support of this process, KMD developed a framework for co-producing County Climate Information Services (CIS) Plans together with key stakeholders. This describes how services will be delivered at county level complete with communication strategy and content of the services.

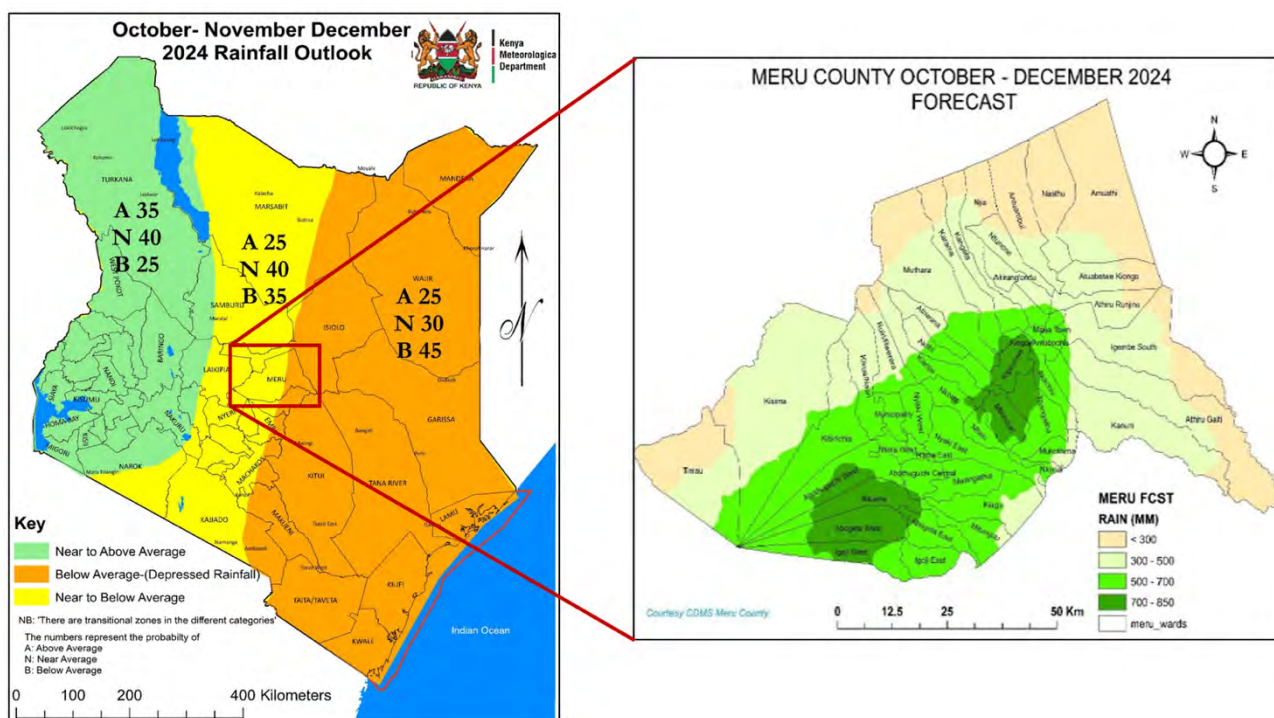


Figure 1.4-5. October-December 2024 seasonal rainfall forecast presentation from the Kenya Meteorological Department, downscaled for Meru County. Source: KMD, <https://meteo.go.ke/forecast/seasonal-forecast>, accessed 31 Oct 2024.

Exercise



Working individually or in small groups, answer the following questions looking at Figure 1.4-5:

- What do the green colours correspond to? What do orange/yellow colours correspond to? What do green colours correspond to?
- Based on your recollection from the section 1.1, which parts of Kenya experience high rainfall during Oct-Dec season?
- What does the forecast suggest for the Oct-Dec 2024 season's rainfall?

Use of seasonal forecasts

Interpretation

It is important for users to understand the inherently uncertain nature of climate forecasting and know how to interpret and act on probabilistic information.

Historically, many of the regional climate outlook forums (RCOFs) have produced seasonal forecast consensus maps based on forecasting efforts using an array of software and engagement from the meteorologists from many nations within the region. Prior to the RCOF, the technical experts convene on the findings of their different forecast efforts and a qualitative consensus map is drawn delineating different sub-regions with respect to tercile probabilities for precipitation and temperature for the upcoming season (the probability of the season being “above normal”, “near normal” or “below normal”). This format has often made the meteorological community feel comfortable but has created challenges for the user-community. Interpreting a tercile-based consensus probabilistic forecast into an actionable decision requires specific knowledge of what “above normal”, “near normal” and “below normal” mean for a given location and season - this is knowledge that the users may not have directly. Furthermore, critical decisions for agriculture, health or water management may depend on thresholds other than the 33rd or 67th percentiles of temperature and precipitation. These challenges are discussed further in Session 4.5. In response to these challenges, there has been an effort in recent years, particularly in the Greater Horn of Africa Climate Outlook Forum (GHACOF), to present forecast information with the full forecast distribution and to use a fully objective approach to forecast generation. This has been mainstreamed into the forecasting efforts of the IGAD Climate Prediction and Application Centre (ICPAC)² regionally, and Kenya Meteorological Department (KMD) nationally. This alternative format is discussed in Session 2.2.

Other considerations on the use of forecast

In reality, crop yield depends on a number of factors beyond the seasonal rainfall total: the timing of the onset and cessation dates, the timing of planting and harvest dates, the intra-seasonal distribution of rainfall, the number and length of dry spells, the frequency and severity of heat waves, and a host of non-climatic factors (soil fertility, management practices, land use pressures, etc.).

Navigating these decisions successfully requires that the meteorological community be forthright about matters of forecast skill and uncertainty and adequately verify forecasts against historical observations. Further, the NMHS also needs to be sensitive to the needs of users and to try to present information in a usable way for the different user sectors.

² http://digilib.icpac.net/maproom/Climatology/Climate_Forecast/SeasRainFcst.html The more general ICPAC climate maproom page can be found at <http://digilib.icpac.net/maproom/Climatology/>

However, the users also need to appreciate that climate information is inherently probabilistic and uncertain and need to frame their decision making around the probabilistic information that can be produced by the technical experts. Perfectly skilful forecasts many months in advance of a target season are generally not possible. But many forecast outputs can still be useful at guiding decisions. Professionals in various sectors that constitute the user community need to be clear enough in their own understanding of what level of skill and lead time are necessary from a forecast in order to effectively inform a decision. That understanding should guide the users' engagement with the NMHS.

There should also be an understanding on the users' side that because of the uncertain, probabilistic nature of climate forecasting, some forecasts will appear "wrong" (i.e., the forecast leaned strongly towards wet conditions and dry conditions actually occurred). Such events may imply a need to refine and reevaluate the forecast methodology, but do not necessarily mean that the forecasting enterprise (led by regional organizations and NMHS) is inherently untrustworthy or lacking in value. Both the user community and the meteorological community should bring a historical perspective to this engagement and strive to keep in mind the mixture of successes and failures over time to try to continuously improve the process of forecasting, communication and engagement.

The forecasting continuum

While the main focus of this module is the seasonal forecast it is important to understand that forecasts are made at different time scales and horizons, from the familiar weather forecasts to climate change projections. Different forecasts are based on different premises. For example:

Weather forecast predicts the short-term evolution of atmospheric conditions over a period of a few days and is mostly based on our knowledge of current atmospheric conditions

Seasonal forecasts predict the climatic conditions several months ahead and are based on the fact that warmer or cooler sea surface temperatures, such as in the case of ENSO or IOD, impact large scale circulations that bring moisture into the continents and impact rainfall

Climate change projections attempt to predict the evolution of climate several decades ahead and are based on the change of atmospheric composition thus the change in the energy that our climatic system receives and redistributes via global ocean and atmosphere circulations and uses to melt the ice and increase the temperature of the oceans and continents.

It is important to understand that the longer the horizon of the forecast, the greater the uncertainty and the less precise the forecast in terms of spatial and temporal resolution as well as amounts.

Figure 1.4-6 illustrates different types of forecasts, and associated time and space scales, and underpinning drivers. Forecasts at the scales in between weather, seasonal and climate change,

such as sub-seasonal (characteristics of rainfall or temperature within the season) or decadal (evolution of rainfall and temperature in beyond next year) are still in their infancy.

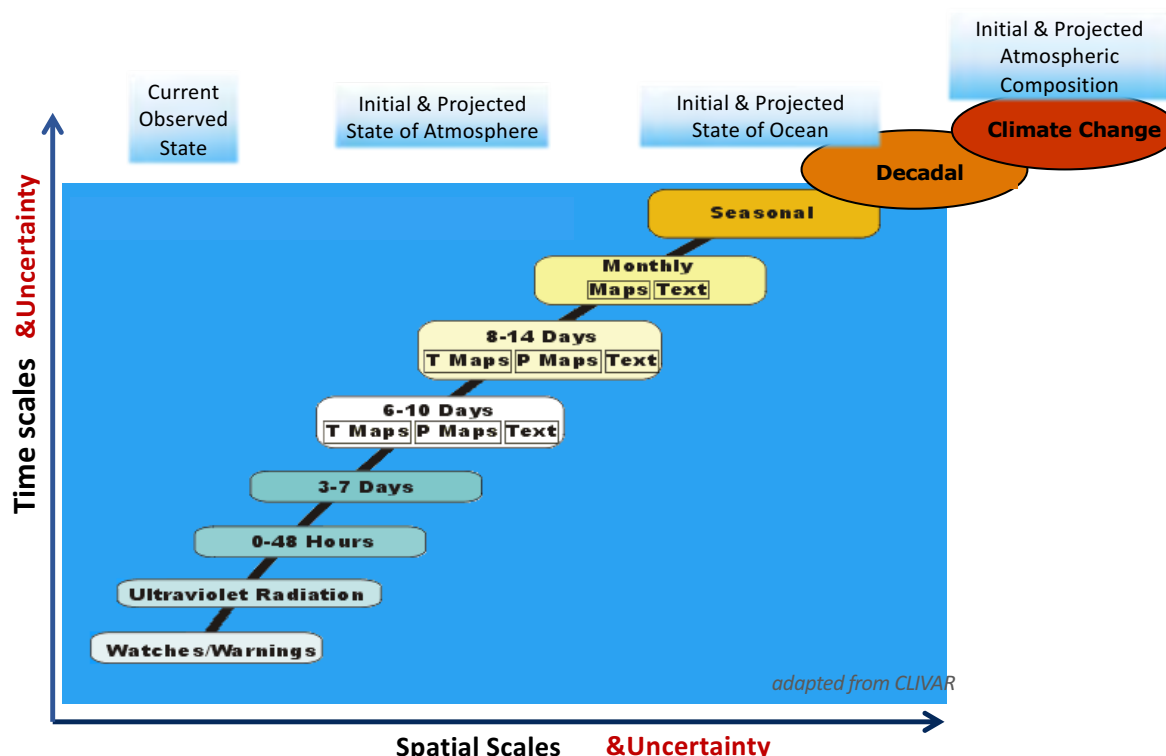


Figure 1.4-6. Probabilistic Schematic representation of different types of forecasts as a function of temporal and spatial scales and uncertainties. The main factors underpinning different types of forecasts are listed at the top of the figure. Source: adapted from CLIVAR.

Indigenous knowledge in weather forecasting

Many indigenous communities globally use traditional weather and climate forecasting, based on observations of their immediate environment, to guide their decisions, as a way to cope with climate-related risks (Nkuba et al., 2022). Local communities across the globe, which are not equipped with scientific instrumentation and analytical tools and techniques, have developed the art of assessing and anticipating weather conditions over generations of accumulated experience. Indigenous forecasts are largely based on observation of various faunal, floral and other physical changes in their surroundings that precede or accompany meteorological phenomena of interest (Rautela and Karki, 2015; Roncoli et al., 2002). Numerous studies across Africa have found that producers do not oppose scientific forecast and indigenous forecasts, rather use them to complement their indigenous systems (Nkuba et al., 2022; Roncoli et al., 2002), and increasingly value them as their indigenous forecasts become less reliable due to climatic but also environmental changes. Discrepancies among forecasts or between forecasts and outcomes are not considered failures. Communities have the ability to work within multiple knowledge systems and blend traditional wisdom with new agricultural techniques to strengthen their resilience, demonstrating that integrating various forecasting methods enhances decision-making rather than causes confusion. Participatory Scenario Planning (PSP)

in Kenya represents an important forum for integration and harmonization of indigenous knowledge and meteorological information (Ochieng' et al., 2021).

As an example, the Nganyi community in western Kenya possesses remarkable indigenous knowledge on weather forecasting, honed over centuries of close observation of their environment (Zachary et al., 2021). Their methods are deeply intertwined with their cultural practices and beliefs, offering valuable insights into local climate patterns. Table 1.4-1 summarizes some of the indicators that they use to forecast local weather conditions. The Nganyi community's indigenous knowledge on weather forecasting is a valuable resource that has enabled them to adapt to their environment for centuries. It is a testament to the power of close observation, traditional practices, and intergenerational knowledge transfer. The PSP, conducted in Baringo county is helping integrate this local knowledge with scientific climate forecasts to improve decision-making for crop farmers and pastoralists. A collaborative process, it brings together scientists, local communities, and decision-makers to interpret climate forecasts and develop actionable plans based on shared knowledge. Conducted in local languages it strengthens resilience by improving the dissemination of climate information through meetings, digital platforms, and community gatherings. It ensures that climate information is accessible, relevant, and useful for specific local conditions. By valuing indigenous forecasting methods alongside scientific predictions, PSP also fosters inclusive engagement and enhances trust in climate services, building climate resilience and promoting sustainable development.



Self-Check

1. What are the two main types of forecasts? Cite advantages and drawbacks of each.
2. What are the main sources of uncertainty? Can uncertainty be avoided? How do forecasts deal with the uncertainty?
3. Would you base your farm decisions on a deterministic high resolution seasonal forecast? Explain why or why not.

Table 1.4-1. Indigenous weather indicators from the Nganyi Community in Western Kenya, based on <https://aiccra.cgiar.org/news/blending-indigenous-traditional-knowledge-scientific-weather-predictions-enhance-livestock>

Type	Indicator
Bio-indicators	<i>Plants:</i> The Nganyi closely observe the flowering and fruiting patterns of specific indigenous trees and plants. For example, the flowering of certain acacia trees indicates the onset of the rainy season.
	<i>Animals:</i> The behaviour of animals, such as birds, insects, and amphibians, is also a key indicator. Changes in bird migration patterns, the croaking of frogs, and the activity of termites can all signal changes in weather patterns.
Astronomical Observations	<i>Stars and constellations:</i> The Nganyi use the position and movement of stars and constellations to predict seasonal changes and rainfall patterns. Certain stars appearing or disappearing can indicate the start or end of a rainy season.
	<i>The moon:</i> The phases of the moon are also considered, with certain phases associated with specific weather conditions.
Meteorological Indicators	<i>Wind patterns:</i> The direction and strength of winds are carefully observed. Specific wind patterns can indicate the approach of rain or dry spells.
	<i>Cloud formations:</i> The Nganyi have a detailed understanding of different cloud types and their associated weather conditions. They can predict rain based on the colour, shape, and movement of clouds.
	<i>Temperature and humidity:</i> Changes in temperature and humidity are also taken into account, with specific combinations indicating different weather patterns.
Cultural Practices and Beliefs	<i>Rituals and ceremonies:</i> The Nganyi have traditional rituals and ceremonies associated with rainmaking and weather forecasting. These practices are not merely symbolic but are also a way of reinforcing their knowledge and ensuring its transmission across generations.
	<i>Sacred sites:</i> Sacred sites, such as forests and hills, are considered to be connected to weather patterns. These sites are protected and respected, contributing to the preservation of the environment and the knowledge associated with it.
Integration with Modern Science	<i>Collaboration with meteorological services:</i> Recognizing the value of both indigenous and scientific knowledge, there have been efforts to integrate Nganyi weather forecasting with modern meteorological data. This collaboration can lead to more accurate and localized weather predictions.

Session 1.5. Climate Change

While climate varies on many time scales, and Sessions 1.1 and 1.2 have discussed some of those scales while Session 1.4 introduced forecasting across time scales, the focus of this section will be on long-term climate change. There is a great deal that can be written on this topic, but the objective of this section is only to provide some of the most essential highlights. The earlier sessions of this Module discuss climate variability on time scales from a few weeks to several decades and our working definition of climate generally refers to a collection of aggregate characteristics established across a period of multiple decades. Climate change happens at an even longer time scales and refers to changes in the climate characteristics over centuries or even longer.

At the end of this session, you will be able to:

- Understand the mechanisms of climate change.
- Differentiate between Global Warming and Climate Change.
- Explain the Greenhouse Effect, including the role of greenhouse gases like carbon dioxide and methane, and difference between natural and human contributions.
- Describe direct and indirect impacts of climate change on societies.
- Explain how adaptation strategies can best prepare societies for both current and future climate challenges, given the high degree of uncertainties about climate projections.

The Earth's climate has changed many times and quite considerably over the course of its 4.6-billion-year history – sometimes quite quickly - due to internal processes within the climate systems and sometimes, due to external events such as a large meteorite strike (Figure 1.5-1). Some of those changes led to massive animal and plant extinctions, some to slow evolution of ecosystems and their inhabitants. Most of long-term variations in climate occurred a long time ago, before humans appeared and were affected by them. Evidence that the climate is and has been changing is apparent in climate time series data in many parts of the world.



Figure 1.5-1. Vredefort Crater (South Africa) *This is the largest verified impact crater on Earth, with an estimated diameter of about 300 kilometres. It was formed over 2 billion years ago and is one of the oldest known impact structures.*

The current concern with the climate change lies in how it will impact human societies, either directly (e.g., through flooding, unbearable temperatures, drinkable water shortages, affecting places where we live, etc.) or indirectly through affecting the environment in which we live or depend upon for our economies and wellbeing (e.g., through droughts, crop and livestock loss, water and energy shortages, etc.). The concern is also due to the fact that climate change is happening quite fast – the effects are quite noticeable from one generation to another – much faster than our societies are able to adapt. Ultimately, it will have large socio-economic costs. On the other hand, measures can be taken to slow the climate change (climate change mitigation) and anticipate and adapt to new climatic conditions (climate change adaptation). This session will review the causes of current climate change, put it into perspective relative to past changes in climate and review the impacts of climate change globally and in Kenya.

The mechanism of the current climate change

We learned in Session 1.2. that solar radiation is the primary source of energy for the Earth and climate, and that ocean and atmosphere play a critical role in redistributing the energy between equatorial zones and higher latitudes, between oceans and land masses, etc. The atmosphere plays also a critical role in keeping the Earth warmer than it would be without it. Indeed, while the atmosphere is transparent to the visible light from the Sun – the reason we can see the Sun and its radiation reaches Earth's surface – it does not let all types of radiation easily pass through. In particular, it absorbs the so called infra-red radiation, i.e., the molecules of some of the gases in the atmosphere will absorb this specific type of energy and their temperature will rise. To explain the infrared radiation in very simple terms: any object whose temperature is in

the range of $\pm 80^{\circ}\text{C}$ emits thermal longwave infrared radiation³. We cannot see it like the radiation emitted by the Sun, which is much hotter, but we can feel it in the form of heat. Some nocturnal animals and some special cameras can see it and capture it as image (Figure 1.5-2) and it is sometimes referred to as night vision.



Figure 1.5-2. Examples of Visible and Infrared images. Left: a picture of a man in visible light; Middle: a picture of the same man in Infrared light; Right: an infrared picture of an elephant, taken at night. Sources: <http://nhm.ac.uk>, <https://www.elephantlisteningproject.org/thermal-imaging/>.

Exercise



- Looking at the IR images in Figure 1.5 2: if warmer objects are brighter yellow or red and cooler objects are purple or blue (the images are not in the same colour-scale): what are the warmer and the cooler part of the man (Figure 1.5 2, middle)? Why there are such differences?
- Looking at the scale in the right figure (in $^{\circ}\text{C}$), what is the approximate temperature of the warmest parts of the elephant, and of the coldest parts? What is the approximate temperature of the water?

Figure 1.5-3 shows the schematic paths of the visible (emitted by the Sun) and infrared (IR, emitted by the Earth) radiations. Solar energy mostly passes through the atmosphere and, upon reaching the surface of the Earth, is either reflected or absorbed by the surface, increasing its temperature. Some of the solar energy can be reflected or absorbed by the clouds and aerosol particles in the atmosphere. The infrared radiation, or terrestrial energy, is mostly reflected and absorbed by the molecules in the atmosphere and only a fraction crosses to outer

³ In reality any object whose temperature is above absolute zero or -273.15°C emits electromagnetic radiation whose properties depend on object's temperature. For example, the Sun, whose surface temperature is about $5,600^{\circ}\text{C}$ emits radiation that is visible to human eye while human body, with temperature around 36°C emits longwave infrared radiation, invisible to human eye. The full theory behind radiative properties of objects is beyond the scope of this course.

space. In other terms, the atmosphere acts like a blanket and keeps the Earth warmer than it would be without it. The average global temperature of the Earth is around 15°C and would be around minus 18°C , without the atmospheric 'blanket', known also as *greenhouse effect*. This effect occurs naturally in the atmosphere and helps keeping the Earth habitable.

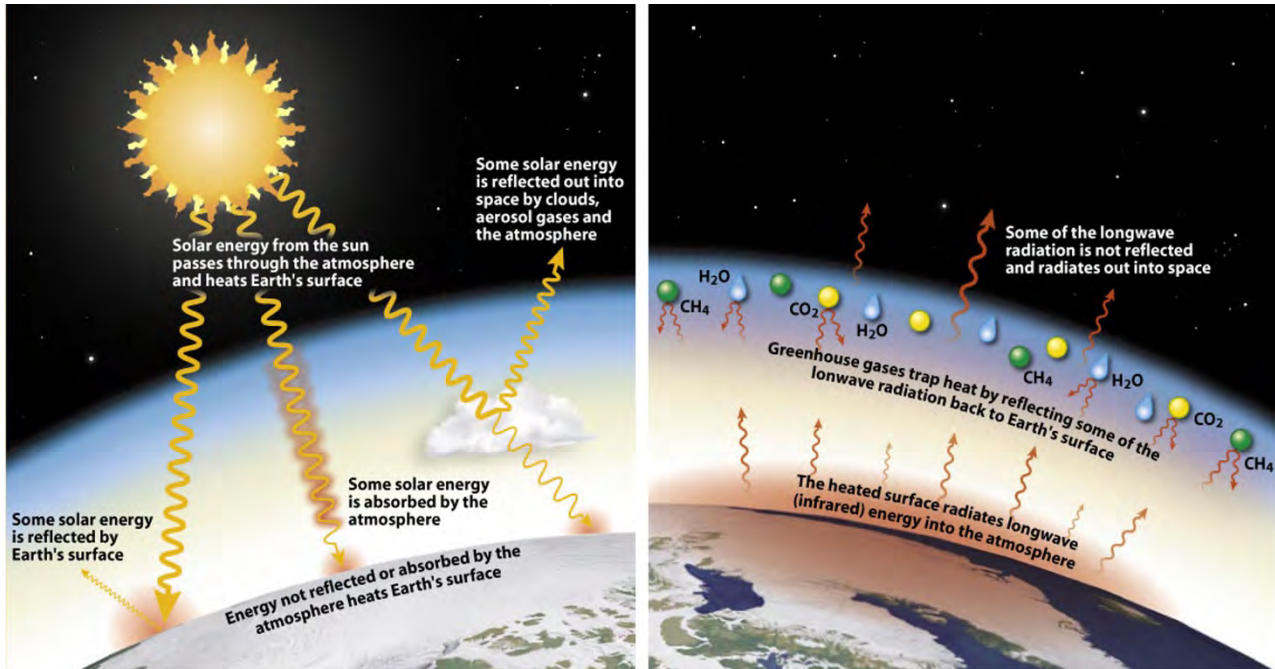


Figure 1.5-3. Left: paths of solar (visible) radiation through the atmosphere. Right: paths of the IR radiation emitted by Earth surface. Source: https://forces.si.edu/atmosphere/02_04_07.html

The term “greenhouse effect” comes from an analogy to greenhouses – structures with glass walls and roofs, often used to grow vegetables or flowers in cold climates, or to control growing conditions, like humidity, etc. Both greenhouses and the greenhouse effect work by retaining heat from sunlight, but the way they retain heat differs. Greenhouses retain heat mainly by preventing the air heated by the solar radiation from escaping the greenhouse. In contrast, the greenhouse effect retains heat by restricting the rate at which heat, not air, escapes to space.

Not all the gases in Earth’s atmosphere contribute to the greenhouse effect. The main gases in the atmosphere are: Nitrogen constituting around 78% of the atmospheric gases, oxygen around 20.9% and Argon around 0.9%. They do not contribute to the greenhouse effect. The remainder, less than 1%, is composed of approximately 12 different gases, among which carbon dioxide, water vapor, methane, nitrous oxide and water vapor and fluorinated gases are the most active in trapping IR. In other words, a very small fraction of atmospheric gases, measured in parts per million (ppm) is responsible for keeping our planet habitable. It is easy to see that even a small perturbation in the amount of these ‘Greenhouse Gases’ (GHG) can have large effects on the amount of energy trapped by the atmosphere. For the last 150 years or so, human activities linked to industrialization, have added GHG to the atmosphere, in amounts sufficient to cause additional trapping of energy in the system. Figure 1.5-4 illustrates the natural vs human-induced greenhouse effects.

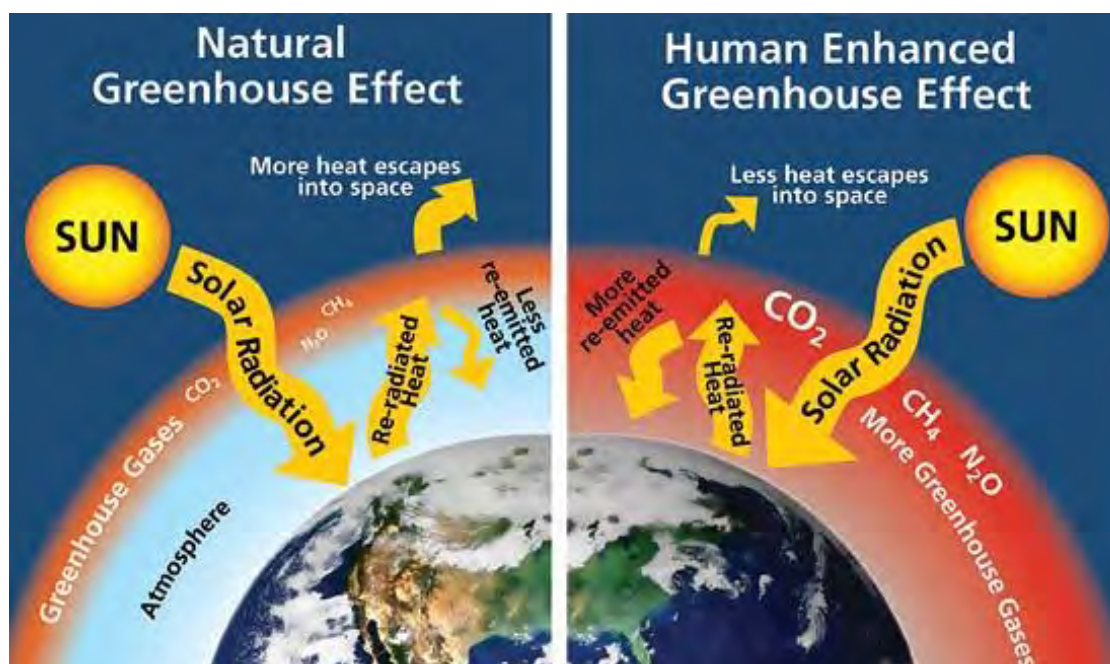


Figure 1.5-4. Schematic Diagram of the natural greenhouse effect and the human enhanced greenhouse effect.

The main greenhouse gases that are causing climate change include carbon dioxide and methane. The current increase in GHG amounts in the atmosphere are unequivocally linked with human activities. Since the 1800s, human activities have injected vast amounts of carbon dioxide into the atmosphere, primarily due to the burning of fossil fuels like coal, oil and gas for heating and transportation. Clearing land and cutting down forests also release carbon dioxide. Agriculture, oil and gas operations are major sources of methane emissions. Energy, industry, transport, buildings, agriculture and land use are among the main sectors releasing greenhouse gases (Figure 1.5-5).

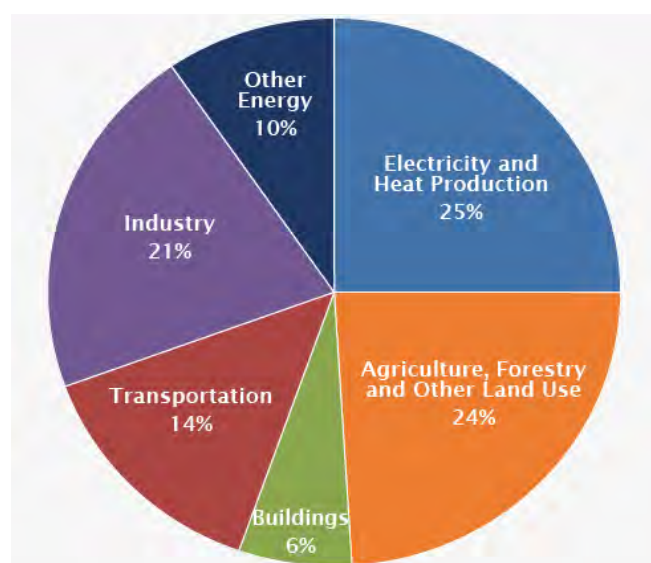
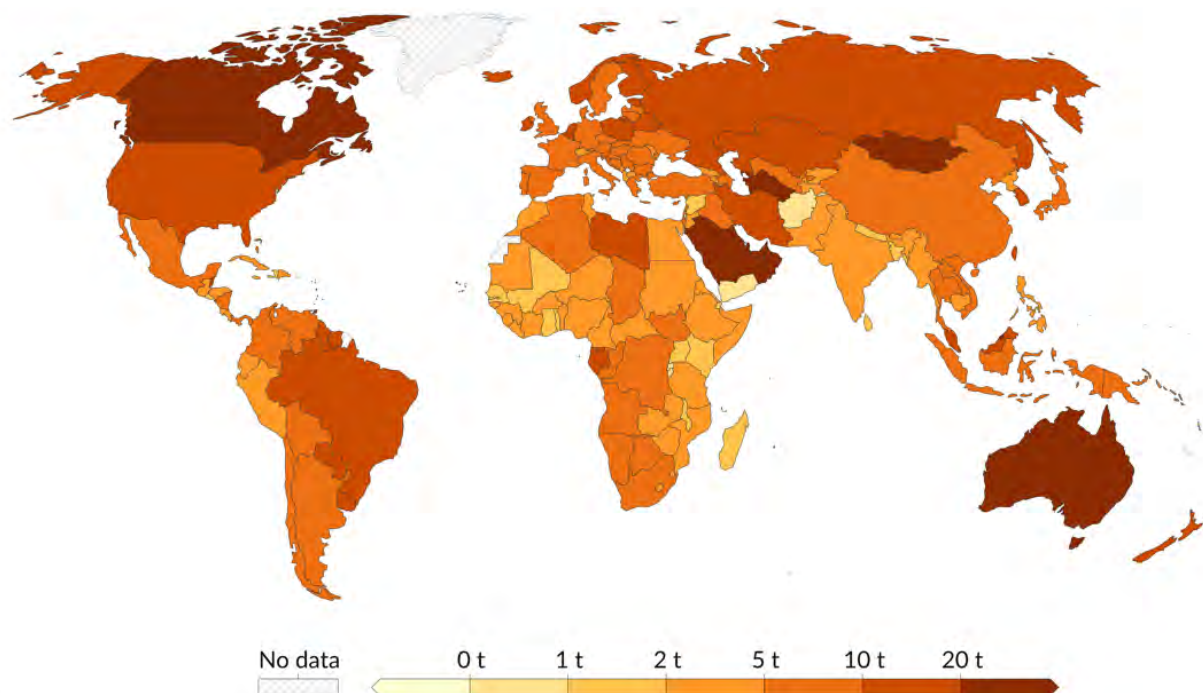


Figure 1.5-5. Global greenhouse gas emissions by economic sector. Source: IPCC (2014).

Due to differences in development and industrialization levels, different countries do not contribute equally to such emissions, with the contribution of developing countries per capita

(per person) being smaller (Figure 1.5-6). At the same, their economies being dominated by climate-sensitive sectors such as agriculture, they will be the most affected by climate change.



Data source: Jones et al. (2023); Population based on various sources (2023)

Note: Land-use change emissions can be negative.

[OurWorldInData.org/co2-and-greenhouse-gas-emissions](https://ourworldindata.org/co2-and-greenhouse-gas-emissions) | CC BY

Figure 1.5-6. GHG emissions per capita in 2021, in tonnes of CO₂ equivalents over a 100-year timescale. Source: <https://ourworldindata.org/grapher/per-capita-ghg-emissions?time=latest>

Global Warming or Climate Change?

Although people tend to use these terms interchangeably, global warming and climate change are not exact synonyms. “Global warming” refers to the rise in global temperatures due mainly to the increasing concentrations of greenhouse gases in the atmosphere. “Climate change” refers to the changes in climate over a long period of time linked with the increase in the energy of the climate system due to increase in concentrations of greenhouse gases in the atmosphere. These changes will affect precipitation, temperature, and wind patterns and more.

As we saw in Session 1.2.2, the energy in the ocean-atmosphere system and the differences herein are responsible for many processes within the climate system, such as ocean currents, movements of air masses, evaporation etc. It is easy to imagine that all these aspects will be affected by the increased greenhouse effect trapping more energy within the system. In fact, the additional energy in the system will not all be used to increase the global temperature, but will contribute to various climatic processes such as melting polar ice sheets, increase evaporation, increase the intensity of storms, and some of it can be stored e.g., in the ocean. Figure 1.5-7 illustrates the split of additional energy between various types of energy and processes within the climate system. If these different mechanisms were not at play and all the additional energy was transformed into temperature increase, our Earth would be much warming even faster.

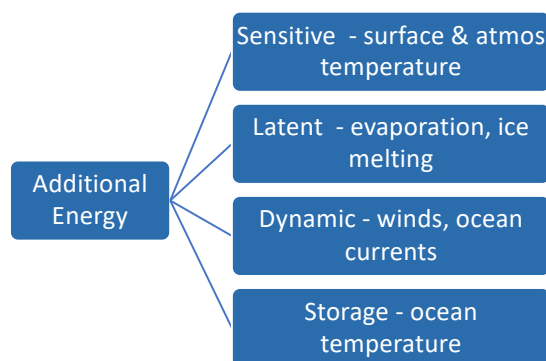


Figure 1.5-7. Schematic illustrative partition within the climate system of the additional energy linked with the increase in greenhouse gases in the atmosphere.

Exercise



- The current climate change is caused by the increase of the amount of GHG in the atmosphere. Thinking about the Yucatan Meteorite: which of the meteorite impacts had similar effect? What is the difference between that event and the current climate change mechanism?
- Looking at the map of average temperatures in Kenya (Figure 1.2-2) what are the minima and the maxima? Section 1.5 stated that the natural greenhouse effect maintains the global temperature at 15°C. Does this temperature match what you see in Kenya? If not, how can you explain the differences?
- Which of the terms 'Global Warming' or 'Climate Change' applies to what will happen in Kenya in the coming decades?

The impacts of current climate change

How is climate change predicted?

To predict climate over the next 100 years or so., scientists use General Circulation Models, like the ones described in Session 1.4, Figure 1.4-2. The models are essentially like mini-laboratories, where different scenarios can be tested. Because they will simulate climate over a very long period of time, these models are first tested by simulating climate observed over the past 100 years. If they successfully simulate the main characteristics of past climate, such as average global temperature and the amplitude of its variation, like the ones in Figure 1.3-6, the models are instructed to increase the GHG concentration in the atmosphere according to anticipated emission rates.

Considering the exact future GHG emission rates are not known and highly depend on the way various societies develop in the future, five possible scenarios of GHG increase are tested, describing broad socioeconomic trends that could shape future society (called shared socioeconomic pathways or SSP), intended to span the range of plausible futures. They include: a world of sustainability-focused growth and equality (SSP1); a "middle of the road" world where

trends broadly follow their historical patterns (SSP2); a fragmented world of “resurgent nationalism” (SSP3); a world of ever-increasing inequality (SSP4); and a world of rapid and unconstrained growth in economic output and energy use (SSP5).

These shared socioeconomic pathways, in turn, lead to different scenarios of climate evolution and a range of possible outcomes. Note that: As in the case of seasonal forecasts, climate change projections are not about predicting a sequence of weather events but about their statistics and how they can vary over time. The models are imperfect and only capture the reality to a certain degree. Thus, climate change projections should not be taken at face value at a given location but as indications of probable outcomes. In addition, different models may have different strengths and weaknesses capturing various climate phenomena, as for seasonal forecasts, it is best to consider outcomes provided by a range of models. Therefore, probabilistic approaches and ranges of outcomes should always be considered.

However, despite the caveats above, with appropriate approaches we can have confidence in climate change projections and models because of their physical basis, and their skill in representing observed climate and past climate changes. Models have proven to be extremely important tools for simulating and understanding climate, and there is considerable confidence that they are able to provide credible quantitative estimates of future climate change, particularly at larger scales. Figure 1.5-8 provides the latest projections of global mean surface temperatures, according to various development scenarios. Note that the extent of future climate change depends on what we do now to reduce greenhouse gas emissions. The more we emit, the larger future changes will be and some scenarios project an increase on global temperature on the order of 5 °C, much greater than the increase observed over past 100 years, and represented in Figure 1.3-6, leading to uncharted territories for local climate.

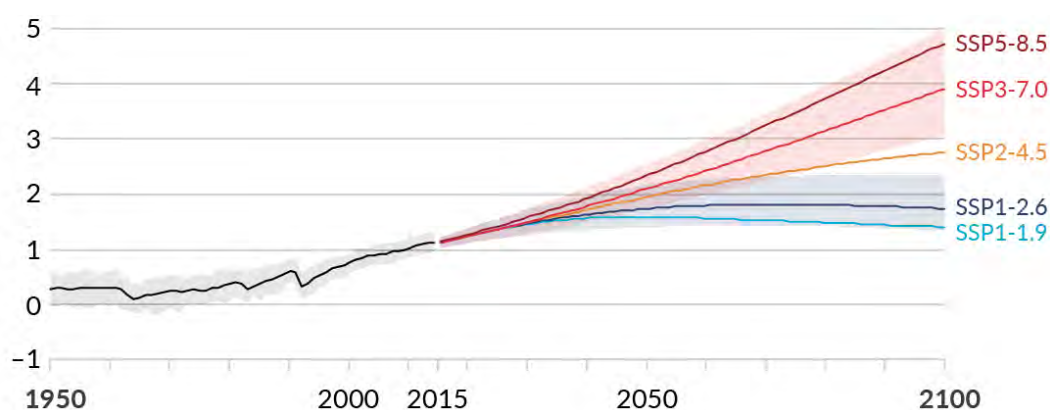


Figure 1.5-8. Observed and simulated global surface temperature change (°C) relative to the 1850-1900 mean temperature for the different SSP emissions scenarios, IPCC, AR6

Global impacts of climate change

The changing climate impacts society and ecosystems in a broad variety of ways. For example, climate change can alter rainfall, influence crop and fish yields, affect human and animal health, cause changes to forests, water bodies and other ecosystems, and even impact our energy supply. Climate-related impacts are occurring across the countries and over many sectors of

our economy and reviewing them all is beyond the scope of this course. In this session we will touch upon two important aspects of climate impacts-related results: the work of the IPCC and the changes to the water cycle.

Climate change impacts at local level

While there are many findings and analyses for many regions of the globe within the IPCC reports, the type of analysis necessary to assess potential impacts of climate change local level, with the granularity relevant to decisions at national or sub-national levels, needs to be done taking into account the high variability of climate, landscapes and livelihoods and other socio-economic factors that characterizes the location. Figure 1.5-9 illustrates the scale mismatch between the scale at which climate operate and the climate projections are made and the scale at which socio-economic operate.

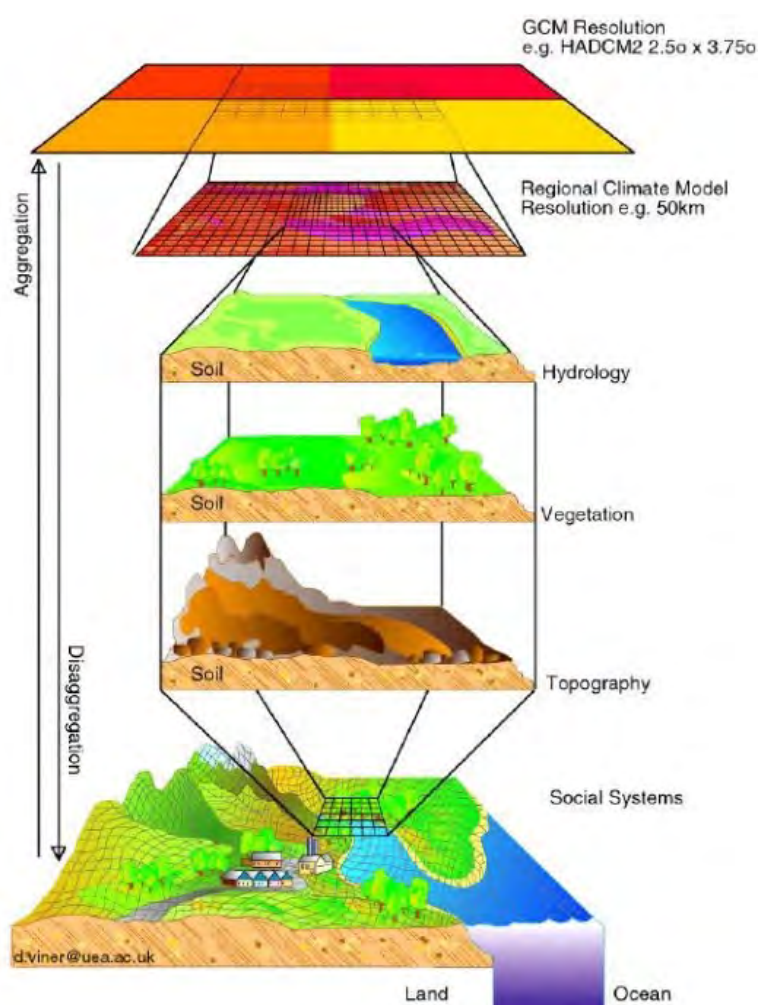


Figure 1.5-9. Schematic illustration of the scale of climate change models (top layer) vs the scale at which social systems operate and adaptation occurs. Intermediary layers show local data needed to “localize” projections. Source: David Viner, Climate Research Unit, University of East Anglia, UK (n/d).

The biophysical impacts of climate change, that can be obtained from climate and other biophysical components’ models are further compounded by socio-economic fragility of the country. Significant amounts of local information are necessary to ‘localize’ the projections, as illustrated by the intermediary layers of local factors.



Exercise

Figure 1.5-10 represents the variations of global surface temperature over past 20,000 years, together with projections for the next 100 year or so. Note that the temperature on the vertical axis is presented as anomalies with respect to late 19th century – beginning of the industrialization. Note also unequal intervals for time the time, on the horizontal axis, whereby the past and the next 100 years have the same spacing as 1000 or even 10,000 years earlier – this is important for reading the graphs.

- Have a look at the period going back approximately 10,000 from now. This is a period of relatively stable climate in recent Earth's history that allowed emergence of agriculture and establishment of human societies as we know them now. There were, however variations in Earth's surface temperature within this period. Identify the main 'warm' and cold periods on the figure. What were approximate global surface temperature anomalies during these periods?
- Have a look at the future 100 years. The dotted line represents projections.
 - ♦ What is the meaning of the three arrows?
 - ♦ Taking the middle global temperature increase, how much warmer is the global temperature projected to be with respect to today's temperature?
- Have a look at the end of the last Ice age that happen about 20,000-15,000 years ago.
 - ♦ What was the range of global temperature anomalies then?
 - ♦ How long did it take for the temperature to reach the zero line?
 - ♦ What would be the temperature increase over the same length of time if the temperature continues to increase at the rate projected for the next 100 years?
- Use the elements above to explain how unusual the current climate change is?

Climate change scepticism

A "climate sceptic" is someone who challenges or downplays the prevailing understanding of global warming, especially the notion that it's driven primarily by human actions. These individuals often believe that global warming is a natural and cyclical event. Some even argue that climate change might eventually yield positive outcomes or that technological advancements will eventually address the issue. More often than not, this climate scepticism stems from a lack of understanding, an unease about confronting unsettling realities, or a resistance to implementing stringent measures. It's worth highlighting misconceptions and falsehoods about the climate are rampant on social media platforms. It's crucial to be vigilant about the sources from which we glean information.

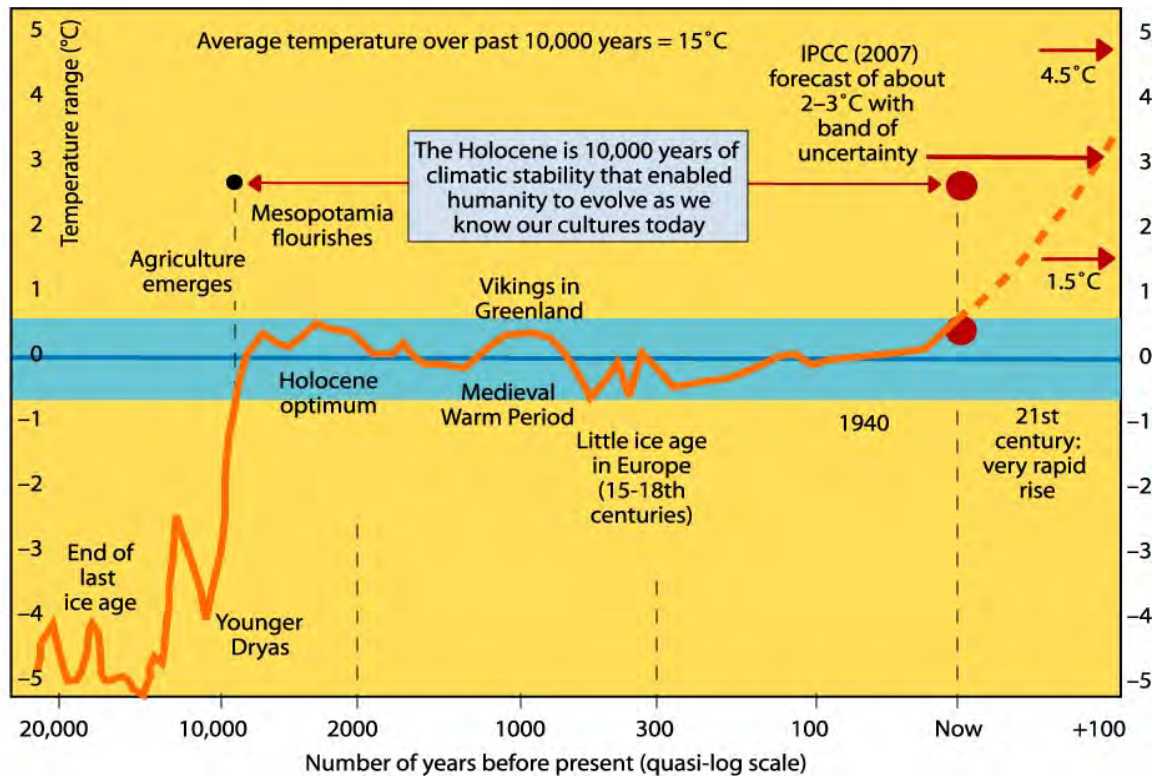


Figure 1.5-10. Reconstruction of the global Earth's surface temperature over past 20,000 years. Note the stable period over the last 6-8,000 years and the 4-5 degree C global mean temperature difference between the Last Glacial Maximum and the present.

Many of the climate-sceptic arguments rely on the fact that Earth's climate, including temperature and carbon dioxide content in the atmosphere, have varied in the past. While it's true that our planet has experienced several climate changes over its long history, the one we currently live in is faster and more violent than ever. In addition, it is directly caused by human activity - that was not the case before. Previous climatic variations had two main causes: (a) volcanic eruptions, which are responsible for cooling (by emitting particles into the atmosphere, which return sunlight); and (b) alternation between glacial and warm periods (approximately every 10,000 years). A change caused by the variation of the Earth's orbit relative to the Sun.

Current changes are not related to any of these phenomena. Climate scientists are certain that the primary reason for the increases in the atmospheric concentrations of carbon dioxide, methane and other greenhouse gases is because of human activity. There is no serious debate about this point in scientific circles, even though there is (unfortunately) a political and social debate about it in some regions of the world.

Below are a few of climate-sceptic's arguments and their rebuttals.

- *"The climate was warmer in the past, like in the Middle Ages."*

Drawing parallels with today is misleading. The warmth during this era was regional (Europe), not global. Furthermore, its impact pales in comparison to the climate changes we observe currently.

- *"There is no global warming, it's still cold!"*

It's crucial not to confuse weather with climate. Weather pertains to short-term atmospheric phenomena and aims to forecast conditions in specific locations over brief periods. In contrast, climate refers to statistics of weather and one cold event will not affect observed warming trends. Moreover, isolated instances of record low temperatures in a specific location over a short duration aren't indicative of overall climate trends. To gain a comprehensive understanding, you need to consider average temperatures globally.

- *"1°C is nothing, scientists are too alarmist."*

While a single degree might seem inconsequential to us, the ecosystems certainly feel the impact. Consider the minor shift required to change rain to snow, and vice versa. In addition, we are talking about 1°C global average which can translate to much more in certain locations, as well as to other consequences such as more frequent extreme rainfall and winds leading to flooding and other destruction, or prolonged droughts impacting food production etc.

- *"It doesn't matter, humans, fauna and flora are able to adapt!"*

Throughout history, climate variations have played a pivotal role in mass extinctions. It's an undeniable fact. Countless animal and plant species are already feeling the harsh impacts of the rapid climate shifts. Such swift changes don't afford them sufficient time to adapt, which in many cases would involve migration.

Humans aren't exempt from these challenges. While our adaptability may be superior, massive human migrations could become necessary. However, in today's world, this isn't a straightforward proposition. Habitats that remain suitable for habitation are tightly regulated by well-defined borders. This means that cross-border migrations have become far more complex than they might have been in ages past.

If we fail to anticipate and prepare for these shifts, the inevitable large-scale migrations could lead to heightened tensions at borders, potentially even escalating to armed confrontations.

- *"You can't even get weather forecasts right for a few days ahead, how can you pretend to predict climate?"*

With climate projections we do not predict individual patterns but general trends. Suppose we heat a pan of water; we know the water will get hotter, but we don't know where the bubbles will appear when it starts boiling. So, we can predict general trends even if sometimes we can't predict the exact detail.

- *"We're heading into an ice age."*

Ice age cycles are on the order of tens of thousands of years. Global warming will have consequences in the next couple of decades. We need to worry about the next 100 years, and not hope that an ice age in over 10,000 years will solve our looming problems.

- *"Solar cycles cause global warming."*

While it is true that Sun's activity and emitted radiation vary over time, in recent decades, the sun has been slightly cooling & is irrelevant to recent global warming.

Climate Change Adaptation and Mitigation

Two concepts are important to distinguish when talking about climate change: *adaptation* and *mitigation*. Climate change adaptation means adjusting to the effects of climate change, while climate change mitigation means reducing the causes of climate change. Mitigation and adaptation are complementary strategies that work together to protect people from climate change. However, mitigation actions will take decades to affect rising temperatures, so adaptation is necessary now. The less we mitigate today, the more adaptation we'll need later, and adaptation will become less effective. Both are necessary to protect people and the planet from climate change.

Climate change adaptation

Climate change adaptation is the process of adjusting to the effects of climate change. This can include changing. Climate change adaptation refers to the process of adjusting practices, systems, and structures to minimize the negative impacts of climate change. It involves making changes to behaviors, systems, and ways of life to enhance resilience, ensuring communities can function despite climate challenges. Adaptation also includes planning for future risks associated with climate change. Overall, climate change adaptation helps reduce vulnerability and supports long-term sustainability in the face of environmental changes. Examples of climate change adaptation:

- *Agriculture*: Growing crops or varieties that are more tolerant to drought, heat, or flooding.
- *Infrastructure*: Building seawalls, flood defences, and climate-resilient infrastructure.
- *Planning*: Creating green spaces, improving water storage, and managing land to reduce wildfire risks.
- *Insurance*: Providing new insurance schemes for climate-related threats.
- *Early warning systems*: Developing systems to warn people of extreme weather events.
- *Ecosystem restoration*: Restoring natural ecosystems and wildlife habitats.
- *Building*: Using new building technologies and materials to withstand extreme weather.

Adaptation can happen at the local, national, and international levels. Adapting to climate change helps protect people, economies, and the environment. It also helps communities benefit from opportunities associated with climate change. Reducing emissions now (mitigation) can make it easier to adapt to the changes that are unavoidable.

Climate change mitigation

Climate change mitigation focuses on reducing or preventing the emission of greenhouse gases (GHGs) into the atmosphere, thereby lessening the extent of future climate change. It involves human interventions to decrease the sources of these gases, such as burning fossil fuels for energy, or enhancing the "sinks" that absorb them, like forests and oceans. Key mitigation

strategies include transitioning to renewable energy sources like solar and wind power, improving energy efficiency in buildings and transportation, adopting sustainable land use practices that protect forests and promote carbon sequestration, and developing and deploying carbon capture and storage technologies. Effective mitigation is crucial to limiting global warming and its associated impacts, requiring concerted efforts at individual, national, and international levels.

The examples in Table 1.5-1 illustrate the wide range of actions that can be taken to mitigate climate change. It's important to remember that effective mitigation requires a combination of approaches, implemented at all levels, from individual actions to international agreements.

Climate information for adaptation

In general, climate information needed to design adaptation plans will depend on the scope of the adaptation planning/analysis, ranging from initial risk screening and detailed risk analysis to assessing risk management options (Lu, 2011). While the issue of climate change brings about the notion of modifications of what is usually deemed to be steady and immutable, climate varies on a number of scales. Simply put, human activities as well as natural systems develop in response to such variations and can cope with a range of climatic conditions without serious damage. Figure 1.5-11 conceptualizes current climate variations and the coping range. Occasionally, climate variations exceed the coping range and the system is put under higher stress or severely damaged. If the frequency of such events is low, the system will progressively recover or reach a new state. Within such framework climate change means that severe impact events may happen more frequently, and/or events of unprecedented magnitude can occur, putting the system under more stress, potentially not recoverable.

Adaptation is aimed to alleviate or support the recovery from such damaging events. Note that high impact events in the future can occur more frequently due to any combination of:

- change in the average, keeping the amplitude of the variability the same (Figure 1.5-12a);
- change in the amplitude of variability, keeping the average the same (Figure 1.5-12b); or
- change in the frequency of rare events on one side of the distribution (Figure 1.5-12c).

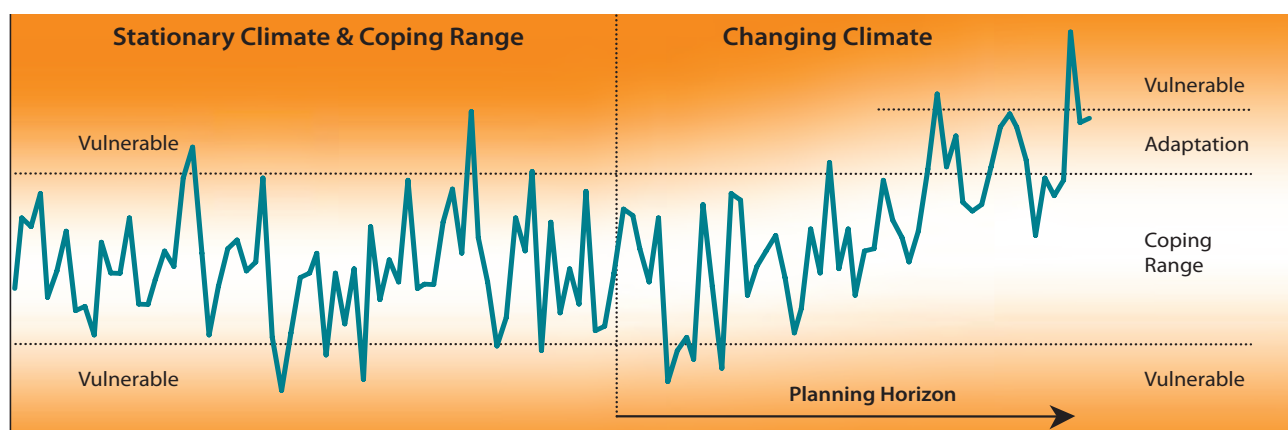


Figure 1.5-11. Conceptual illustration of historical and future climate, coping range and adaptation.
Source: IPCC (2007).

Table 1.5-1. Examples of climate change mitigation strategies.

Sector	Mitigation strategy
Energy Supply	Renewable energy sources: replacing fossil fuels (coal, oil, gas) with solar, wind, geothermal, and hydropower for electricity generation.
	Improving energy efficiency: using less energy to achieve the same output, through better insulation in buildings, more efficient appliances, and smarter grid management.
	Carbon capture and storage (CCS) technologies: capturing CO ₂ emissions from power plants and industrial facilities and storing them underground.
	Nuclear energy: as a low-carbon source of baseload power (though it has its own set of challenges).
Transportation	Electric vehicles (EVs) and plug-in hybrids, reducing reliance on gasoline and diesel-powered vehicles.
	Improving public transportation, making buses, trains, and subways more accessible and efficient.
	Encouraging cycling and walking for shorter distances, reducing reliance on motorized transport.
	Developing more fuel-efficient airplanes and ships, reducing emissions from international travel and shipping.
Land Use and Forestry	Protecting and restoring forests, as they absorb and store CO ₂ from the atmosphere through photosynthesis.
	Afforestation and reforestation: planting new trees and restoring degraded forests to increase carbon sequestration.
	Sustainable agriculture practices, such as reducing fertilizer use, improving soil management, and reducing food waste.
Industry	Improving energy efficiency in industrial processes, reducing energy consumption in manufacturing and other industries.
	Developing and using alternative materials, replacing high-emission materials like cement with more sustainable options.
	Reducing industrial process emissions, such as methane from oil and gas production and nitrous oxide from fertilizer production.
Waste Management	Reducing waste generation through reuse, recycling, and composting.
	Capturing methane from landfills, and using it as a source of energy.

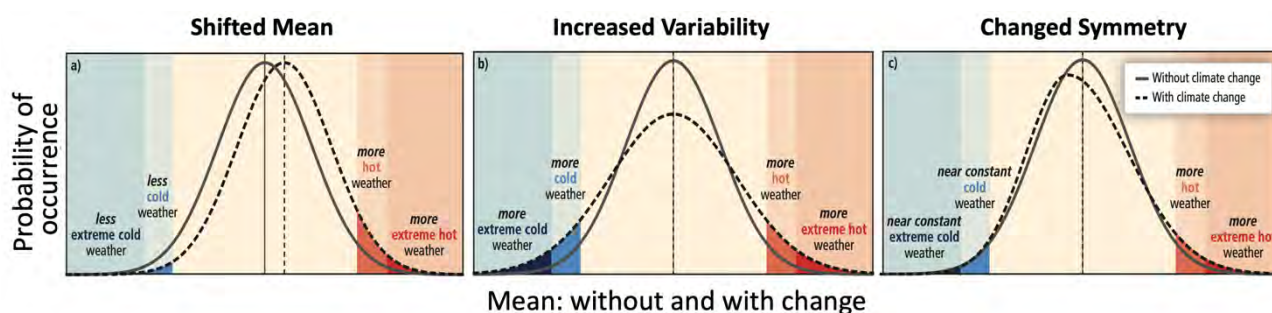


Figure 1.5-12. The effect of changes in temperature distributions between present and future climate on extreme values: (a) a simple shift of the entire distribution toward a warmer climate; (b) an increase in temperature variability with no mean shift; (c) an altered shape of the distribution, in this example a change in asymmetry toward the hotter part of the distribution. Source: IPCC (2007)

While designing adaptation plans and seeking climate information it is important to keep in mind the following elements:

Climate information vs. impacts information

Diverse past and projected statistics of meteorological data, as cited above and applied to rainfall, temperature, atmospheric moisture, solar radiation, wind etc. are climate information and should be available from Meteorological Services. Changes in crop yields due to variations in temperature, forecasts of areas flooded in a flash flood after heavy rain or changes in vector-borne disease incidence due to variations in temperature and rainfall, are usually beyond the mandate of climate information producers. Such information is usually co-developed with a given sector or decision maker, using impact models (e.g., crop models, hydrological or flood models, vector and disease models).

Uncertainty

The practitioners need to accept that information about future climate is provided with a certain level of uncertainty, inherent to projections of the future. This needs to be factored in the decision process. However, uncertainty does not mean that future climate is totally unknown or that projections are false. Moreover, uncertainty can be quantified and decisions can still be made. There are four main sources of uncertainty in climate projections:

- future levels of anthropogenic emissions and occurrence of natural phenomena (e.g., volcanic eruptions);
- imperfections of the climate models used to project changes in climate;
- imperfect knowledge of current climate that serves as starting point for projections; and
- difficulty in representing, thus reliably projecting, interannual and decadal variations.

Time horizon

The type of information needed will depend on the type of adaptation intervention or investment and, among others, on how far into the future the return on investment is expected. Figure 1.5-13 presents examples of different decision types as function of their time horizon. Larger infrastructure investments (irrigation, transportation network, dams, etc.) have usually

longer time horizons than individual decisions/investments such as cropping portfolio or farm planning. Time horizon of the intervention or investments will impact the precision with which the information can be provided. While the amounts of rainfall or the probability of long dry spell in the coming rainy season can be predicted with a certain degree of accuracy, only general tendencies in rainfall, with a wide uncertainty, can be provided for a horizon of 30 to 50 years. Information with such a range of uncertainty might not be suitable for farm planning. In addition, farming systems 50 years from now will most probably result from successive adaptation stages rather than from changes planned 50 years ahead of time. Furthermore, not all of these changes will be driven by climate, with global and local markets and economy, customer preferences etc. playing a significant role. Adaptation interventions other than large scale infrastructures generally focus on much shorter time horizons, more compatible with decisions at individual and community levels and project cycles. At such horizons, changes in climate might be less important than interannual variability, and even not significant. In addition, IPCC (2012) recommends focusing on measures that provide benefits under future climate scenarios but also under current climate, so called no-regret options, as valuable starting points for addressing potential future trends in climate. They have the potential to offer benefits now and lay foundation for addressing changes in the future. With respect to the conceptual frameworks, such approach expands the current coping range, irrespective of the direction that climate change is going to take.

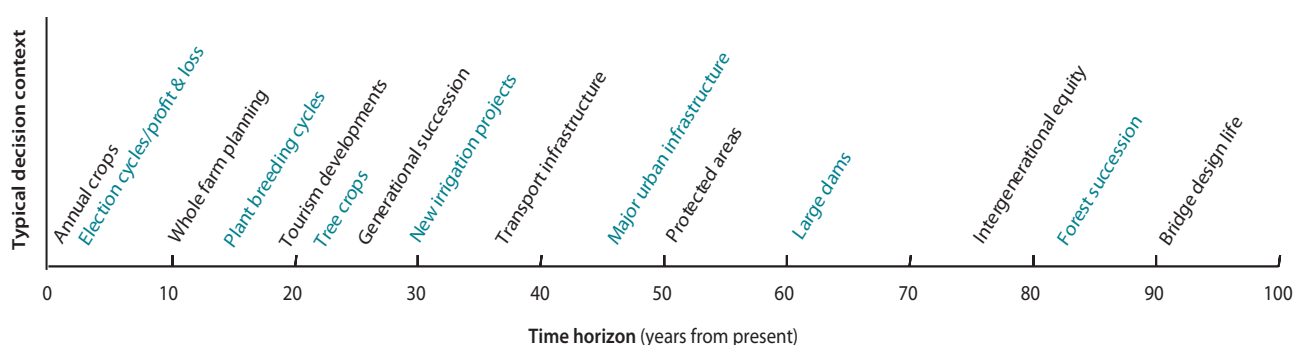


Figure 1.5-13. Adaptation decision contexts and their associated time horizons. Source: Lu, 2007

Figure 1.5-14 presents a more complete continuum of horizons, including shorter time scales, and related adaptation applications. Note that the ability to provide climate information ahead of time for horizons shorter than several decades derives from drivers that are different from anthropogenic emissions, and that different time-scales have different drivers and different data needs. Thus, the issue of adaptation to climate change requires focusing on data collection and climate information not only for the distant future.

Appropriate use of climate information for adaptation

The climate is inherently uncertain, and this won't change even with better science. We need to learn how to deal with it, especially for long term planning, where the uncertainty is the greatest. Climate models have limits and there is a need to use them in a smart way, while also dealing with uncertainty. While climate projections and studies can help, decisions shouldn't depend on them alone.

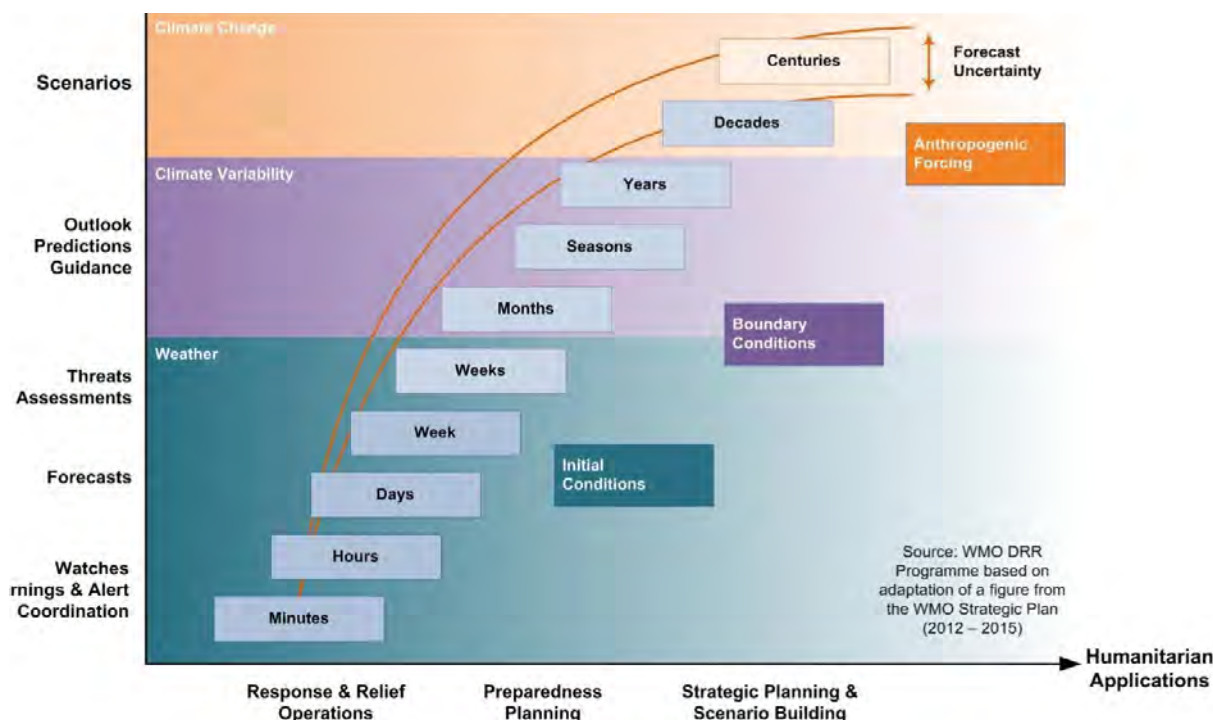


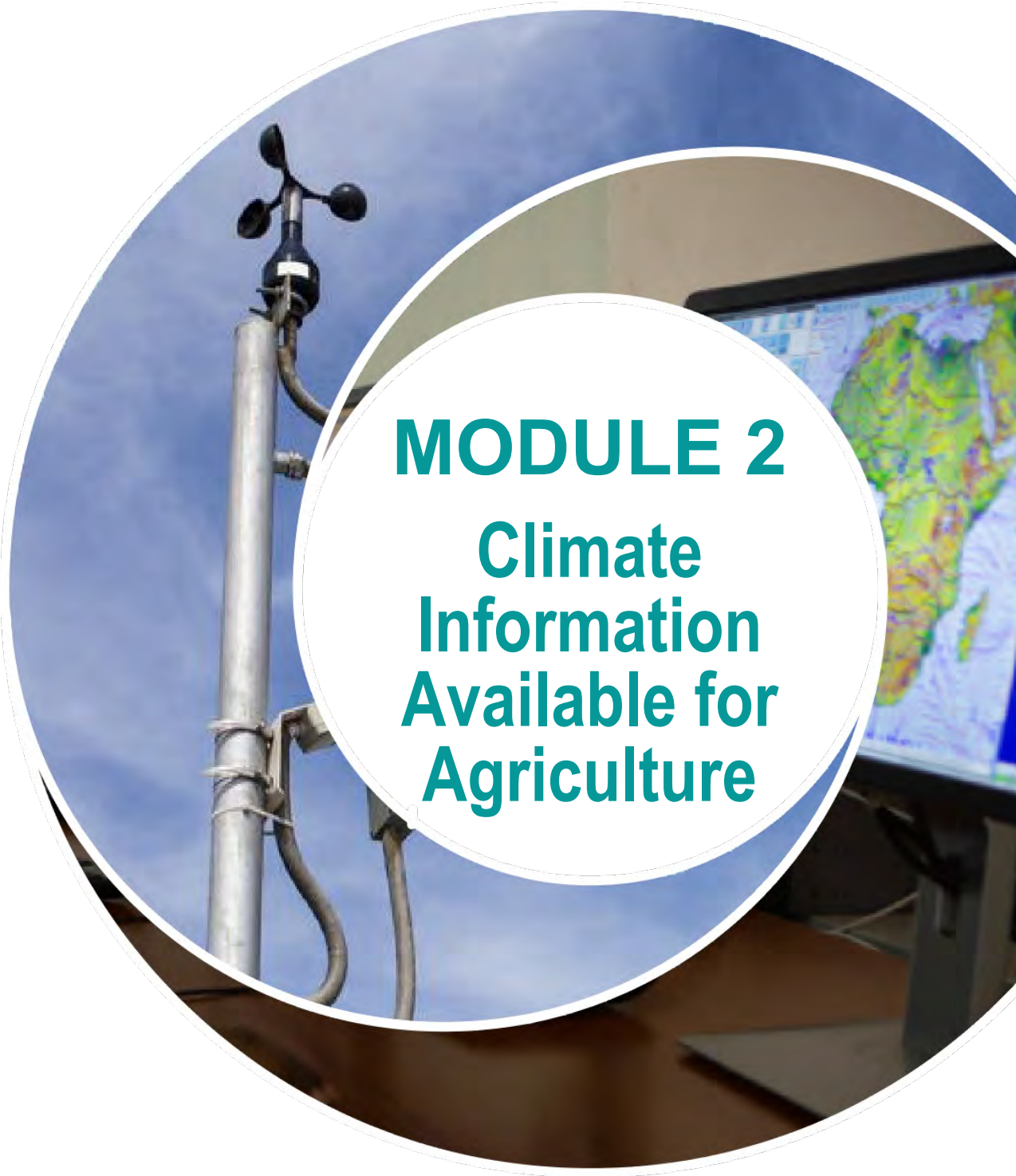
Figure 1.5-14. Schematic diagram showing the relationship between climate timescales and emergency and adaptation mechanisms. Source: *Mason et al. (n.d.)*, adapted from *WMO (n.d.)*.

Experts now recognize the risks of designing adaptation strategies around projected future climate conditions and impacts – sometimes referred to as a “top-down” or “predict-then-act” approach. Preferred approaches start with the adaptation decision and available options, and aim for flexible, practical solutions that could handle the range of plausible future climate conditions. They include (Walker et al., 2013):

- *Robustness*, which aims for outcomes that are acceptable across a wide range of plausible future climate conditions;
- *Resilience*, which aims to build capacity and mechanisms to anticipate, absorb, and recover quickly from shocks or stresses;
- *Flexibility*, which involves reassessing and adjusting plans as conditions change.
- *Resistance*, by over-designing critical infrastructure to withstand extreme events – but this can be expensive.

Self-Check

1. What is greenhouse effect? Is it natural or man-made? Why is it important for Earth's climate?
2. What is the difference between 'global warming' and 'climate change'?
3. What is the main cause of climate change?
4. What are the main likely impacts of climate change in Kenya?



MODULE 2

Climate Information Available for Agriculture

MODULE 2 | CLIMATE INFORMATION AVAILABLE FOR AGRICULTURE

Module 2: Climate Information Products and Tools Available for Agriculture provides an overview of relevant weather and climate information products and services that are, or will soon be, available through the Kenya Meteorological Department (KMD), Kenya Agricultural and Livestock Research Organization (KALRO), National Drought Management Authority (NDMA), and International Livestock Research Institute (ILRI). It teaches participants how to navigate, interpret and use relevant historical, monitored and forecast information products available through KMD's web page and the interactive online climate information Maproom products. It also provides information on other tools in agriculture including the Kenya Ag-Data Hub, the Kenya Agriculture Observatory Platform (KAOP), and specialized forecast and advisory bulletins.

By the end of this module, you will be able to:

- Understand agriculture-relevant products and services available through KMD, MoALD and NDMA web pages.
- Navigate KMD Maproom products.
- Interpret and use relevant information products from KMD website and Maproom, NDMA, and KAOP.

Session 2.1. Overview of Products Available for Agriculture and Livestock in Kenya

As a mandated government institution, Kenya Meteorological Department (KMD) regularly provides weather and climate information for different users and sectors, the main one being that of agriculture. This information is provided through different channels that includes newspapers, television, radio, weather bulletins, emails, social media, word of mouth, and through its web page. This session provides an overview KMD's ENACTS (Enhancing National Climate Services) Maproom products.

At the end of this session, you will be able to:

- Identify relevant climate information products available through KMD's web page.
- Describe the main content of relevant bulletins available from KMD and NDMA.
- Explore Kenya Agricultural Observatory Platform (KAOP).
- Describe Kenya's Agriculture Data Hub (AgDataHub).

KMD Online Products

As a mandated government institution, Kenya Meteorological Department (KMD) regularly provides weather and climate information for different users and sectors, the main one being that of agriculture. The most important weather and climate information products made available through KMD's web page⁴ include the following:

- Daily weather forecasts;
- Five-day weather forecasts;
- Weekly forecasts (7-day weather forecast)
- Monthly rainfall forecasts;
- Seasonal rainfall forecasts;
- Historical climate data;
- Dekadal (i.e., 10-daily) Agrometeorological Bulletin;
- Weekly Biometeorological Bulletin; and

⁴ <https://meteo.go.ke>

- advisories and alerts for extreme climate events like droughts and floods.

Some of this information is also disseminated through other channels including: newspapers, television, radio, weather bulletins, emails, social media platforms, and Barazas and other community gatherings.

KMD's Agrometeorological Bulletin

Kenya Meteorological Department's ten-daily agrometeorological bulletin⁵ provides summaries on weather conditions, rainfall patterns, and their impacts on agriculture across different regions in Kenya. The bulletin typically includes detailed data on rainfall distribution (Figure 2.1-1), temperature variations (Figure 2.1-2), and the condition of crops and livestock. It highlights specific regional weather conditions affecting agricultural activities, such as dry or wet spells, and predicts potential impacts on crop and livestock health and productivity. This information aids producers and other local decision makers plan and manage agricultural practices effectively.



Figure 2.1-1. Spatial distribution of rainfall during 11-20 October, 2024. Source: KMD, <https://meteo.go.ke/forecast/agrometeorological-bulletins>, accessed 31 October, 2024.

⁵ <https://meteo.go.ke/our-products/dekadal-agrometeorological-bulletin/>

Rainfall departure from the expected. This is an analysis of seasonal cumulative rainfall against the long term mean as shown in Figure 2.1-2.

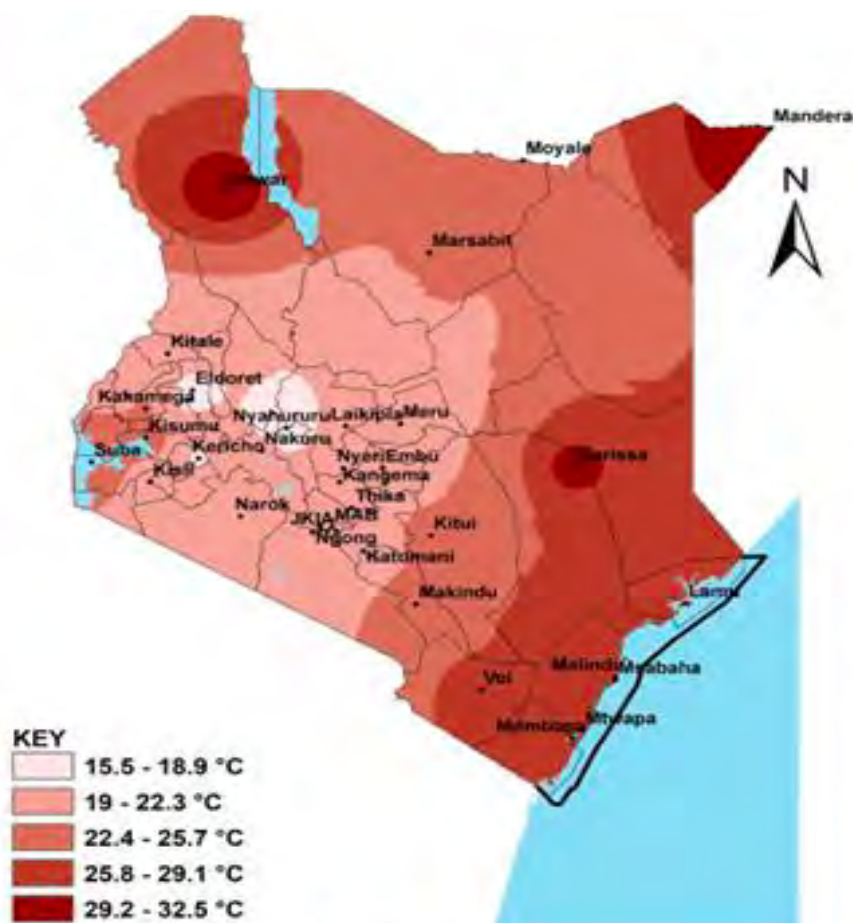


Figure 2.1-2. Spatial distribution of dekadal average temperature during 11-20 October, 2024. Source: KMD, <https://meteo.go.ke/forecast/agrometeorological-bulletins>, accessed 31 October, 2024.

Kenya Agricultural Observatory Platform (KAOP)

The Kenya Agricultural Observatory Platform (KAOP)⁶ is an integrated digital platform designed to provide agricultural data and climate information to support decision-making in Kenya's agricultural sector. KAOP aims to gather, analyse, and disseminate location-specific climate and agricultural information from various sources. It integrates information to produce tailored advice on crop varieties, suitable fish species, soil preparation, sowing rates and times, irrigation, fertilization, pest and disease control, harvest timing, and storage options. KAOP is available as both a mobile application and a web application. Figure 2.1-3 shows an example of a location-specific advisory from the KAOP website. AICCRA, KALRO, and the Kenya Meteorological Department have collaborated to upgrade and expand KAOP, integrating ward-level weather forecasts, and strengthening back-end data processing capabilities (Akshatha and Dhulipala, 2023).

⁶ <https://www.kaop.co.ke/>

The screenshot displays the Kenya Agricultural Observatory Platform (KAOP) interface. At the top, the KAOP logo and name are on the left, and a 'Home' link is on the right. Below the header is a large image of a field with a red location pin icon in the top right corner. A search bar with three dropdown menus is present: 'Select county' (Machakos), 'Select constituency' (Machakos), and 'Select ward' (Township), followed by a 'Submit' button. Below the search bar is a navigation menu with five options: 'Weather', 'Agronomic advisory' (highlighted in yellow), 'Market information', 'Pests', and 'Livestock advisory'. On the left side of the main content area is a 'Value chains' sidebar with a list of crops: Maize (highlighted), Finger millet, Onion, Sorghum, Mango, Goat, Napier, Banana, Green Grams, Honey, Passion Fruit, Improved Chicken, and Beans. The main content area is titled 'Maize' and contains four sections: 'Site selection' (advising a site away from shade and roads), 'Land preparation' (advising on manure and fertilizer), 'Pre-planting' (advising on certified seeds), and 'Varieties' (advising on seed acquisition through KEPHIS or agro-dealers). Each section has a 'Read more' button.

Kenya Agricultural Observatory Platform
KAOP

Home

Select county
Machakos

Select constituency
Machakos

Select ward
Township

Submit

Weather Agronomic advisory Market information Pests Livestock advisory

Value chains

- Maize
- Finger millet
- Onion
- Sorghum
- Mango
- Goat
- Napier
- Banana
- Green Grams
- Honey
- Passion Fruit
- Improved Chicken
- Beans

Maize

Site selection

Select a site away from shade to allow for sufficient sunshine and should be at least 10 meters away from the road to prevent dust and vehicle fumes

Read more

Land preparation

Add manure and fertilizer with recommendations from soil testing and analysis

Read more

Pre-planting

Common planting materials include certified seeds and farmer saved seeds

Read more

Varieties

Best variety and quality seed can be acquired through KEPHIS USSD service or Seed Sector Platform Kenya or from certified agro-dealers

Read more

Figure 2.1-3. Example of location-specific advisory from KAOP. Source: <https://kaop.co.ke/advisory/agronomic/-1.5113801964/37.2799198903>, accessed 30 October 2024.

Kenya AgDataHub

The *Kenya AgDataHub* is a digital platform that is being developed through the AICCRA project (Dhulipala et al., 2022). The platform is meant to serve as a national scale agriculture and climate data hub, and a digital aid for the integration of climate and weather data into agriculture decision making from national to farm levels. The primary target users of the AgDataHub are agricultural research organizations and public and private agricultural extension providers who are responsible for creating weather-related agricultural advisories for crops and livestock. The AgDataHub is expected to also assist agricultural financial service providers, such as banks, lenders and insurance companies to quantify and manage risk, and improve productivity and profitability. It will connect to databases and platforms of a range of meteorological, agricultural and statistical information providers, and provide a common entry point for users to access a range of information to support agricultural decision making across levels. The AgDataHub is therefore not a new agricultural data collection or statistical system, but a brokering platform between the providers and users of data. The platform will integrate agriculture and climate-related data into user-friendly dashboards and decision support tools. The AgDataHub will also be embedded with a mobile application that can be configured to assist organizations in data collection and management. In Kenya, the AgDataHub is being implemented jointly by KMD and the Kenyan Agricultural and Livestock Research Organization (KALRO), and integrated with the Kenya Agricultural Observatory Platform (KAOP).

Specialized climate information for animal agriculture

Vegetation and surface water resources

Satellite remote sensing provides an effective way to monitor rangeland quality and productivity, and availability of surface water resources. Real-time information about vegetation and surface water resources, interpreted in the context of historical analyses of seasonal cycles, variability and trends, provides useful information for managing climate related risks in extensive livestock systems, and particularly pastoralism.

The Kenya National Drought Management Authority (NDMA), established in 2016, is mandated to provide products and services to prevent or mitigate drought emergencies. NDMA issues monthly Drought Early Warning Bulletins (DEWBs) for arid and semi-arid counties⁷ that include:

- *Vegetation Condition Index* (VCI), a satellite remote sensing proxy for rangeland conditions;
- monitored and historical rainfall data;
- crowd-sourced information about pasture and browse vegetation conditions, and surface water resources for livestock and people;
- surveillance information about crop and livestock conditions and prices; and
- household wellbeing indicators covering income, and health and nutrition status.

⁷ <https://knowledgeweb.ndma.go.ke/Public/Resources/CountyBulletins.aspx?ID=11>

NDMA's DEWBs include advisories for addressing drought-related hazards to agriculture, livestock, and human welfare. Extensive livestock systems are a particular focus, since this is the dominant livelihood in the arid and semi-arid regions that NDMA is mandated to serve.

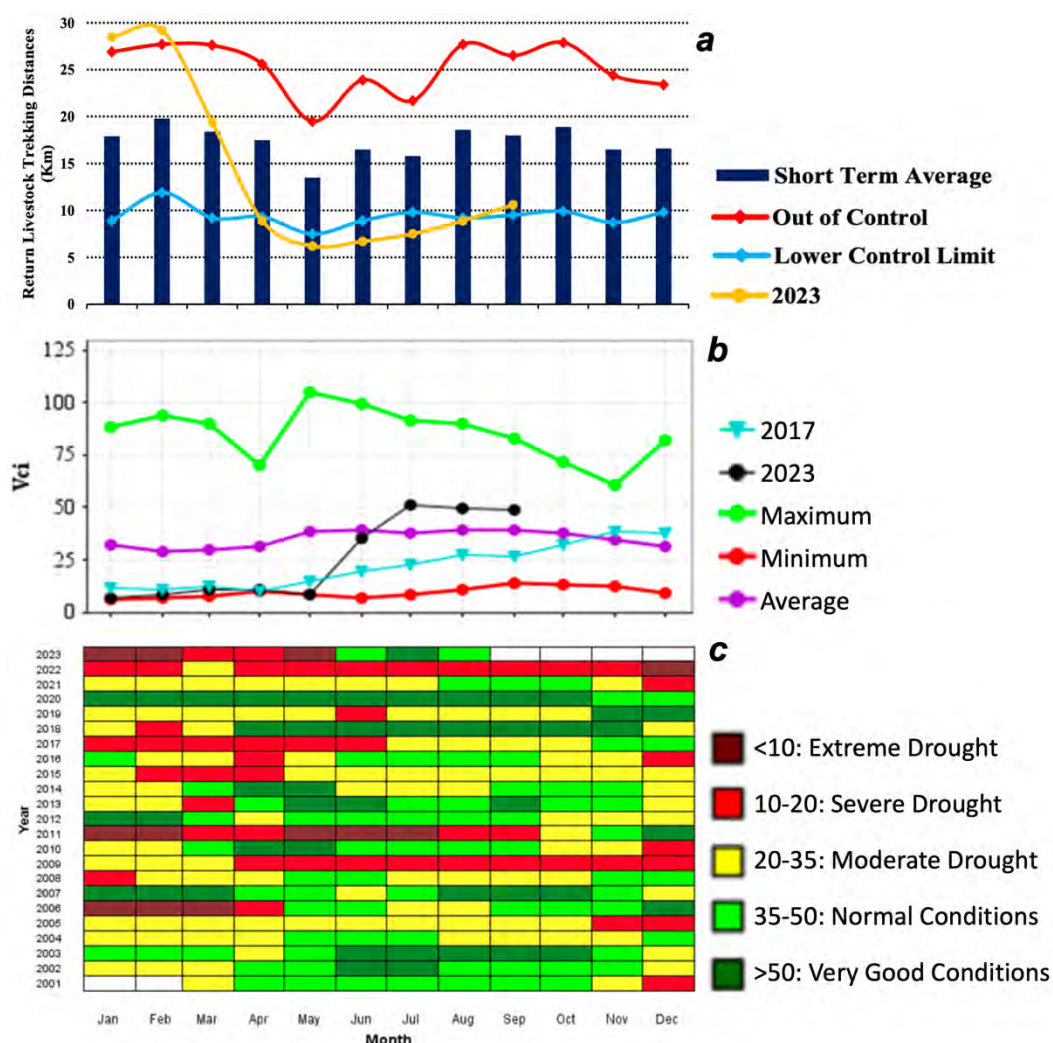


Figure 2.1-4. Examples of monthly pastoralist resource information in DEW Bulletin: (a) VCI in current year compared with historical ranges and reference year; (b) historical drought categories based on VCI; and (c) average livestock trekking distance to nearest watering point. Source: Marsabit DEW Bulletin September 2023, <https://knowledgeweb.ndma.go.ke/Public/Resources/ResourceDetails.aspx?doc=8d859dba-db98-4802-b91a-4fcfa156a9e6>, accessed 20 Oct 2025.

Vegetation remote sensing information is or has been available from a variety of non-governmental and international sources. Platforms with products tailored to pastoralists' needs in East Africa, such as: SERVIR East Africa (a joint project of NASA and USAID), and Predictive Livestock Early Warning System (PLEWS, a project of FAO and Texas A&M University) (Matere et al., 2020) have unfortunately been dependent on project funding that has not continued.

Heat stress

Livestock both in intensive and extensive open grazing are susceptible to extreme heat stress, due to the rising climatic temperature, humidity and solar radiation. Heat stress occurs when environmental conditions cause an increase in animal's body temperature above the normal

range, impacting overall health and their productivity. The frequency of heat stress for different livestock species is tied to warming caused by climate change, and is projected to increase significantly across the East African drylands, especially among the livestock species with less thermoregulatory abilities (Rahimi et al., 2021; Thornton et al., 2021).

KMD's Weekly Biometeorological Bulletin⁸ provides information that is relevant to heat stress in the form of locations that recorded average temperatures exceeding 35°C in the preceding 7 days. However, in addition to air temperature, heat stress is influenced by short wave solar radiation absorbed by unshaded animals, and by the influence of humidity and wind on evaporative cooling. The most useful meteorological heat stress indexes combine, at a minimum, air temperature and humidity. Heat stress monitoring and early warning systems are relatively advanced in developed countries, but (at the time of writing) have yet to be operationalized at a national level in Kenya and across East Africa's drylands. Livestock heat stress, and the widely-used Temperature-Humidity Index (THI), are discussed further in Session 3.1.

Fisheries hazards

Impacts of climate risk on land-based agricultural livelihoods are experienced largely through crops, animals and the ecosystems they depend on. In the case of open water fisheries in the Indian Ocean and Lake Victoria, on the other hand, weather hazards directly threaten the safety of fisher folk. KMD issues two forecast bulletins that are focused on open water fisheries safety.

The KMD Lake Victoria Fishing Forecast is a daily bulletin that provides forecasts of wind and wave conditions, rain and thunderstorm activity, cloud cover and visibility. Eastern Lake Victoria is divided into three zones: Open Lake Siaya and Busia; Open Lake Homa Bay and Migori, and Gulf of Winam. Forecasts and alerts cover 6-hour periods over the next 24 hours. Colors summarize degree of meteorological hazard:

- *Green*: No severe weather is expected.
- *Amber*: Potentially dangerous weather is expected. Be prepared.
- *Red*: Dangerous and potentially life-threatening weather conditions are expected. Take immediate action to ensure your safety.

The KMD The Marine Forecast bulletin summarizes hazard conditions (color coded), and provides:

- 7-day forecast wind and wave conditions off the Kenya coast and neighbouring Western Indian Ocean, presented as maps and text;
- Daily high and low tide schedule and heights; and
- 9-day ocean current forecasts.

⁸ <https://meteo.go.ke/our-products/weekly-biometeorological-bulletin/>

Session 2.2. KMD's ENACTS Maproom: Historical Climate

This session provides an overview KMD's ENACTS (Enhancing National Climate Services) historical climate Maproom products. The ENACTS Maproom is a collection of interactive maps and other graphs that enable users to generate information on past, present, and future climate. The Maproom is dynamic in that the maps and figures are generated by the user instantly, as the maprooms are linked to the original climate data. Users can focus on specific areas of interest with information extraction and summarization capabilities. This session presents historical analyses available in the Climate Analysis and the Climate and Agriculture Maprooms.

At the end of this session, you will be able to use maprooms products to:

- Characterize the climate of Kenya in terms of seasonality, extremes, and trends.
- Explain the effect of different phases of ENSO on rainfall over different parts of Kenya.
- Identify historical onset and cessation dates over different parts of the country.

The Climate Analysis Maproom

The Climate Analysis Maproom provides information about past climate, such as rainfall and temperature quantities at any point, at national or subnational levels. Historical climate data could be used in many different ways that help us understand the drivers of observed climate variability and change. For example, it could help in determining whether observed changes in agricultural productivity are linked to variations in climate or some other factor, such as soil degradation. It can also support informed decision-making in agricultural practices. For instance, historical climate information can help in deciding on appropriate times for land preparation, selection of seed or animal breeds, planting, weeding, application of fertilizer, and control of pests and diseases.

Inside the Climate Analysis Maproom

The Climate Analysis Maproom is the most extensive maproom as it consists of several sub-maprooms (or products) that allow analysis at different timescales (daily, dekadal [10-day],

monthly and seasonal). Analysis of historical climate data in this maproom include the following (Figure 2.2-1):

- Daily, dekadal, and monthly rainfall analysis;
- Seasonal mean, trends, and probability of extremes;
- ENSO/IOD analysis;
- Standardized Precipitation Index (SPI).

There are tabs, common to all maprooms, that provide description of the product you are exploring, some information about the datasets used to generate the products, explanations of the common tabs used to navigate the products, and contact information of developers (Figure 2.2-2). The “Description” tab provides some information about the maproom products one is looking at. “Data Documentation” describes the data used to create the maprooms. “Instructions” provide explanations of some useful buttons. “Contact Us” provides contact info for the institution or person managing the maproom (in this case KMD).

Monthly Climate Analysis

The monthly analysis allows users to view rainfall; maximum, minimum and mean temperature; monthly climatology, seasonality, anomalies, and trends. The monthly analysis, which is based on 30-years of historical observation, may be used to characterize the climate of a locations including, spatial distribution of rainfall or temperature during a specific month (Figure 2.2-3), and seasonality (Figure 2.2-4).

Seasonal Climate Analysis

This sub-maproom allows users to view rainfall; maximum, minimum and mean temperature climatology; anomalies; and probability of exceedance at seasonal time scale. The user defines the season (in terms of constituent months). The analysis is presented as a mean in the map (Figure 2.2-5), anomalies (Figure 2.2-6), trends, and probability of exceeding a chosen threshold. Similarly, daily and dekadal precipitation analyses are generated in the same way as monthly rainfall analysis, using the Climate Analysis Maproom by specifying the required input (analysis).

Extreme Analysis

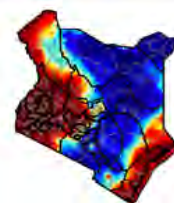
This interface facilitates the exploration of extreme monthly and seasonal rainfall and temperature characteristics. For rainfall, these characteristics include total rainfall, number of wet/dry days, rainfall intensity, and number of wet/dry spells. The user can define the season as well as the daily statistics of interest and then map the probability of having values above (exceeding) or below(non-exceeding) a user-defined threshold. The map (Figure 2.2-7) shows how likely or unlikely the selected threshold will be crossed. The user can also look at the variance or coefficient of variation for a quantity of interest to get a sense of the range of variability across years. Clicking on the map will then produce the probability of exceedance as well as the probability density function (PDF) graphs for the selected location (Figure 2.2-8).

Daily Precipitation Analysis

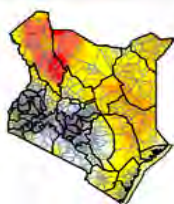
The Maproom explores historical daily precipitation by calculating simple seasonal statistics.

**Extreme Rainfall Analysis**

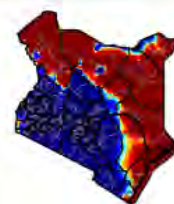
The Maproom facilitates the exploration of the history of extreme monthly and seasonal rainfall characteristics.

**Daily Temperature Analysis**

The Maproom explores historical daily temperature by calculating simple seasonal statistics.

**Extreme Temperature Analysis**

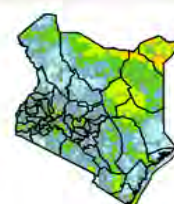
The Maproom facilitates the exploration of the history of extreme monthly and seasonal minimum and maximum temperatures.

**Dekad Climate Analysis**

Rainfall and temperature time series reconstructed from station observations and remote sensing proxies. This interface allows users to view rainfall, maximum, minimum and mean temperature dekadal climatologies and anomalies.

**Probability of Seasonal Rainfall Conditioned on ENSO**

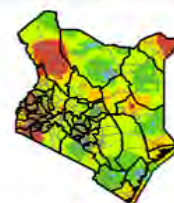
This map shows the historical probability (given in percentile) of seasonal average monthly rainfall falling within the upper (wet), middle (normal), or bottom (dry) one-third ("tercile") of the 1981-2014 historical distribution in the country given the state of ENSO (El Niño, Neutral, La Niña) during that same season.

**Monthly Climate Analysis**

Rainfall time series (1981-2022) and temperature time series (1981-2022) reconstructed from station observations, remote sensing and other proxies. This interface allows users to view rainfall, maximum, minimum and mean temperature monthly climatologies and anomalies.

**Probability of Seasonal Temperature Conditioned on ENSO**

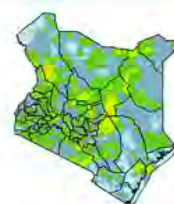
This map shows the historical probability (given in percentile) of seasonal average monthly minimum or maximum temperature falling within the upper (hot), middle (normal), or bottom (cold) one-third ("tercile") of the 1981-2014 historical distribution in the country given the state of ENSO (El Niño, Neutral, La Niña) during the previous season (e.g. Jan-Mar temperature against Oct-Dec ENSO state).

**Seasonal Climate Analysis**

Rainfall time series (1981-2022) and temperature time series (1981-2022) reconstructed from station observations, remote sensing and other proxies. This interface allows users to view rainfall, maximum, minimum and mean temperature seasonal climatologies, anomalies and probability of exceedance.

**Probability of Seasonal Rainfall Conditioned on IOD**

This map shows the historical probability (given in percentile) of seasonal average monthly rainfall falling within the upper (wet), middle (normal), or bottom (dry) one-third ("tercile") of the 1981-2014 historical distribution in the country given the Terciles of IOD (Positive, Neutral, Negative) during that same season.

**Seasonal Trend Analysis**

Rainfall time series (1981-2022) and temperature time series (1981-2022) reconstructed from station observations, remote sensing and other proxies. This interface allows users to view rainfall, maximum, minimum and

**Probability of Seasonal Temperature Conditioned on IOD**

This map shows the historical

Figure 2.2-1. The Climate Analysis Maproom



Figure 2.2-2. Useful tabs available for all maprooms.

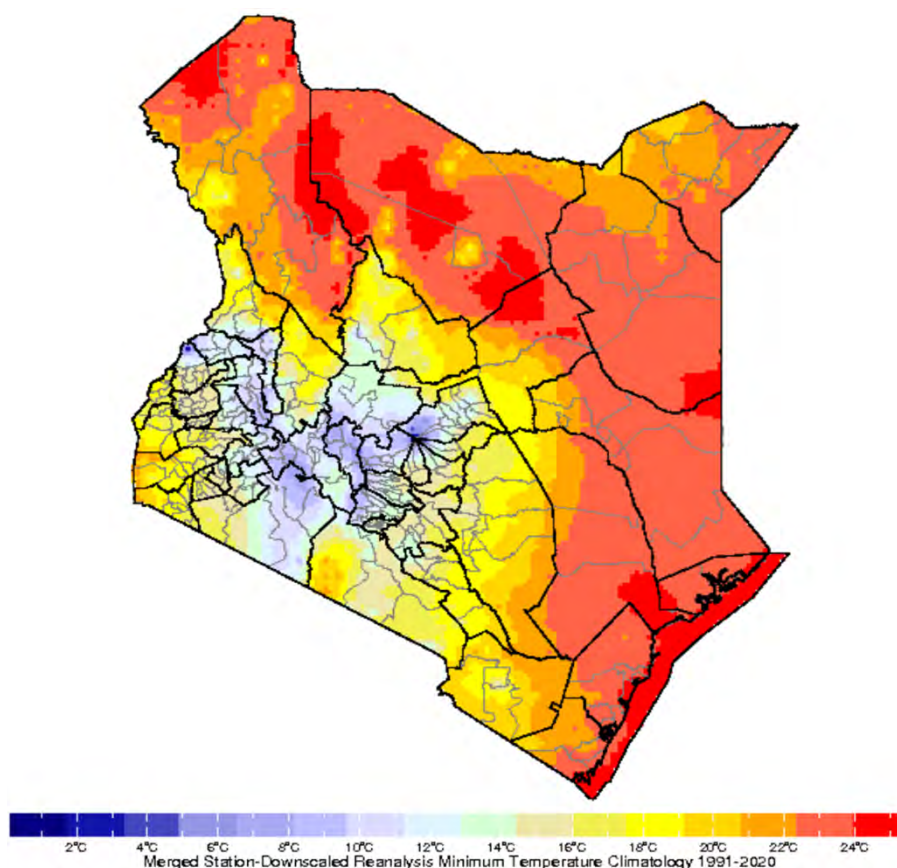


Figure 2.2-3. Climatology (normal) of minimum temperature during the month of January. Bluish colours show colder temperatures while orange and red colours show warmer temperatures. It is clear that the spatial pattern of temperature follows that of elevation.

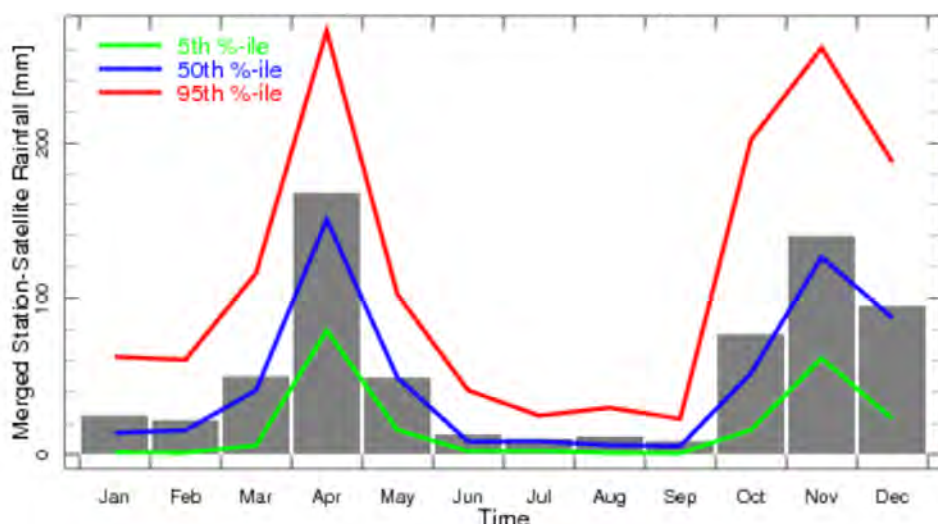


Figure 2.2-4. Graph generated in the Climate Analysis Maproom showing rainfall seasonality for central Kenya, showing the two distinct seasons. The bars show the mean rainfall (climatology) for each month, while green, blue and red lines show, the 5th, 50th, and 95th percentiles, respectively.

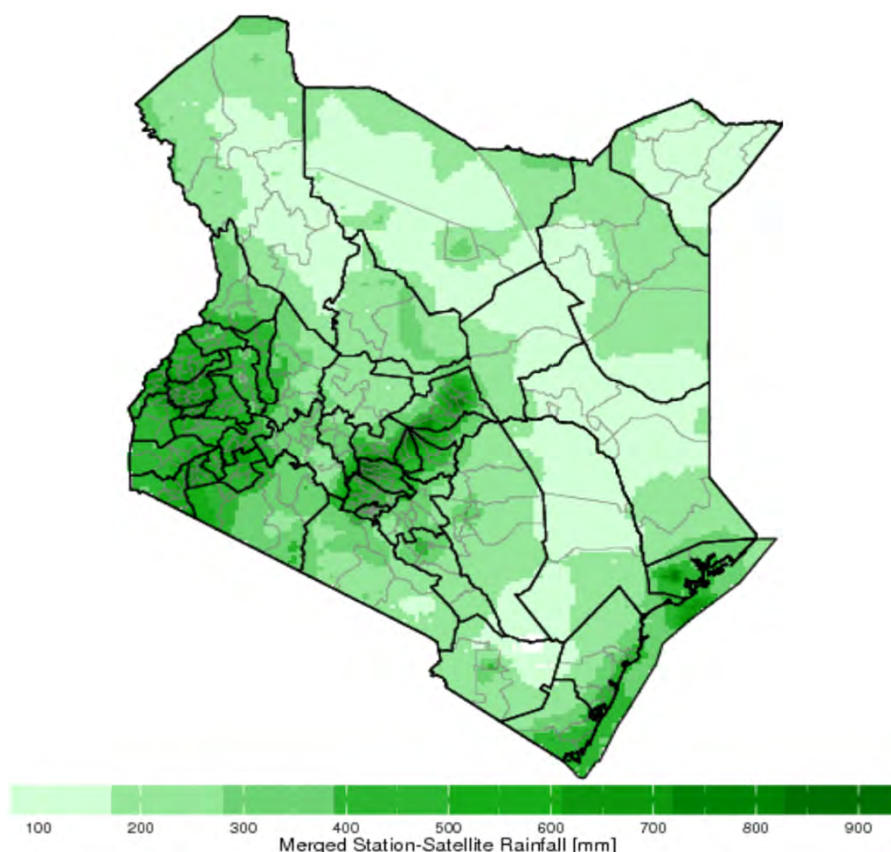


Figure 2.2-5. Spatial distribution of rainfall climatology (normal) during the March-April- May season. This figure shows seasonal rainfall totals of above 500mm (dark green colours) over western parts of the country, and mostly dry conditions (light green colours) over northern part of the country.

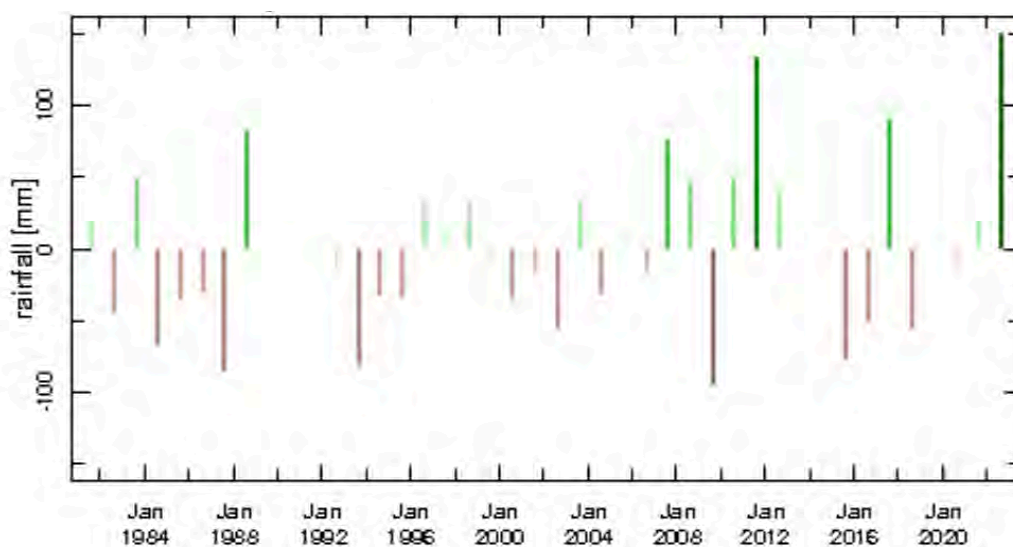


Figure 2.2-6. Seasonal rainfall anomalies during the March to May season for Laisamis. For each year, the bars show whether seasonal total rainfall for a given year was above normal (brown colours) or below normal (green colours). The length of the bars shows how much below or above normal the seasonal rainfall for a given year was.

Figure 2.2-8a shows the probability (Y-axis) of exceeding a given number of dry days (X-axis) for the selected location. For example, the probability of exceeding 20 dry days is about 80%, while the probability of exceeding 30 dry days is about 30%. The probability density function (Figure 2.2-8b shows the probability of experiencing a given number of dry days. For example, the most

probable number of dry days for this location is about 25, while the probabilities of experiencing below 10 dry days or above 50 dry days are very low.

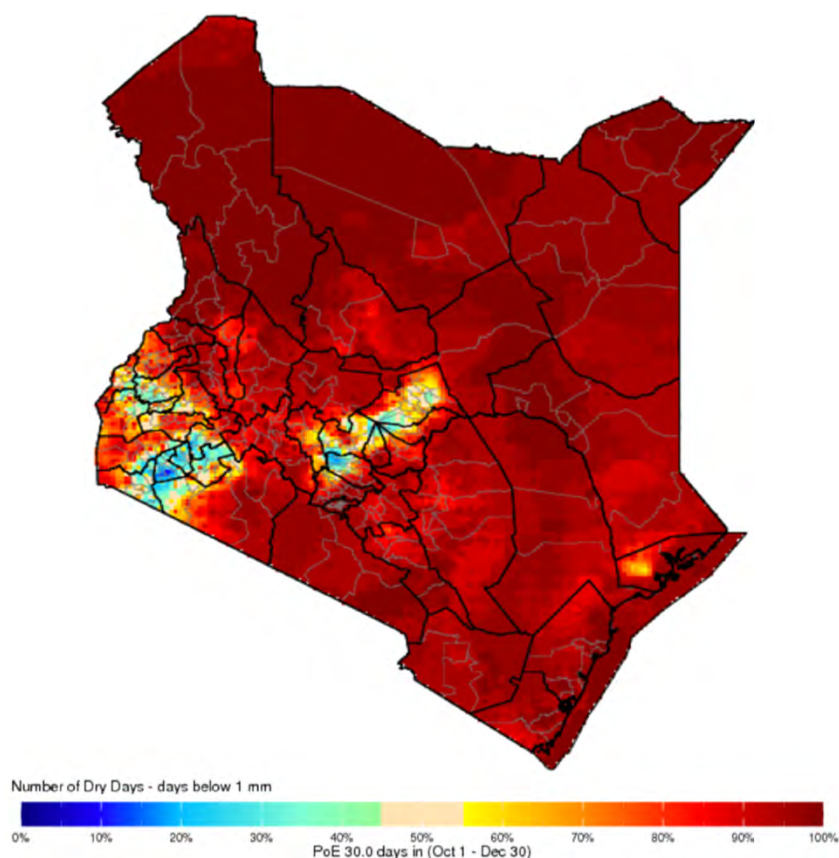


Figure 2.2-7. Probability of having over 30 dry days during the Oct-Dec season.

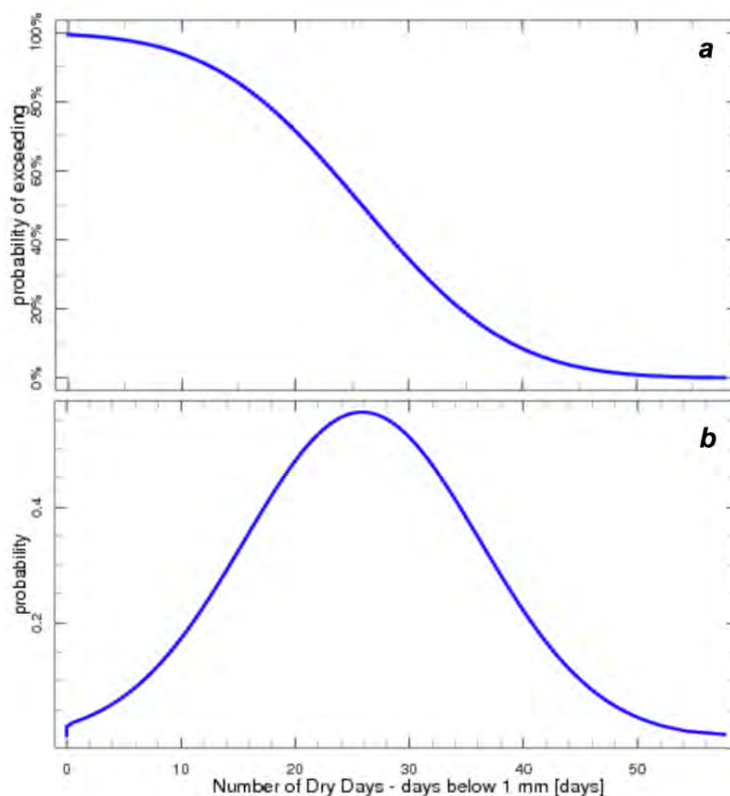


Figure 2.2-8. Probability of exceedance (a) and probability density function (b) of number of dry days during the October-December season for Chogoria, Maara, Tharaka-Nithi, Kenya.

Probability of Seasonal Rainfall Conditioned on ENSO and IOD

This maproom allows users to explore the probability that seasonal average rainfall will fall within the upper (wet), middle (normal), or bottom (dry) category (tercile) of the historical rainfall distribution during El Niño, La Niña, or Neutral ENSO (El Niño -Southern Oscillation) conditions.

This information is not a forecast. It is based just on historical observations of rainfall and sea surface temperature conditions. However, it is a good tool for exploring the effect of different ENSO phases (El Niño, La Niña, or Neutral) on seasonal rainfall over an area of interest. For instance, if the coming season is expected to be an El Niño season, then this maproom can help to assess the expected impact of El Niño over an area of interest.

This maproom may be used to analyse:

- Maps showing probabilities of a location being drier, wetter, or normal for a given season and ENSO phase (Figure 2.2-9); and
- Time series of seasonal rainfall total at a given location for a particular season and the ENSO phase of each year (Fig 2.2-10).

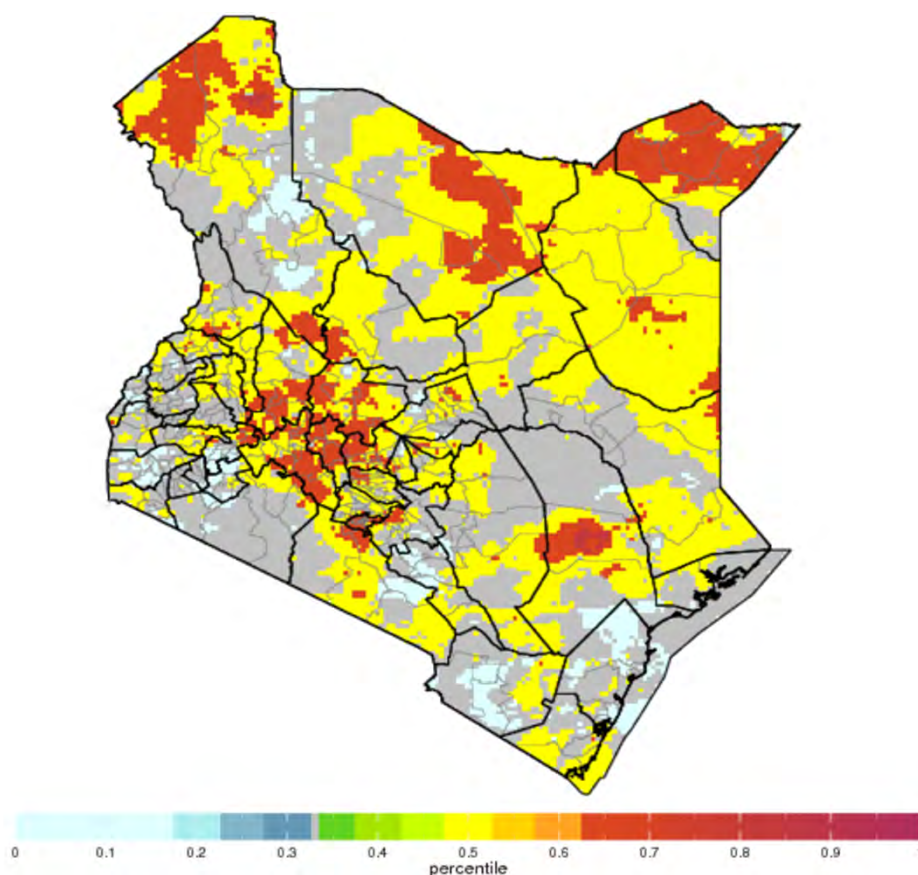


Figure 2.2-9. Probability of a dry Mar-Apr-May season during La Niña. This map shows the chance of the season being dry during La Niña years. Areas with red colour have high chance of being dry during La Niña, while areas with green or light blue colours have very low chance of being dry during La Niña.

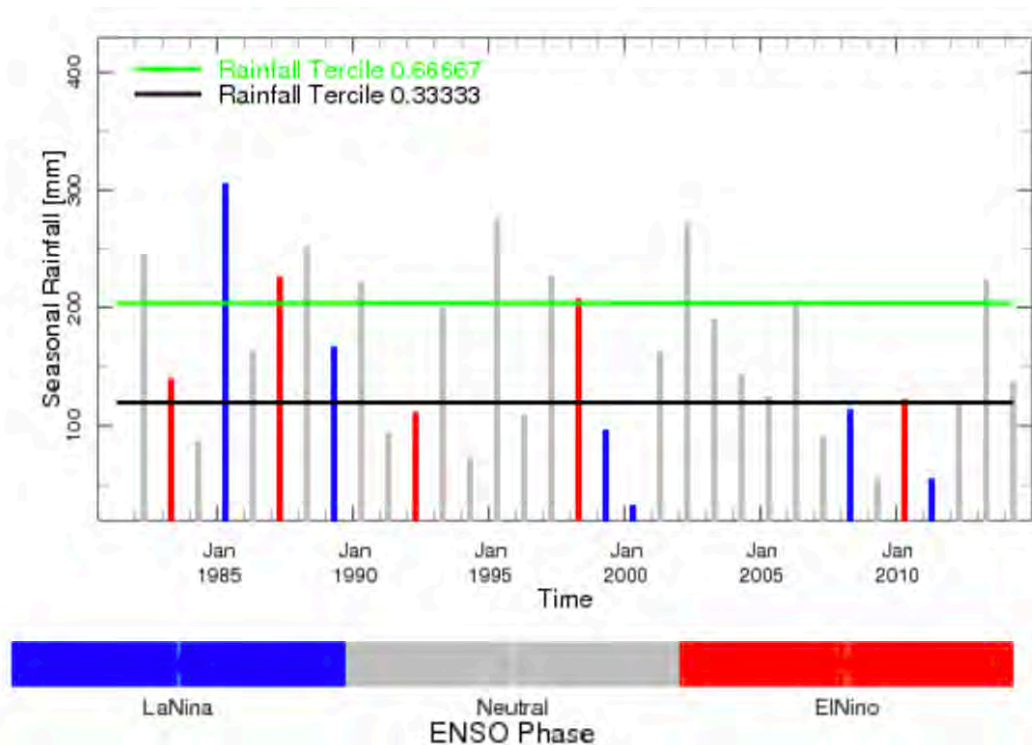


Figure 2.2-10. Time series of the seasonal rainfall total during Jul-Aug-Sep season and an ENSO phase for a selected county in Kenya. Rainfall values (Y-axis) below the black horizontal line represent below normal values, values between the black and green horizontal lines represent normal values, while values above the green line indicate above normal values. The red bars represent El Niño years, blue lines La Niña years, grey lines neutral years. Almost all El Niño years show below normal rainfall for this county.

Similarly, the Seasonal Rainfall Terciles conditioned on IOD Maproom, allow users to explore the influence of the Indian Ocean Dipole (IOD) index and examine how its phases affect the probability that seasonal average rainfall will fall within the upper (wet), middle (normal), or lower (dry) tercile of the historical distribution in a specified region, taking into account the corresponding IOD phase (Positive, Neutral, or Negative) for that season.

Self-Check

1. Which maproom is best for identifying the driest and wettest months of a given location?
2. Increase in temperature is expected to decrease coffee production. How would you check this risk over a given coffee growing area?
3. You have been asked to check if a given wheat variety, that requires about 450 mm of seasonal total rainfall, can be grown in a given ward. Which maproom, which "Seasonal

The Climate and Agriculture Maproom

There are a number of benefits of climate information to agriculture and food security. This includes developing sustainable and economically viable agricultural systems, sustainable aquaculture, resilient livestock and improving production. Climate information also improves crop and livestock quality, reducing losses and risks, reducing costs, increasing efficiency in the use of water, labour, and energy, and conserving natural resources. The Climate and Agriculture Maproom offers users an array of climate information products that can aid different agricultural decision making. This maproom is separate from the Climate Analysis Maproom, but it is included under Climate Analysis because it is all based on the analysis of historical climate data.

What is The Climate and Agriculture Maproom Used For?

The Climate and Agriculture Maproom enables users to analyze different variables of historical climate information to help them make critical decisions in their agricultural planning and practice. These decisions may include when to plant or stock fish, when to move the livestock to grazing reserve, when to purchase feeds, when to apply fertilizer or pesticides, and selecting other suitable practices to support the growth of crops, livestock, and fish under different climatic conditions. In addition to this agriculture-specific maproom, the climate maprooms presented in the previous chapter can also provide valuable information for agriculture-related applications.

Inside the Climate and Agriculture Maproom

The Climate and Agriculture Maproom has sub-maprooms (products) that include daily precipitation analysis, historical onset and cessation dates as well as climate suitability for crops. Onset date is the start of the rainy season as identified by agronomic criterion. These often include passing a certain threshold in cumulative rain over a few days and not being followed by a long break in rains (dry spells) that could damage germinating crops and undermine livestock growth. The cessation date is the date when the season is assumed to end and is based on the available soil moisture. Having the onset and cessation dates also allows to estimate the length of that specific season (by calculating the difference between the cessation and the onset dates). Extracting and presenting information at any administrative level enables focus on a specific area of interest. Figure 2.2-11 is the Climate and Agriculture Maproom for Kenya.

Daily Precipitation Analysis

This sub-maproom allows the user to explore historical daily precipitation by an array of different statistics. Many options are available for producing annual time series of a chosen seasonal diagnostic of the daily precipitation, such as the number of dry/wet days and dry/wet spells. The user can then choose to map (Figure 2.2-12) the mean, standard deviation or probability of exceeding the chosen threshold, over years. Clicking on the map will generate a location-specific graph (Figure 2.3-13) for the chosen diagnostic.

In this and other maprooms, users can extract and plot information over different administrative boundaries (country areas) by clicking on the map or picking an administrative name from the drop-down list, once having chosen which level of administration they want. Among other analyses, this component may be used to determine:

- the increase/decrease of rainfall in a certain area over time;
- how dry/wet spells (consecutive x number of dry/wet days) affect crop growth and livestock body conditions;
- which areas experience heavy rainfall and have the potential to be flooded; and
- which areas may experience drought.

Climate and Agriculture

The variability of seasonal precipitation, and the sub-seasonal statistics of these, play a key role in the quality and quantity of agricultural output.

This Maproom includes maps and analyses of seasonal statistics of historical precipitation and seasonal precipitation forecasts

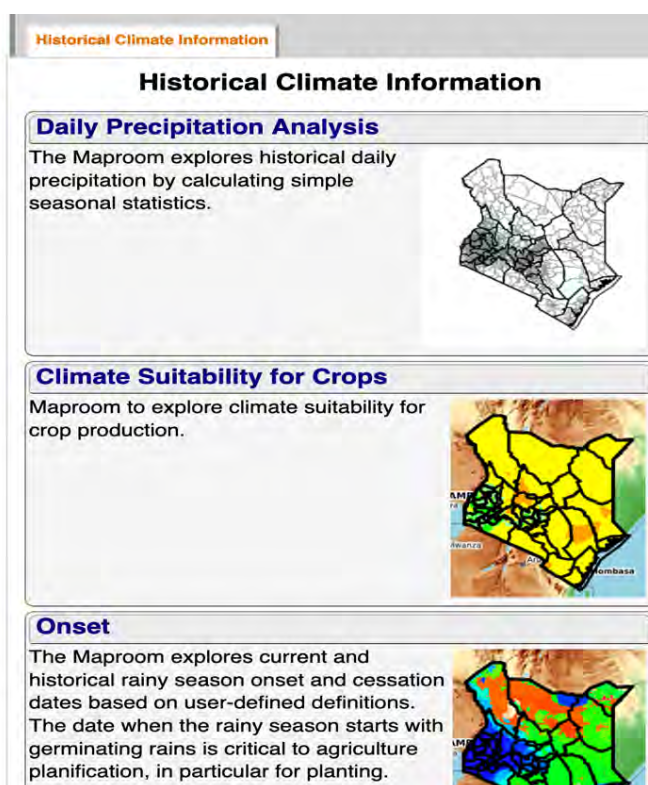


Figure 2.2-11. Overview of the climate and agriculture maproom.

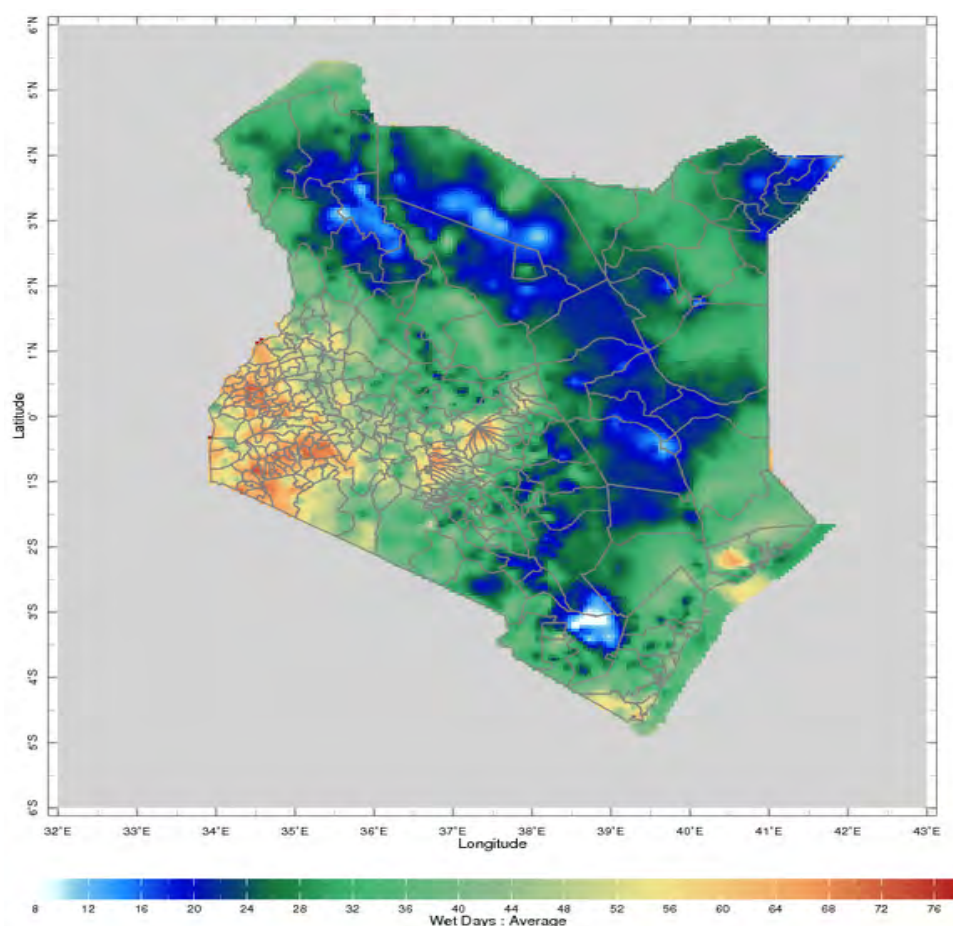


Figure 2.2-12. Average number wet days during March to May season over Kenya. The map shows low number of rainy days over the rift valley region and higher number of rainy days over western highlands

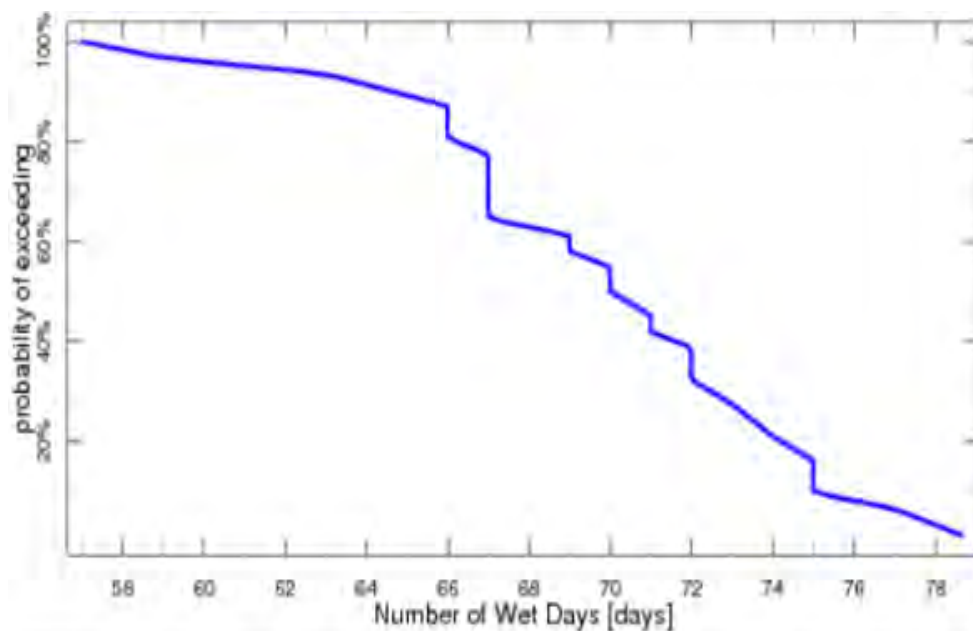


Figure 2.2-13. Probability of having wet days above a given threshold during the March- May season for a specific location over Kenya. The X (horizontal) axis shows the number of wet days while the Y (vertical) axis shows the probability(chance) of getting above a given number of rainy days (exceedance probability). For example, the probability of having above 60 rainy days for the selected location is over 90%, while the chance of having above 70 rainy days is about 50%

Onset and Cessation Dates

This maproom enables users to explore historical rainy season onset and cessation dates based on user-defined criteria. The date when the rainy season starts is critical for deciding on the optimum planting date. By enabling the exploration of the history of onset dates, the Maproom also allows users to understand the spatial and temporal variability of onset dates and therefore characterize the risk for a successful agricultural campaign associated with it.

The definition of the onset used here is a significantly wet event (e.g., 20 mm in 3 days) that is not followed by a dry spell (e.g., a 7-day dry spell within the following 21 days). The actual date is the first day of the wet event. The onset date is computed instantly for each year according to the definition, and is expressed in days since an early start date (e.g., Feb 1). The search for the onset date is made from that early start date and for a certain number of following days (e.g., 60 days). The default definition of the cessation date is the first date after a given date (e.g., June 1) in 60 days when the soil water balance falls below 5 mm for a period of 3 days. Then the maproom shows yearly statistics of the onset or cessation date, including the mean (by default) and the standard deviation or probability of exceeding a chosen starting or end date. Clicking on the map (Figure 2.2-14) will then produce a local yearly time series (Figure 2.2-15) of onset and cessation dates, as well as a table with the actual dates (as opposed to days since early start), and a probability of exceedance graph (Figure 2.2-16).

Note that if the criteria to define the onset or cessation date are not met within the search period, the analysis will return a missing value. And if the analysis returns 0 (days since the early start), it is likely that the early start date is picked within the rainy season.

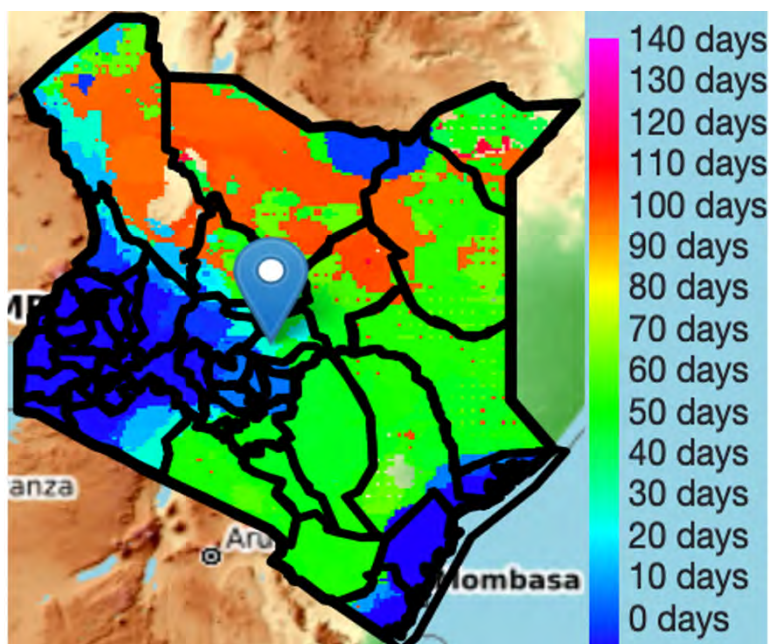


Figure 2.2-14. Mean onset dates for the different parts of the country, counted from the earliest start date (1 February). Thus, 10 represents onset date of 10 February. White areas mean that either the criteria were not met or this is not a rainy season for that area.

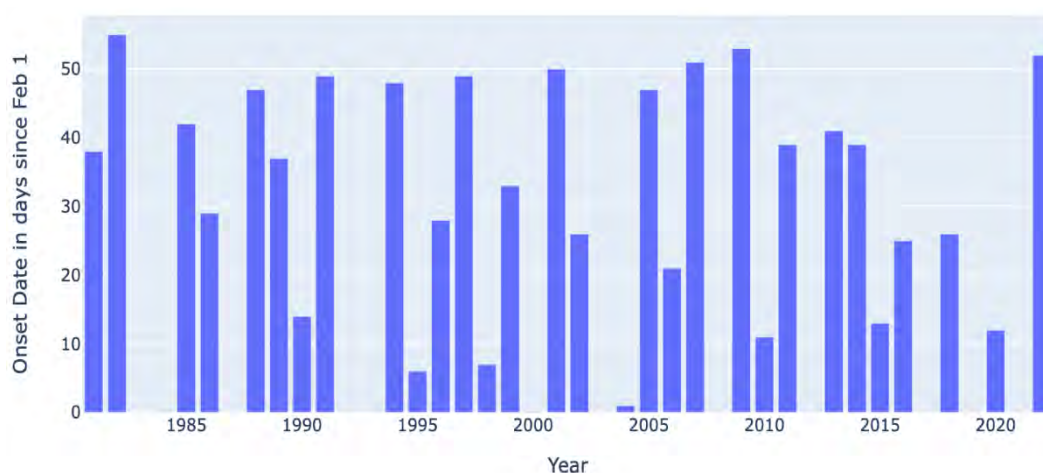


Figure 2.2-15. Example time series of onset dates for the selected location (0.025°N , 37.525°E) shown on the map above.



Figure 2.2-16. An example showing the likelihood (probability of) onset after or before a given date shown for the location shown on the map above. For instance, the probability of onset after day 20 (20 February) is about 80% (which means the likelihood of onset before 20 February is 20%).

Self-Check: Climate and Agriculture Maproom

1. How do you find the probability of having onset before or after a give date (say March 1st)?
2. What were the earliest and latest onset dates in the period from 1981 to 2020 for the location shown on the map (Figure 2.2.14)?

Session 2.3. KMD's ENACTS Maproom: Monitored and Predicted Climate

This session continues the presentation of KMD's ENACTS Maprooms. It presents the Climate Monitoring and the Climate Forecast Maprooms.

At the end of this session, you will be able to use maprooms products to:

- Assess the progress and performance of the current seasonal at dekadal, monthly, and seasonal level.
- Assess the expected performance of rainfall during the coming season.

The Climate Monitoring Maproom

The Climate Monitoring Maproom enables monitoring of the current season at dekadal, monthly and seasonal time scales. Different maps and graphs are used to compare the current season with the climatology or with recent years.

What the Climate Monitoring Maproom is Used for

The Climate Monitoring Maproom provides routinely updated dekadal (10- day), monthly and seasonal rainfall for the whole country along with analysis tools. It enables monitoring of the current season, allowing for the comparison of the current season to either the climatology or recent years. Users can monitor the season for any specific location by selecting that region (either point, district, provinces, or any administrative boundary) on the map and choosing the type of analysis desired

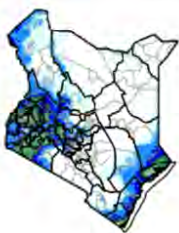
Inside the Climate Monitoring Maproom

The Climate Monitoring Maproom has tools that allow users to analyse the data at different temporal and spatial (point, box, or administrative boundaries) scales. Available analyses include dekadal, monthly and seasonal anomalies as well as analyses of extreme rainfall events. Figure 2.3-1 shows the different sub-maprooms in the Climate Monitoring Maproom for Kenya.

Climate Monitoring

Dekadal Rainfall

This Analysis tool allows users to view different presentations of the the most recent dekad.



WASP 12-month

The 12-month Weighted Anomaly Standardization Precipitation (WASP) index provides a simple visual means of extreme rainfall events for the past 12 months, whether they are drought or excess rainfall.



WASP 1-month

The 1-month Weighted Anomaly Standardization Precipitation (WASP) index provides a simple visual means of extreme rainfall events for the past month, whether they are drought or excess rainfall.



Monthly SPI

The Standardized Precipitation Index is an indicator of extreme rainfall events, whether they are drought or excess rainfall.



WASP 3-month

The 3-month Weighted Anomaly Standardization Precipitation (WASP) index provides a simple visual means of extreme rainfall events for the past season, whether they are drought or excess rainfall.



Seasonal SPI

The Standardized Precipitation Index is an indicator of extreme rainfall events, whether they are drought or excess rainfall.



Figure 2.3-1 The Climate Monitoring Maproom showing the available analyses options.

This analysis allows users to view different displays of the information about the most recent dekad, month, or season. The default map shows rainfall totals for the most recently available dekad (Figure 2.3-2), but totals for previous dekads can also be displayed.

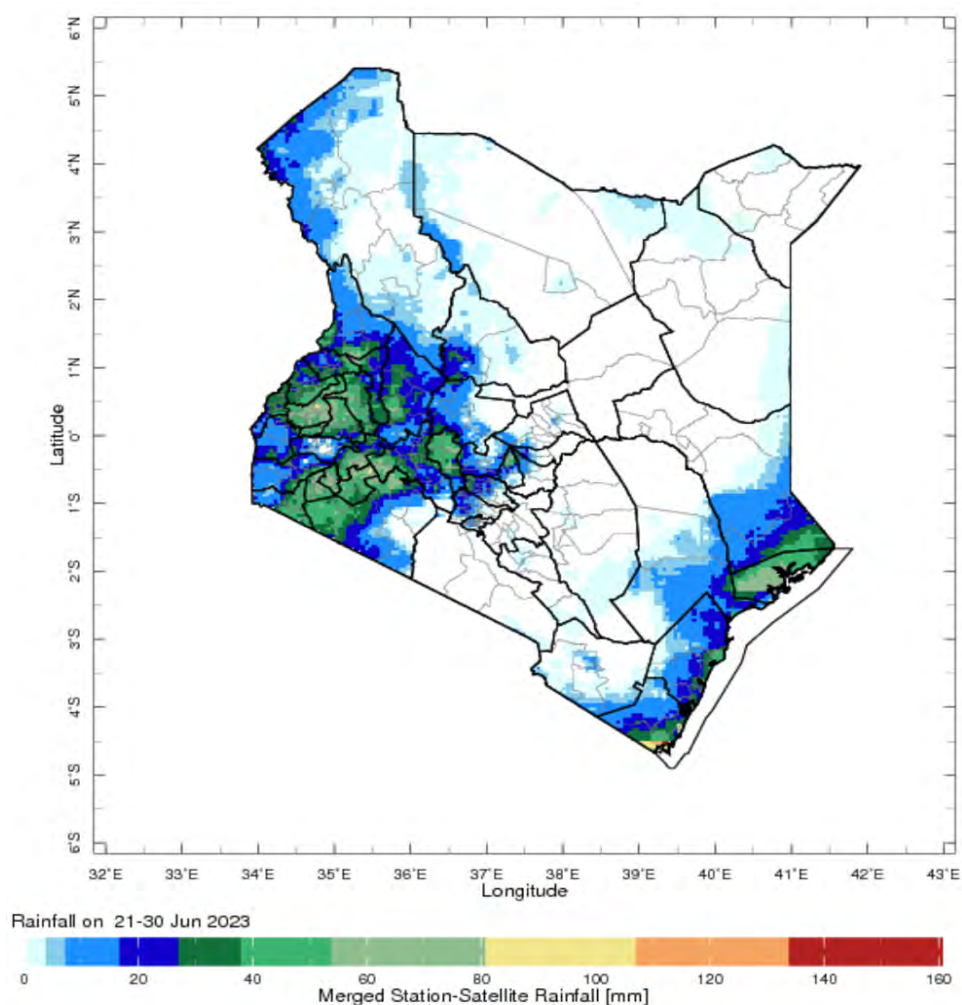


Figure 2.3-2. Total rainfall amount for 3rd decade (11-20) of June 2023.

The Climate Monitoring Maproom can also be used to display maps of rainfall anomalies, cumulative anomalies (over a user-defined time period) and the likelihood of extreme events presented as Standardized Precipitation Index (SPI) for the current year. This is done by selecting from the dropdown menu under “Analysis”. Anomalies show the difference between the most recent dekadal, month, or season rainfall and the expected (long-term average) expressed in mm or as a percentage. These maps offer an array of options to assess the performance of the current season and take action accordingly.

Clicking a location on the map will generate four different time series graphs (Figure 2.3-3), representing the following:

- Dekadal rainfall totals for the selected region over the last 3 years. This can be used to visually compare the performance of the current year with the previous years.
- Dekadal rainfall anomalies for the selected region over the last 3 years, which can be used to assess the performance of the current season relative to the climatology for that location.

- Dekadal rainfall for the current year (thick black line) compared to the previous three years.
- Comparison of the cumulative dekadal rainfall (solid blue line) to the cumulative long-term average rainfall (solid black line) from the start of the year until the latest dekad. The grey plume indicates the range of the 5th and 95th percentile cumulative historical rainfall percentiles. The 5th percentile represents the dry extreme while the 95th percentile represents the wet extreme. Thus, this graph can be used to estimate how extreme the current season is compared to what is normally expected (climatology) for that location.

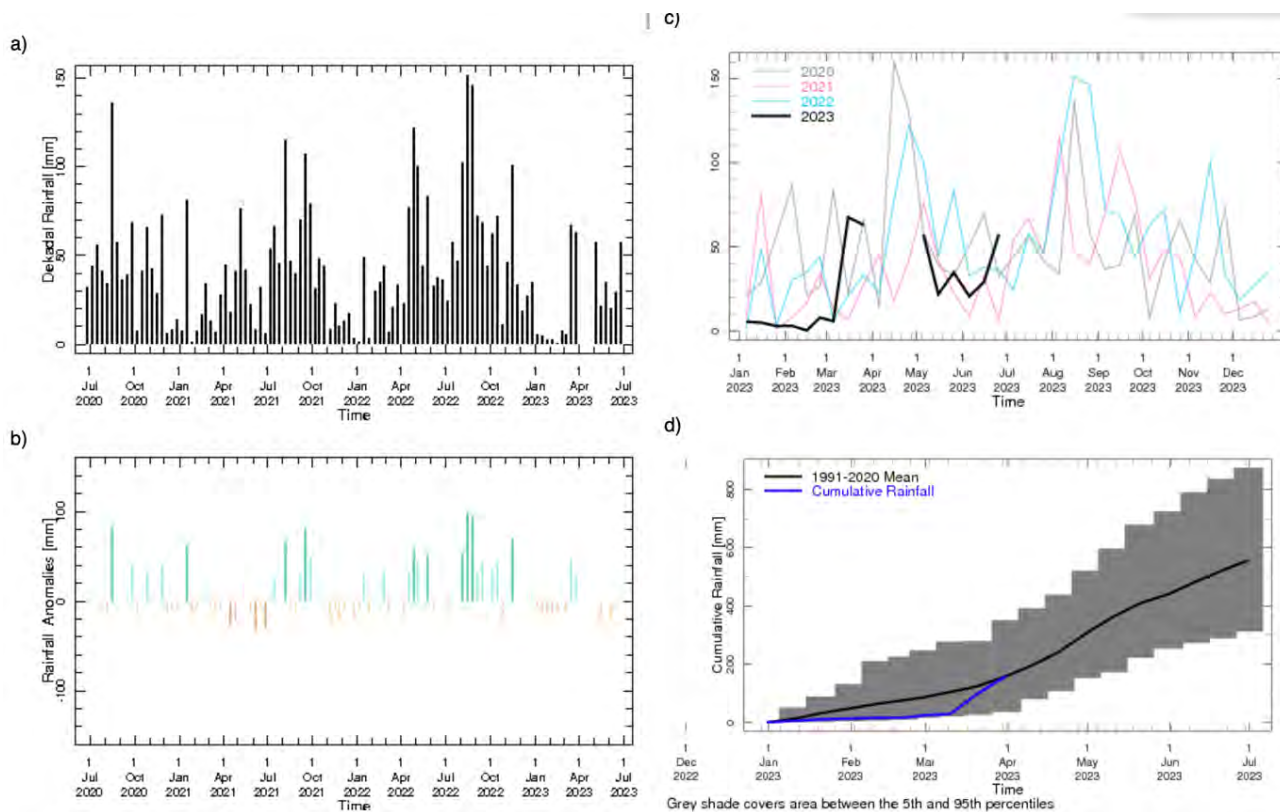


Figure 2.3-3. Climate monitoring graphs (see explanation in the text).

Self-Check

1. Which product would you use to check the severity of a dry dekad or month?
2. Which one is more useful: “cumulative anomalies” or “cumulative anomalies in percentage” and why?
3. From the cumulative graph, where would the blue line be relative to the dark line for a very

The Climate Forecast Maproom

The Climate Forecast Maproom (Figure 2.3-4) presents seasonal forecasts in a user-friendly format. Here it should be noted that this Maproom does not actually generate forecasts; it just presents forecasts generated by the KMD in a more decision-relevant format.

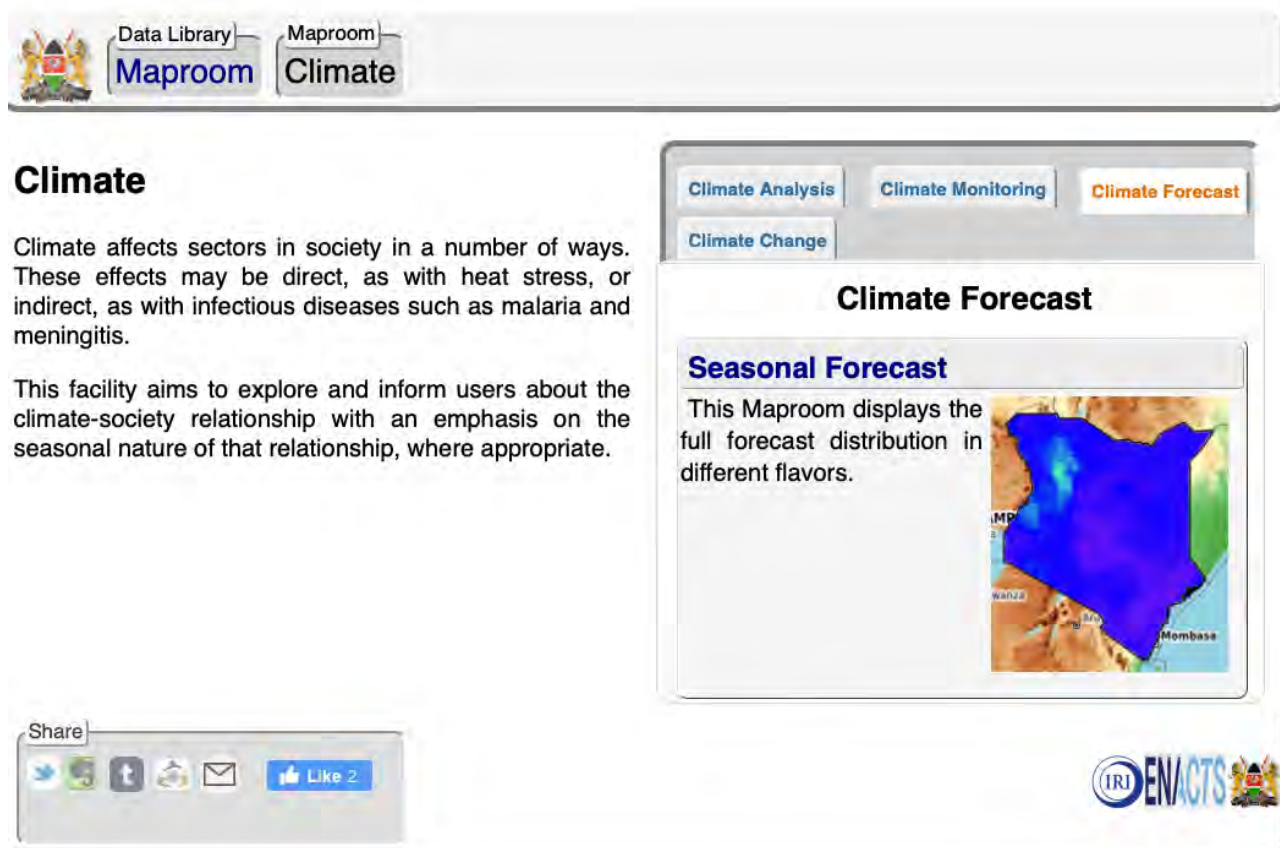


Figure 2.3-4. Frontpage of the Climate Forecast Maproom for Kenya.

Flexible Presentation of Seasonal Rainfall Forecast Maproom

This maproom has transformed how seasonal rainfall forecasts are presented. It deviates from the usual tercile format and presents seasonal forecasts in a flexible format that can be easily understood and used. Instead of the usual terciles (below normal, normal, above normal) presentation, the new forecast Maproom allows users to choose a threshold they are interested in either as percentiles or rainfall amounts. For instance, one can explore the probability that the total rainfall for the coming season is would be above or below 1200mm, or 75th percentile of the historical distribution. The forecast maps are also provided at higher spatial resolutions, making the forecast locally more relevant. The default map shows the most likely seasonal rainfall total amount for the forecasted season.

The forecast can be expressed in different ways:

- Rainfall: most likely seasonal total rainfall;
- Anomaly: deviation in mm of the most likely seasonal total rainfall from yearly average of the most likely seasonal total rainfall;

- Percent of Median: deviation in percentages of the most likely seasonal total rainfall from yearly median of the most likely seasonal total rainfall; or
- Probability of exceeding or not exceeding a user-defined threshold: forecast probability of seasonal total rainfall to be below or above a user-selected threshold (Figures 2.3-5, 2.3-6).

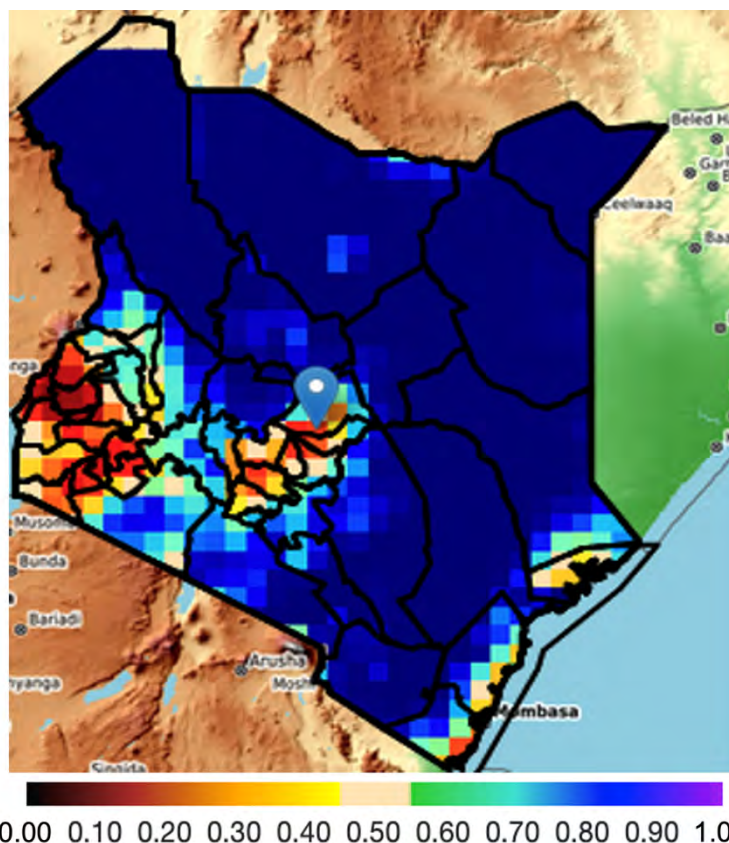


Figure 2.3-5. Forecast probability of the Long Rains (February-April) 2024 seasonal rainfall total, issued in January 2024, exceeding 500 mm. Source: KMD
http://kmddl.meteo.go.ke:8081/python_maproom/flex-fcst-mon

Clicking on the map will display specific forecast information for the selected location. This includes the probability of exceedance as well as the full forecast distribution (Figure 2.3-6) at that given location, compared with the historical distribution. Comparing the forecast and climatological distributions enables the user to assess the likelihood that seasonal rainfall will be above or below any rainfall threshold. For example, the climatological probability of exceeding 200 mm is about 75%, while the forecasted probability of exceeding 200 mm is about 85%.

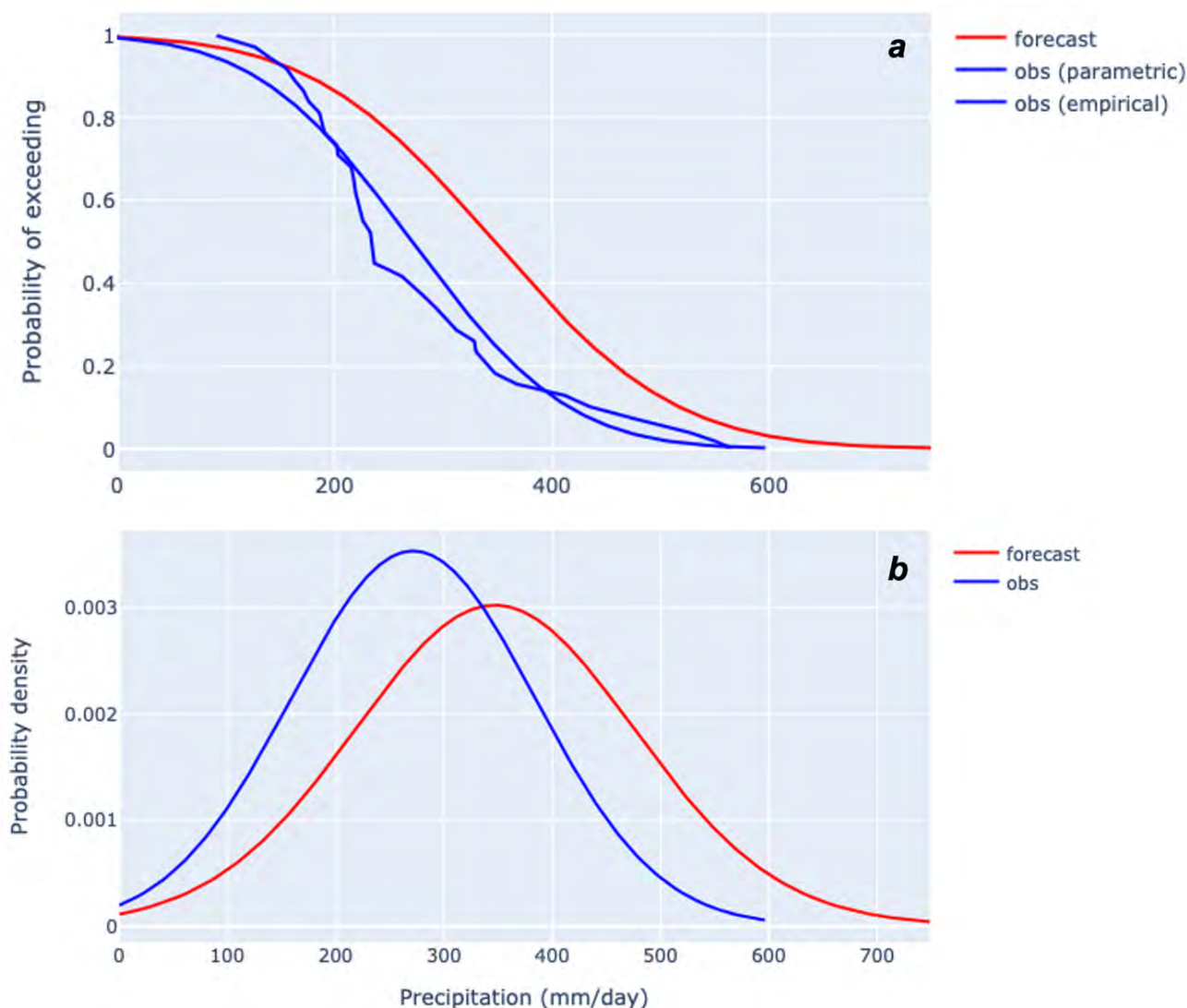


Figure 2.3-6. Forecast probability of exceedance (a) and probability density (b), comparing the forecast (red) with the expected (climatological in blue), Issued January 2024 for February-April at - 0.134°N, 35.875°E. The black line in panel a is historical data, and the blue line is a smoothed historical distribution. Comparing the forecast and expected lines enables the user to assess whether the predicted seasonal rainfall will be above or below the expected for each rainfall threshold. For instance, the climatological probability of exceeding 300 mm is about 40%, while the forecasted probability of exceeding 300 mm is about 65%.

Self-Check

1. What is the difference between the tercile presentation of seasonal forecast and the presentation in the Flexible Forecast Maproom?
2. Using the Probability exceedance graph, how would you tell if the forecast is above or



MODULE 3

Climate-Sensitive Agricultural Decisions

MODULE 3 | CLIMATE-SENSITIVE AGRICULTURAL DECISIONS

Module 3: Climate-Sensitive Agricultural Decisions aims to strengthen understanding of the interaction between climate and farm decision-making. Understanding what climate-sensitive decisions producers make and the factors that influence their decisions is essential for understanding how climate services can support agricultural decision making. In this module, you will learn how climate variability interacts with farmers' environments, goals and constraints to influence their management decisions. You will gain awareness of some of the tools and methods used to characterize and analyze climate-sensitive agricultural management decisions. You will also about options that are available to producers to manage climate-related risk, including production technologies, diversification, seasonal climate forecasts, and index-based agricultural insurance.

By the end of this module, you will be able to:

- Explain how climate risk, risk aversion and producer characteristics impact decision making and wellbeing.
- Identify types and time scales of climate information that can support particular producer decisions.
- Interpret implications and limitations decision analysis and decision support tools.
- Recognize options available for producers to manage climate-related risk.
- Explain to producers the role, strengths and limitations of index-based agricultural insurance.
- Harness freely available tools tailored to the agricultural sector to support climate-informed decision-making.

Session 3.1. How Climate Risk Impacts Producers

Climate is among the most important driver of agricultural risk, particularly in rainfed sub-humid to arid environments. Climate-related risk complicates farm decision making, and contributes to poverty and food insecurity. This session covers mechanisms by which climate-related risk impacts agricultural productivity and profitability, and the wellbeing of rural households who depend on agriculture.

By the end of this session, you will be able to:

- Define terms and concepts related to risk.
- Explain the main pathways by which climate risk impacts the livelihoods and wellbeing of smallholder households.
- Explain two mechanisms by which the impact of a climate shock on farmer livelihoods can persist long after climate conditions return to normal.

Risk concepts

Producers operate in an environment that is affected by *stochastic* variability, meaning that they are affected by randomness. Sources of stochastic variability, such as climate and market prices, are important drivers of agricultural risk. *Risk* refers to impacts of stochastic variability on productivity, profitability or some aspect of wellbeing.

The term *risk* is used in two contrasting ways. The fields of agricultural economics and decision analysis view risk as the full range of variability of impacts, and considers the impact of the resulting uncertainty about future conditions. This perspective uses dispersion statistics (e.g., standard deviation, coefficient of variation) to quantify risk. This course generally uses this definition of risk. A hazard perspective, used widely in disaster risk management, treats risk as the likelihood that a disaster or other damaging event will occur. This perspective uses discrete probabilities of experiencing adverse events to quantify risk.

Several concepts are relevant to risk and its impacts on agriculture. In the context of climate, *hazard*, *shock* and *extreme event* refer to a climate-related physical phenomenon that has the potential to trigger adverse impacts on human wellbeing – directly or through the natural resource base. A *stress* refers to a condition that can lead to adverse impacts, but that occurs over a longer period than a shock. *Compound risk* refers to instances when more than multiple types of simultaneous hazards interact. *Exposure* refers to the frequency and severity of environmental shocks or stresses that a community experiences.

Vulnerability refers to characteristics of human communities or social systems that cause them to be susceptible to adverse impacts, such as increased food insecurity, poverty or mortality, when exposed to an external shock or stress. This perspective treats the likelihood of experiencing adverse impacts as a function of internal characteristics that determine vulnerability, and exposure to external shocks or hazard events. Note that some disciplines and communities use the term vulnerability to refer to the combined effects of internal characteristics and exposure on the likelihood of adverse impacts.

In the context of development, *resilience* refers to the capacity of an individual, community or society to resist moving to a less desirable state (e.g., poverty), or to recover if it is already in an undesirable state (relative to a development goal), in the face of stochastic shocks or long-term stresses. From a development perspective, vulnerability and resilience can be viewed loosely as opposite concepts, although resilience considers wellbeing over long time scales while vulnerability may focus also on immediate impacts of shocks. The concept of resilience is used differently by different disciplines and communities, and has evolved considerably from its initial focus on ecological systems (Barrett et al., 2021).

Coping refers to the actions that individuals or communities take to withstand a shock and limit its immediate adverse impacts. Although the coping strategies of rural households reduce the immediate impacts, some coping strategies reduce livelihood opportunities or increase vulnerability in the long term. *Adaptation* involves adjustment in natural or human systems in response to actual or expected climatic stimuli or their effects, which moderates harm or exploits beneficial opportunities. Although adaptation is used in several ways, it typically refers to changes over longer time periods than coping.

Impacts on plant, fish and livestock production

Climate conditions impact crop, fish and livestock production systems through a range of mechanisms (Table 3.1-1). These mechanisms by which climate conditions impacts crop, livestock and fishery productivity are quite varied and sometimes quite context-specific.

Solar radiation drives conversion of atmospheric CO₂ into plant biomass through photosynthesis. Temperature controls the rate of plant phenological development, and most plant physiological processes and fish growth and development. Precipitation determines the water that is available to plants from the soil, and water for aquaculture and influences availability and movement of soil and nutrients. Potential evapotranspiration drives plants' uptake of water and nutrients from the soil. Temperature variability can also be an important driver of production in tropical environments where temperatures fluctuate near upper or lower thresholds that crops or animals can tolerate. Variations in the amount, timing and distribution of precipitation is often the dominant source of year-to-year variability of production, income and consumption in *dryland* (i.e., rainfed production in sub-humid to arid environments) agricultural systems in the tropics, and in flood prone locations.

Table 3.1-1. Examples of weather and climate impacts on biological productivity.

Parameter	Impacts
Crops	
Solar radiation	• CO₂ conversion into plant biomass through photosynthesis
Temperature	• Rate of phenological development • Most plant physiological processes
Precipitation	• Water available from the soil • Movement and availability of soil nutrients
Potential evapotranspiration	• Drives uptake of water and nutrients from the soil
Temperature, humidity, wind	• Population dynamics and movement of pests, pathogens
Livestock	
Drought	• Reduced feed availability from rangelands • Reduced milk, meat and offspring production • Loss of body condition and value • Mortality from disease, starvation and thirst
High temperature and humidity	Reduced meat and milk production
Weather hazards (flood, windstorms, lightening)	• Livestock mortality • Disease outbreaks
Fisheries	
Water temperature	• Growth and breeding of fish • Coral bleaching affecting breeding sites for ocean fish • Susceptibility to pathogens
Precipitation	• Erosion and siltation into lakes and small water bodies • Destruction of fish habitat, leading to loss of biodiversity • Ocean acidification causing shellfish mortality and loss of biodiversity • Eutrophication, algal blooms leading to fish suffocation
Weather hazards (flood, windstorms, lightening)	• Flooding leading to fish escapes, introductions, destruction of fish farms and infrastructure • Hazardous open water navigation, fishing activities • Water pollution from storm runoff • Low oxygen events associated with fish kills
Drought	• Reduced water availability for inland aquaculture • Reduced availability of feed ingredients for fish • Loss of fish habitats

Crops, pastures and rangelands

Precipitation represents the supply of water that is potentially available to plants, whereas potential evapotranspiration (*PET*) represents plant demand for water. Crop and pasture plants are sensitive to dynamic interactions between daily weather, soil water balance, and phenological stage. Growing season average rainfall therefore typically shows only weak correlation with local crop yields, even in environments that are strongly water limited. Indexes that capture these dynamic interactions can be obtained by combining daily precipitation and *PET* data with a simple soil water balance model. A soil water balance model calculates changes in water content in the rooting zone by adding inflow from precipitation, irrigation and capillary rise from lower layers; and subtracting outflow from evapotranspiration, surface runoff and deep percolation (Figure 3.1-1). Simple soil water balance models may ignore some of these processes (e.g., runoff, capillary rise).

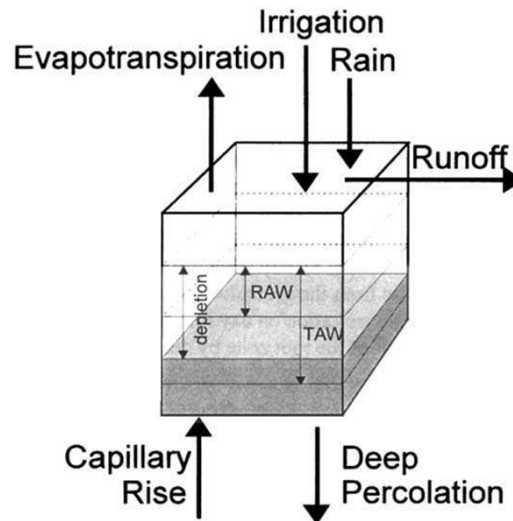


Figure 3.1-1. Schematic of soil water balance. Adapted from Allen et al., 2006.

The most widely used index for capturing the relationship between precipitation and plant requirements is the *water requirement satisfaction index (WRSI)* (Frere and Popov, 1979). It is calculated as the ratio of crop actual evapotranspiration AET_c to potential transpiration PET_c , accumulated through the growing season, or:

$$RSI = \sum_{t=1}^n \frac{AET_{c_t}}{PET_{c_t}},$$

where n is the number of periods (days or dekads) in the growing season, and t is a given day or dekad number. Crop water requirement on day t is *PET* adjusted for the stage of canopy development:

$$PET_{c_t} = K_{c_t} * PET_t.$$

Actual evapotranspiration is reduced on days when the soil water content SW contains insufficient water to meet the crop's demand:

$$AET_{c_t} = \min(PET_{c_t}, SW_t).$$

Daily soil water content is updated by simply adding precipitation, and subtracting AET and runoff:

$$SW_t = SW_{t-1} + P_t - AET_{c_t} - runoff_t.$$

WRSI accounts for daily precipitation P , potential evapotranspiration PET , crop canopy development K_c (relative to full canopy cover), and root zone water-holding (WHC) of the soil. By integrating dynamic information about the amount and timing of rainfall, in a manner that relates to the way crops respond to rainfall, *WRSI* is generally more strongly and more linearly related to crop yields than other rainfall-based drought indexes.

Plant response to climate conditions is generally nonlinear and sometimes *nonmonotonic* (i.e., increasing and decreasing over different parts of the range of variability), and climate variability interacts with this nonlinearity to reduce average productivity. This interaction can be illustrated graphically with a nonlinear crop yield response curve to growing season rainfall (Figure 3.1-2). Although both panels have the same mean rainfall, the higher rainfall variability in the right panel results in lower mean yield. Note that the decreased mean productivity does not capture the damaging impact of a year with very low production, which can impact household wellbeing in subsequent years.

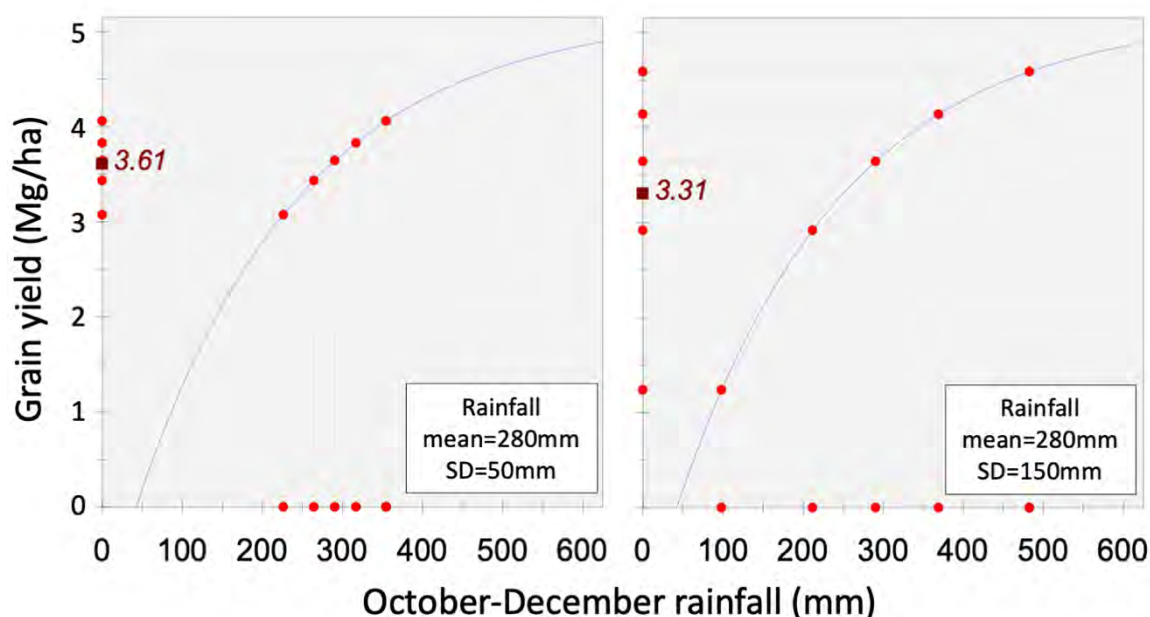


Figure 3.1-2. Nonlinear grain yield response curve to growing season rainfall, illustrating reduced mean yield in response to increased rainfall variability.

Livestock

Hydrometeorological hazards, such as flooding, wind storms and lightening, can kill unprotected animals. Heat stress, from a combination of high temperatures and low potential evaporation, also has a direct impact on animals, and suppresses meat and milk production (Chen et al., 2024; Garner et al., 2017).

Excess heating is a function of internal heat generated by animal metabolism and exertion, air temperature, and in the case of animals in direct sunlight, absorption of shortwave solar radiation. Cooling through evaporation is influenced by temperature, humidity and wind.

The simplest and most widely used heat stress indexes combine the effects of air temperature and humidity. Heat stress in African livestock is primarily assessed using the *Temperature-Humidity Index* (THI), a widely adopted metric that combines ambient temperature and relative humidity to quantify thermal stress. The general formula is:

$$THI = 0.8 \times T + ((RH / 100) \times (T - 14.4)) + 46.4,$$

based on the equation of Mader et al. (2006), where T is temperature in °C, and RH is relative humidity in percent. However, the index is sometimes calculated differently for different animal species (Rahimi et al., 2021):

- *Sheep and goats*: using the livestock and poultry heat stress indices (LPHSI) formula developed for the Suffolk breed;
- *Dairy and beef cattle*: using an equation developed for Holstein-Friesian Breed; and
- *Poultry*: based on an index developed for laying hens.

THI values are categorized into different levels of heat stress severity (i.e., none, mild, moderate and severe) based on specie- and sometimes breed-specific thresholds. These categories are used to recommend potential heat stress response strategies (Table 3.1-2). Indexes that also consider wind and solar radiation may better predict heat stress in animals under some conditions (Wijffels et al., 2021; Yan et al., 2021).

Table 3.1-2. Example (from Vanuatu) of cattle heat stress response strategy advisories based on TH heat stress index categories. Source: Sorenson et al., 2025.

Risk level	Response level	Response strategies
Very low	No to minimal action	• Provide shade to maintain cattle's thermal comfort zone • Clean manure in and around water troughs and under shade structures reducing humidity from wet manure • Provide additional water in troughs
Low	Be aware	• Move cattle under trees for additional shading • Perform maintenance check on shading infrastructure and water storage facilities • Limit grouping of cows
Medium	Be prepared	• Limit animal movements and handling • Provide consistent sources of water supply in troughs • Observe breathing condition and panting frequency
High	Take action	• Increase roughage content of diet (nutrition program—low heat increment feed ingredients (fats and oils)) • Intermittently sprinkle cows for cooling purposes • Establish several areas for shading

Other climate impacts on livestock tend to be more indirect, since animals do not directly use resources such as solar radiation, CO₂ or precipitation from the atmosphere. High and rising temperatures, droughts, floods, and other extreme weather events impact livestock by reducing the availability and quality of feed (via forage crops and rangelands) and water, which directly affects animal physiology, welfare, and chances of survival. Resulting poor nutrition weakens immunity, making animals more susceptible to disease (Munteanu and Schwartz, 2022), hence lowering animal productivity, and increasing morbidity and mortality. Episodes of severe drought lead to widespread livestock mortality in pastoral communities and other extensive livestock production systems in semi-arid to arid lands, by degrading rangeland conditions and reducing forage and fodder productivity.

Fisheries

Climate impacts on fish production differ somewhat for open water (ocean, lake) fisheries, and pond aquaculture systems. Hydrometeorological hazards, such as turbulence from wind storms and flooding, and lightening, affect navigation and sometimes lead to loss of life for fisherfolk, particularly in open water fisheries. Flooding leads to fish escapes and infrastructure damage in aquaculture systems. It can also introduce fish in areas that are not gazzeted fishing grounds, leading to conflicts. Storm runoff impacts fisheries by increasing water pollution. At longer time scales, rising water levels in lakes and oceans adversely impact fishing communities by damaging fishery and aquaculture infrastructure.

The biodiversity and productivity of ocean fisheries depend on upwelling driven by winds. Upwelling makes nutrient-rich deep waters available support the growth of seaweed and plankton, which in turn are food for fish. The world's most productive aquatic ecosystems, such as the west coast of Peru, depend on regular upwelling driven by atmospheric circulation. On the other hand, winds that drive upwelling can also cause fish larvae and relatively young fish to drift, endangering their survival and reducing their productivity.

Biological threats

Climate, particularly temperature, humidity and wind, has an important but indirect impact on crops and animals by influencing the population dynamics and movement of insect pests, parasites and microbial pathogens.

Many infectious diseases affecting livestock are climate-sensitive. The warming trend is creating more favorable conditions for existing and emerging pathogens and parasites, and increasing transmission risk. Climate conditions alter the epidemiology of these diseases by influencing vectors, pathogens, and host interactions. Warmer temperatures and changing rainfall patterns expand the range and seasonality of vectors (e.g., ticks, mosquitoes), increasing the risk of diseases like Rift Valley fever, leishmaniasis, and tick-borne fevers. Other climate-sensitive livestock diseases in Kenya include Foot and Mouth Disease, Peste des Petits Ruminants (PPR), and lumpy skin disease. Increasing livestock disease pressure often leads to greater use of

antimicrobials to treat diseases, which can accelerate antimicrobial resistance (Ni et al., 2025). In the fisheries sub-sector, Tilapia Lake Virus (TiLV) has emerged as a new disease.

Impacts on the welfare of rural households

Climate-related disasters impact poor countries, and the relatively poor within countries, disproportionately. Shocks associated with extreme climate events trigger cascading productivity and market responses that lead to acute food insecurity. The uncertainty associated with climate variability suppresses agricultural production and livelihoods. Climate impacts on food accessibility propagate through the economy. The adverse impacts of climate risk on food security and its precursors can persist long after a period of climatic stress – a phenomenon known as a “poverty trap.” The discussion of each of these mechanisms below draws from reviews by Hansen et al. (2022, 2019), and is summarized in Figure 3.1-3.

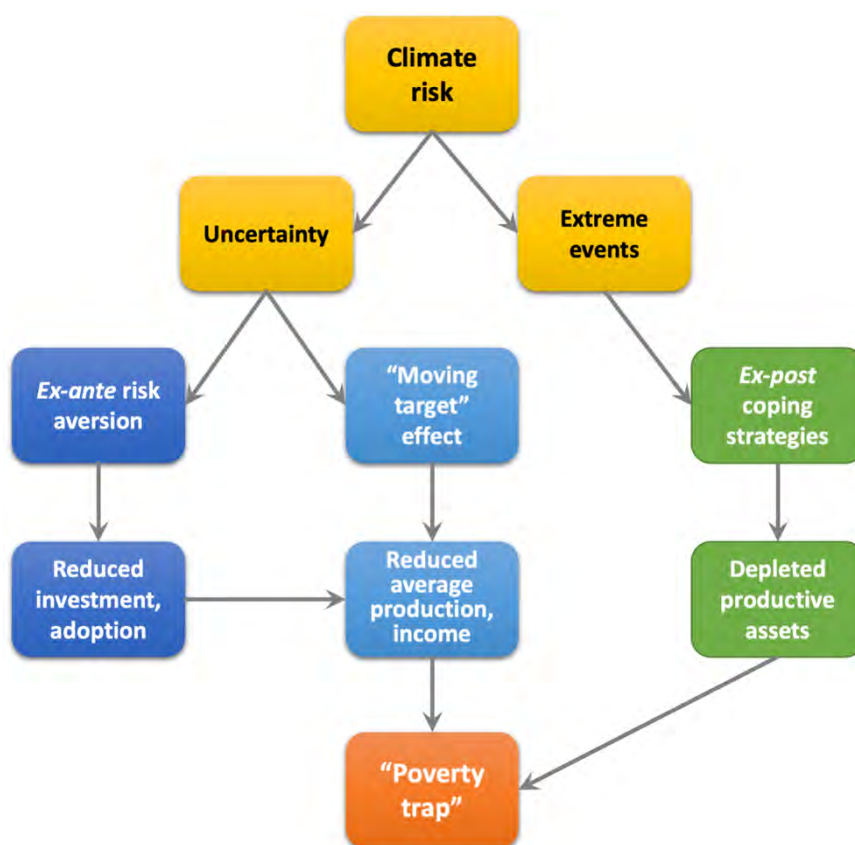


Figure 3.1-3. Main pathways by which climate risk contributes to long-term rural poverty. Adapted from Hansen et al. (2019).

Near-term impacts of climate shocks

Extreme weather and climate events, such as droughts, flooding, or high or low temperature extremes, can lead to reduced food consumption, and resulting health impacts expressed as wasting (i.e., low weight-for-height), stunting (i.e., low height-for-age), underweight (i.e., low weight-for-age) and mid-upper arm circumference (MUAC). While a shock might impact an entire community, the severity of food security and health impacts differs among individuals due to differences in characteristics such as gender, age, asset ownership and social capital.

There are important differences between the sequence of impacts of slow onset (e.g., drought) and rapid onset shocks (e.g., flooding, storms) (Hill et al., 2019) (Figure 3.1-4). A slow onset shock typically triggers a cascade of impacts discussed below: reduced crop, livestock, and fish production; increased staple food prices; reduced terms of trade for labour, animals and capital goods; declining incomes; and reduced food consumption.

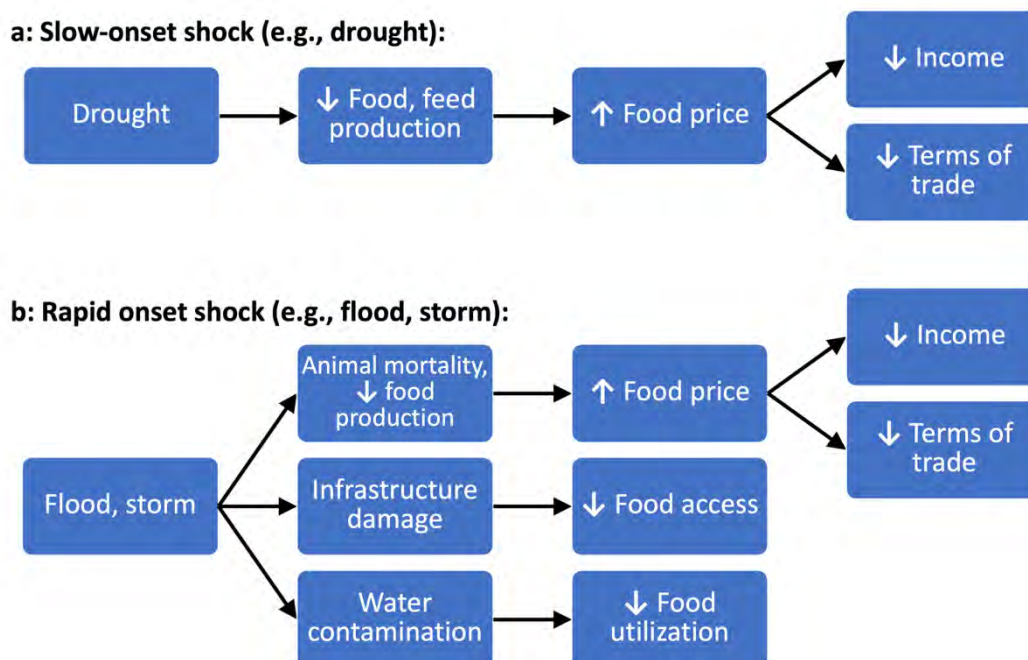


Figure 3.1-4. Typical cascade of impacts from a (a) slow-onset and a (b) rapid-onset climate shock.

The most direct impact of a climate shock is often reduced crop, livestock and fish production – sometimes associated with livestock or fish mortality. For smallholder farming households, failed harvests and livestock morbidity and mortality directly reduces the availability and distribution of food. This often results in food rationing and consumption earlier in the season, prior to the next harvest.

A climate-driven reduction in availability of a staple crop or animal products can increase its price through market equilibrium. A change in production of an agricultural commodity tends to lead to an opposite change in its price. This can be a particular challenge for horticultural crops and animal products that have short shelf lives and high transportation costs. For many agricultural commodities, trade and storage reduce price response to variations in productivity.

In most cases, climate-driven reduction of agricultural output has a negative impact on rural incomes, by reducing sales of farm outputs, and negatively impacting the broader agricultural economy (e.g., agricultural input, agricultural advisory and financial services, post-harvest processing, marketing and transport). Rural households who are net buyers of food face the combined impact of reduced availability through subsistence production, reduced income, and reduced accessibility through higher food prices; whereas increased prices received can partially compensate for the impact of a negative productivity shock on the incomes of producers who are net sellers.

As farm households deplete their food stocks and savings, they increasingly turn to off-farm casual employment to meet the shortfall, which can flood a local labour market. The value of durable assets decreases as affected households seek to exchange assets for food, through distress sales or barter, at the same time demand for these assets is decreasing in response to falling incomes and rising food costs. If a drought reduces staple crop production or reduces grazing resources, it could lead producers to sell their animals, which could result in over-supply and drop in market price.

The impacts of rapid onset shocks can be more complex and more context specific. In addition to damaging crops, immediate impacts of storms or floods can include loss of livestock and other capital assets, livestock and human diseases triggered by contaminated drinking water, and infrastructure damage that leads to loss of access to markets and vital services.

Climatic uncertainty impacts producer decision making

While the impacts of extreme climate conditions (e.g., droughts) on rural communities are more visible, the uncertainty due to climate variability reduces the efficiency of input use, and acts as a disincentive to adopting improved agricultural practices and investing in agriculture.

Uncertainty is a fundamental characteristic of the climate, and a key challenge for climate-sensitive management decisions. If producers knew what daily weather and seasonal climate conditions would be like in the future, they would be able to select the best management options available for those future conditions. However, producers must make decisions before they experience those conditions. The uncertainty associated with climate variability creates a “moving target” for management that reduces efficiency of land and production inputs and hence profitability, because management (e.g., cultivar choice, fertilizer rates, planting density, aquaculture or livestock production systems and breed type or fish species) that is optimal for average climatic conditions can be far from optimal for weather conditions in most seasons. Furthermore, most producers are risk averse, meaning that they prefer options that reduce risk. In the face of climate variability, risk-averse producers do not optimize their management for average conditions, but for adverse conditions. They employ precautionary strategies such as: selecting less risky but less profitable crops, cultivars, fish species and livestock breed types, generally avoiding investing their resources in production assets and technologies, under-use of fertilizers, using livestock or/and fish for precautionary savings rather than income, and shifting household labour to less profitable off-farm activities. Risk aversion and its effect on climate-sensitive decisions are discussed in more detail in Session 3.2.

In extensive grazing systems, which rely on high levels of mobility and flexibility, pastoralists manage high levels of uncertainty in a different way. The drylands are characteristically ecologically unstable, experiencing extremely low and highly variable rainfall distributions, even in non-drought years. By moving regularly, and dynamically changing livelihood practices - for example, by a splitting a herd by species and sending each half to graze different areas based on vegetation cover - pastoralists maximally exploit highly variable resource distributions.

Uncertainty is less a negative force reducing efficiency, in fact pastoral production is uniquely geared towards making a success of uncertainty.

Impacts persist through coping responses and health consequences

The food security impacts of a climate shock often persist long after climate conditions return to normal. This is due both to long-term consequences of early childhood health impacts, and to household coping strategies that deplete productive assets.

A severe or prolonged crisis that leads to malnutrition in utero or during the critical first 1000 days of life can adversely impact the individual's physical and mental health, educational achievement, and income into adulthood. For example, early childhood stunting reduced income later in life by 5-7%, averaged across 34 developing countries that account for 90% of the world's stunted children (Galasso and Wagstaff, 2018). A study of 106,330 women in 19 sub-Saharan African countries showed that drought experienced during early childhood reduced educational attainment and wealth as adults, adversely affected empowerment, and increased the likelihood that their children would have low birth weight – for rural but not for urban populations (Hyland and Russ, 2019).

When a severe climate shock, such as a drought, flood or heat wave, reduces the availability and accessibility of food, vulnerable households typically employ a sequence of coping strategies to endure the immediate crisis. The hardship from initial coping strategies, such as rationing meals, typically lasts only until the next harvest. If the stress is severe and persists long enough, they may implement increasingly drastic coping strategies that reduce their future capacity to provide for their sustenance and livelihood, for example: defaulting on loans, liquidating productive assets, withdrawing children from school and over-exploiting natural resources.

When a household or community is unable to accumulate the necessary resources to escape poverty, the condition is often described as a “*poverty trap*” (Barrett, 2005). In rural settings, a poverty trap is characterized by subsistence food production, poor adoption of improved agricultural production practices, and chronic poverty and food insecurity. Climate risk contributes to poverty traps through the mechanisms described in this session and summarized in Figure 3.1-3.

Session 3.2. Understanding Climate-Sensitive Agricultural Decisions

Understanding what climate-sensitive decisions farmers make, and the factors that influence their decisions, is essential for understanding how climate services can support crop and livestock farmer decision making. Farmers, and the environments in which they operate, can be quite variable. Management practices developed through agricultural research are more likely to be adopted and to benefit farmers if they take these differences into account, and if agricultural extension supports farmers to adapt those practices to their farms, goals, constraints and expected climatic conditions.

By the end of this session, you will be able to:

- Explain how differences in household goals and resource constraints can lead different farmers to select different management options.
- Identify the time scales of important agricultural decisions, and climate information that would support those decisions.
- Use decision trees to describe simple decision problems under uncertainty.

Producer characteristics and decision making

A management decision is *climate sensitive* if the decision maker would select different options if they observed or anticipated different weather or climate conditions. For example:

- In seasons with good rainfall, applying nitrogen fertilizer can increase cereal yields and farm income. However, the same fertilizer application may have little impact on yields, and the fertilizer cost may reduce income, in a season when rainfall is inadequate.
- In dry areas, calving is timed to coincide with the rainy seasons when there is adequate fodder, forage, and water which increases the survival rates of newborns and improves the scoring on reproductive indices, such as calving intervals and conception rates.
- An unexpected rainfall event at harvest maturity can damage the standing crop including standing hay, but early harvest and post-harvest management may avoid that damage.

- Where an aquaculture farmer expects reduced rains, instead of using earthen ponds, they may opt for a liner pond or raised ponds or recirculating water system to minimize on water loss (Mbugua et al., 2021).

Producer characteristics

Although climate has a strong influence on agricultural decision making, producers consider a wide range of factors as they weigh decision options, such as their own goals and constraints, and their physical (e.g., site selection; soil and landscape properties), economic (e.g., input and output prices, access to markets) and social and institutional (e.g., access to services, enabling and constraining policies) environments.

Farm management recommendations are sometimes based on simple criteria such as maximizing the yield of a particular crop, livestock, or fish. However, adoption rates of recommended technologies, innovations and management practices are often low, particularly for smallholder farmers and pastoralists. This is because they consider several different goals beyond maximizing productivity, and face a range of resource constraints. Goals that can influence production management decisions include:

- sustenance (household food production);
- income;
- accumulation of land, livestock and other assets;
- avoidance of drudgery;
- social status; and
- providing better livelihoods for the next generation.

The relative importance of these and other goals can vary considerably across cultures and from farmer to farmer and influenced by a range of factors including local culture, religion and education.

Farm decisions are also influenced by a range of resource constraints, including:

- land available for cultivation and/or livestock and fish production;
- quality and quantity of water;
- technological know-how in agricultural enterprises
- government policies and wider enabling environment for enterprise development;
- availability and timing of household labour;
- capital (i.e., savings, credit, equipment);
- social capital (i.e., ability to access a range of help through social and institutional contacts);
- infrastructure (for example, roads for connectivity to markets, distribution channels, post-harvest storage facilities, and electricity access);
- market access, characteristics, and information; and
- profitability.

These constraints limit farmers' ability to achieve their goals. Smallholder farmers, pastoralists, and particularly disadvantaged social groups such as women, relatively poor farmers, and those lacking education or literacy within smallholder communities tend to be impacted more by resource constraints than larger-scale commercial farmers and ranchers.

When we deal with climate-related risk and the role of information in managing risk, one of the most important factors to consider is the farmer's attitude towards risk. Most individuals dislike risk. Although commercial and smallholder farmers might have similar attitudes toward risk, commercial farmers are often better able to manage climate-related risks through financial instruments such as savings, credit, and insurance. As discussed earlier (Session 3.1), climate variability complicates farm decision making in the following ways:

- It creates a moving target for management that reduces efficiency of input use and hence profitability.
- Risk-aversion leads farmers to select less risky but less profitable agricultural enterprises, use less than the optimal amount of fertilizer, shift household labour to less profitable off-farm activities, and avoid investing in productive assets and improved technologies.

Generalizations about farmer decision making do not fully extend to pastoralists – whose decisions and culture are deeply shaped by climate variability and uncertainty and its connection to vegetation dynamics, water availability and livestock health. Pastoralists' use of climate information for decision making, and associated challenges, are discussed further in Session 3.6.

Time and climate-sensitive agricultural decisions

As producers are aware, timing is very important for agricultural management. We consider three aspects of timing: *seasonality*, *time horizon* and *lead time*.

Seasonality refers to the times of the year when agricultural activities occur, and key reoccurring management decisions are made. For example, rainfed annual crop farmers make important decisions about land allocation, and choice of crops and production inputs just before the start of the rainfall season. For livestock producers, activities such as disease and parasite control (strategic vaccination and deworming) can be scheduled before onset of rains. In aquaculture, stocking time is influenced by seasonality. In particular, after every complete harvest, the production system must be conditioned and repaired by cleaning and disinfection, where possible application of manure, agricultural lime or fertilizer before introduction of a new crop to minimize transmission of parasites and disease-causing microorganisms is undertaken. The annual climate cycle has a large influence on the seasonality of agricultural activities and management decisions. Government financial and policy processes may also influence the annual cycle of agricultural extension activities.

Decision time horizon refers to how far into the future a decision maker considers when evaluating the consequences of a decision option. For example, the choice of what annual crop

or cultivar to plant typically has a time horizon of 3-4 months, because the productivity and profitability of that decision can be affected by conditions from the 3-4 months between planting and harvest. Moreover, in livestock systems, pasture and fodder production and harvesting can be timed for use in the dry season. Once a crop is growing, decisions about field operations such as pest management, supplemental irrigation or when to harvest have much shorter time horizons. On the other hand, the decision to plant or remove perennial crops such as coffee can have a planning horizon on the order of 5-10 years.

Lead time refers to any additional time that may be needed between making a decision and implementing the decision. Some farm decisions require a period to prepare, for example to secure credit, purchase inputs, contract labour or draught animals, before the decision can be implemented. Generally, in aquaculture, simple low-cost technology systems are easily implemented with greater chances of success as compared to more sophisticated, complicated, expensive and relatively high-input technology systems which require time and additional resources to plan (Mbugua et al., 2021).

These three aspects of timing are important for climate services. For climate information to be useful for agricultural decision making, the time scale of the information should match the decision's time horizon plus any preparation lead time. Furthermore, climate services must consider seasonality, as appropriate climate information and support should be available at the times of the year when producers make key climate-sensitive decisions. The lead time and time horizon of a decision determine the time scale of weather or climate information that might support the decision. Table 3.2-1 gives a few examples of when decisions must be made relative to the growing season, and types and time scales of weather and climate information that may be relevant to those decisions.

An *agricultural calendar* is a planning tool that summarizes the timing of agricultural activities for a particular location. In the case of annual crop farming, an agricultural calendar identifies normal time windows for sowing, fish stocking, crop and fish growth and harvesting. It could be expanded to also indicate times for phenological stages such as: vegetative growth, flowering, grain fill, and physiological maturity; and farm activities such as: land preparation, fertilizer application, and weeding. Because crop growth stages and key agricultural activities are sensitive to weather conditions, it is useful to overlay the calendar with graphs of the seasonal climatology of rainfall and temperature. Figure 3.2-1 shows an example calendar for maize at one location (Kitui), overlaid with seasonal climatology graphs for precipitation and temperature. In the case of livestock, the calendar activities include birthing, deworming, dehorning, vaccination, weaning, docking and tagging (Figure 3.2-2).

Table 3.2-1. Examples of climate-sensitive decisions made by agricultural producers, including crop, livestock (sedentary and pastoralism) and fisheries (aquaculture and open water) at varying time scales, and relevant external information.

Timing	System	Decision	Relevant information
Infrequent, before major capital investment	All	Farming system design, business planning	- Historical rainfall, temperature - Market information
	Crops	Cropping system selection	Crop, variety characteristics
	Livestock	Livestock breed, system selection	- Historical rainfall, temperature - Livestock specie, breed characteristics
	Fisheries	Aquaculture system and site selection	- Historical rainfall, temperature - Water quality - Fish species, breed characteristics
Throughout year	Livestock	Herd mobility	- Availability and quality of pasture - Seasonal rainfall forecast - Water availability and quality
		Livestock sales	- Price, market dynamics - Size of herd - Breed value - Reproductive potential - Household needs
Before rainy season	Crops	Farm land allocation	Seasonal rainfall forecast
		Crop, cultivar selection	- Seasonal rainfall forecast - Onset date forecast
		Land preparation, basal fertilizer application	- Seasonal rainfall forecast - Onset date forecast
		Time of sowing	Onset date forecast
	Livestock	Pasture and fodder types	- Seasonal rainfall forecast - Onset date forecast
	Fisheries	Pond maintenance, repairs	Seasonal rainfall and inflow forecast
During rainy season	Crops	Fertilizer side dressing	- Seasonal rainfall forecast updates - Sub-seasonal rainfall forecast
		Irrigation management	- Weather monitoring and forecast - Soil water balance
		Weeding frequency, intensity	Weather forecast
		Pest, disease management	Weather monitoring and forecast
	Livestock	Pasture, fodder conservation	- Weather forecast (rainfall, humidity) - Storage temperature
		Veterinary management	Availability of veterinary resources
		Breed selection for restocking	- Historical rainfall, temperature - Market information

Table 3.2-1 (continued).

Timing	System	Decision	Relevant information
During rainy season (continued)	Livestock (continued)	Selective breeding management	Genetic traits, disease resistance
		Processing and storage of surplus animal products	- Historical rainfall, temperature - Seasonal rainfall forecasts
		Livestock gifting	- Competence of recipient - Size and health of herd
	Fisheries	Pond, nutrition, predator management	- Rainfall monitoring, weather forecast - Water quality (e.g., turbidity, salinity, temperature, pH, O₂, NH₄⁺, NO₂⁻)
End of rainy season	Crops	Time of harvest	Weather forecast (e.g. rainfall, wind)
		Post-harvest handling	Weather forecast (rainfall, humidity)
	Livestock	Pasture, fodder conservation	
	Fisheries	Fish post-harvest handling	Weather forecast (rainfall, humidity)
Dry season	Livestock	Breeding suppression	- Animal health - Seasonal rainfall forecast
		Supplementary fodder and wild fruit and harvests	- Herd size - Household needs
Drought	Crops	Emergency supplemental irrigation	- Seasonal rainfall forecast - Soil water balance - Weather forecast (rainfall)
	Livestock	Herd splitting	- Herd size and composition - Seasonal rainfall outlook - Conflict risk
		Herd offtake	- Market prices - Rainfall monitoring - Seasonal rainfall forecast
		Supplemental fodder purchase	- Seasonal rainfall forecast - Pasture/rangeland condition
		Temporary grazing area or water point access agreements	- Seasonal rainfall forecast - Pasture/rangeland condition
		Labor sharing	- Water quality and availability - Pasture condition
		“Cold-shock” navigation through shelter, limited movement	- Historic livestock health dynamics - Availability of veterinary resources
Post-drought recovery	Livestock	Grazing time and range increases	- Pasture availability - Conflict risk
		Borrow animals	Breed value, traits, disease resistance

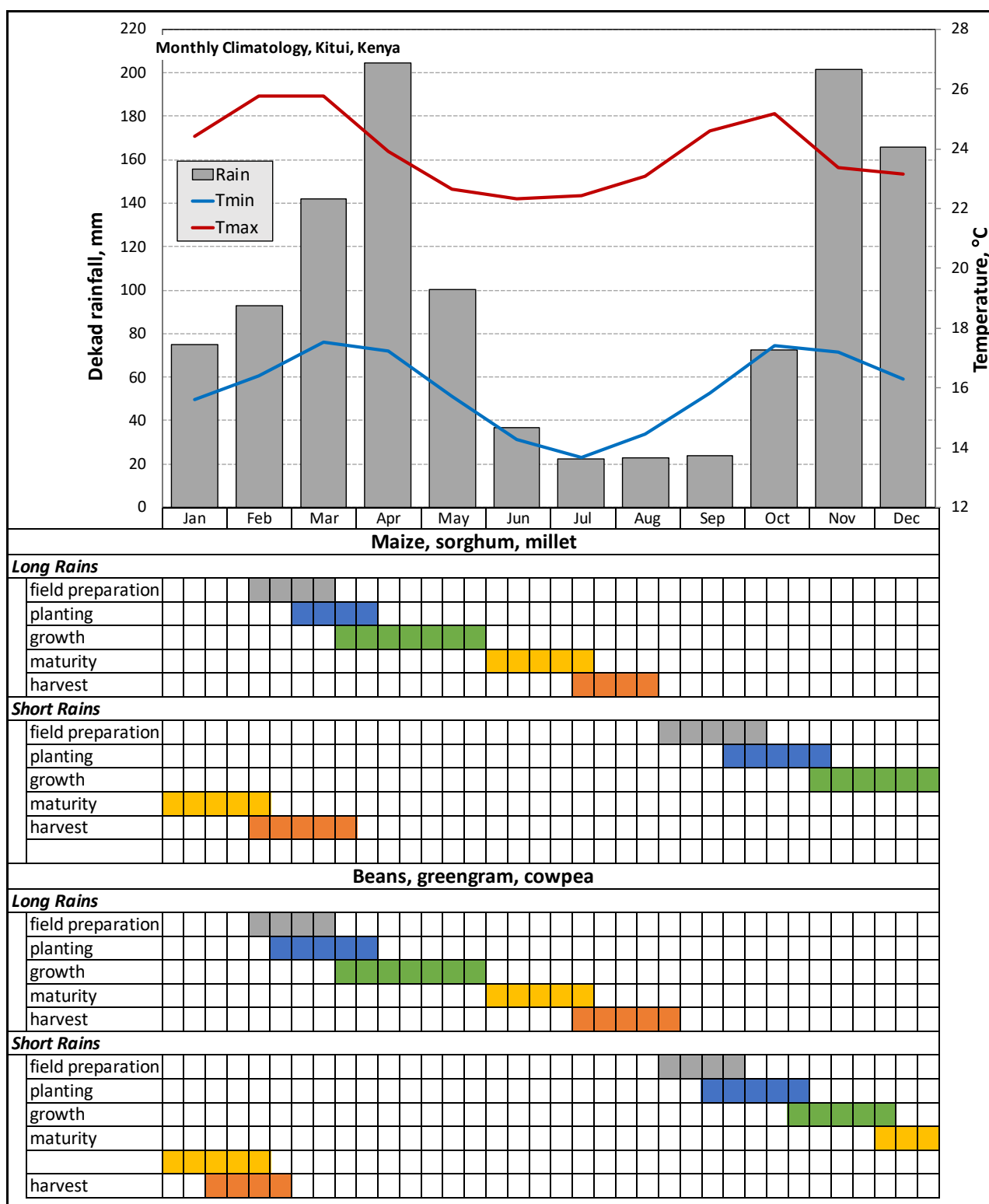


Figure 3.2-1. Illustrative example of an agricultural calendar for Kitui, Kenya, overlaid with mean monthly precipitation and temperature seasonal cycles.

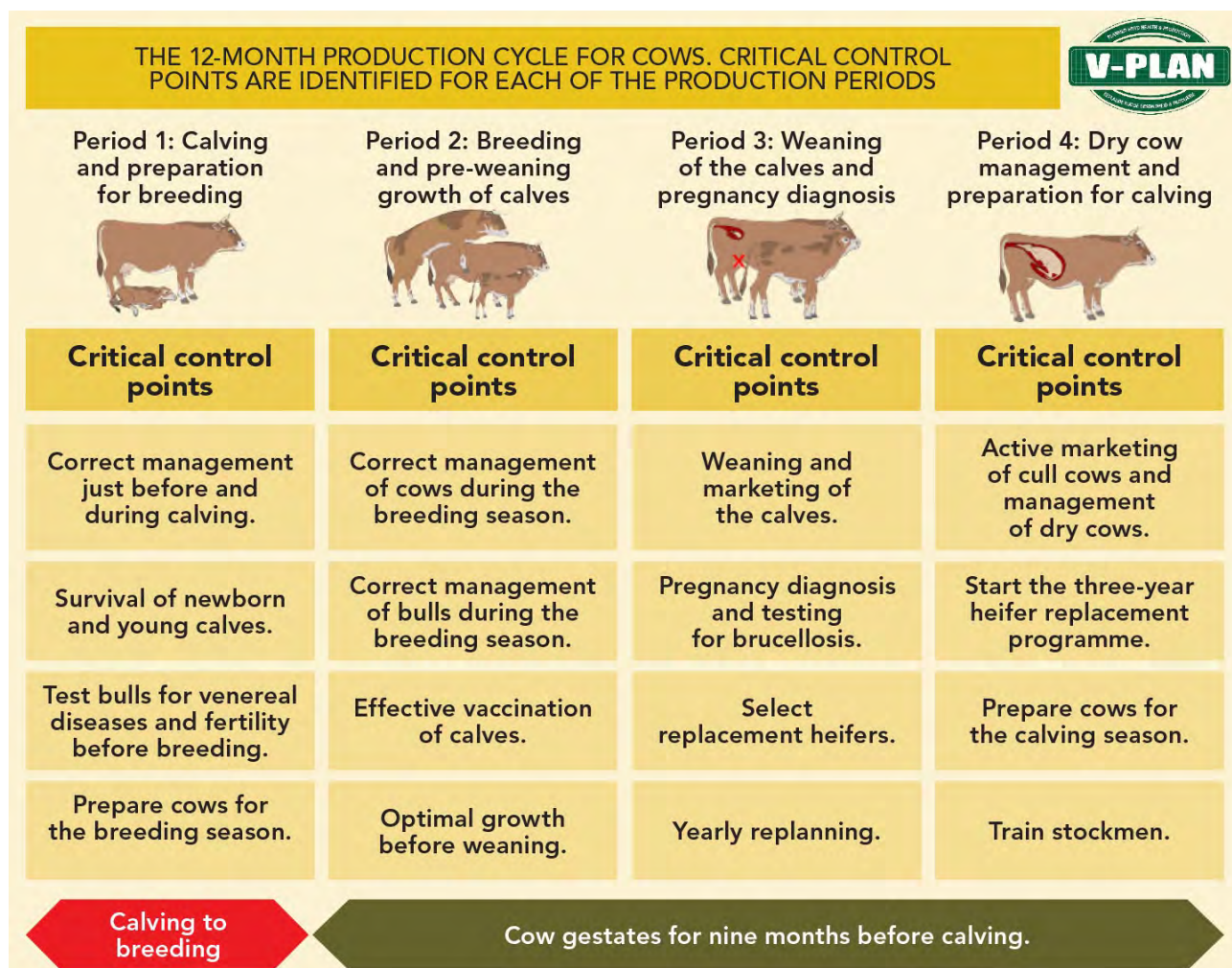


Figure 3-2-2. Example of a livestock calendar. Source: Kriel (2022).

Exercise: Climate-Sensitive Farm Decisions



- Work in small groups, by region:
- List at least 3 climate-sensitive decisions that are import to farmers or other agricultural decision makers in your region. For each decision:
 - ♦ Describe the timing (seasonality, time horizon, lead time) of the decision.
 - ♦ How does climate influence the decision?
 - ♦ What other factors, information, constraints influence this decision?
 - ♦ Would you expect different farmer types to choose different options? Why?
 - ♦ What climate-related information, if any, would support better choices?
 - ♦ Do you have suggestions to improve existing agricultural extension advisories about this decision?

Describing Risky Decision Problems with Decision Trees

The outcome of a climate-sensitive agricultural management decision is a function of the option that a producer chooses, and climate and other external factors that are outside of their control. Climate-sensitive management decisions typically require a producer to choose among a set of options while climate conditions and other states of nature that affect the outcome are still uncertain.

A decision tree provides a useful way to describe management decisions under uncertainty, when the decision has a small set of options, and when the risks that influence the decision outcomes can be described by a small set of states of nature. A decision tree captures these three aspects of a decision problem (Figure 3.2-3).

- First, the producer selects one of the decision options. A square represents a decision node. Each option available for the decision is represented by a line coming from the right of the decision node.
- Second, conditions, or “states of nature,” that are uncertain and beyond the farmer’s control may affect the outcome of the decision. For example, the range of possible seasonal total rainfall can be expressed in terms of three equally probable states of nature: the “below-normal,” “near-normal” and “above-normal” terciles of the historical distribution. A circle represents a chance node, which is followed by two or more lines representing uncertain states of nature and their probabilities.
- Third, the producer either experiences the outcome of the decision, or faces another decision that may affect the final outcome. An end node, shown as a triangle, represents the outcome of a given sequence of decision options and states of nature. For a crop farmer, the outcome might refer to the yield of the harvested crop, expressed as kg/ha; or the income from selling the crop, expressed as KES/ha. For a livestock producer, the outcome could refer to milk production in litres per cow per day or weight gain per day in kilograms. For a fish farmer, the outcome would be the weight of fish produced in kg/ha or kg/m³ of the production unit.

A decision tree provides a useful way to describe management decisions under uncertainty, when the decision has a small set of options, and when the risks that influence the decision outcomes can be described by a small set of states of nature. The branches that follow each decision node and each chance node give this type of diagram its name.

The decision tree represents the flow of time: from decision to uncertain climate conditions, to the final outcome. Recall that the time between a decision and its outcome is called the decision time horizon. Decision trees can also represent sequences of decisions, by adding decision nodes after each state of nature following a chance node. The example below (Figure 3.2-4) represents a sequence of two simple decisions, each with only two options, followed by only two uncertain states of nature. As this example suggests, realistic sequences of farm decisions can easily lead to too many nodes and branches to represent in a diagram.

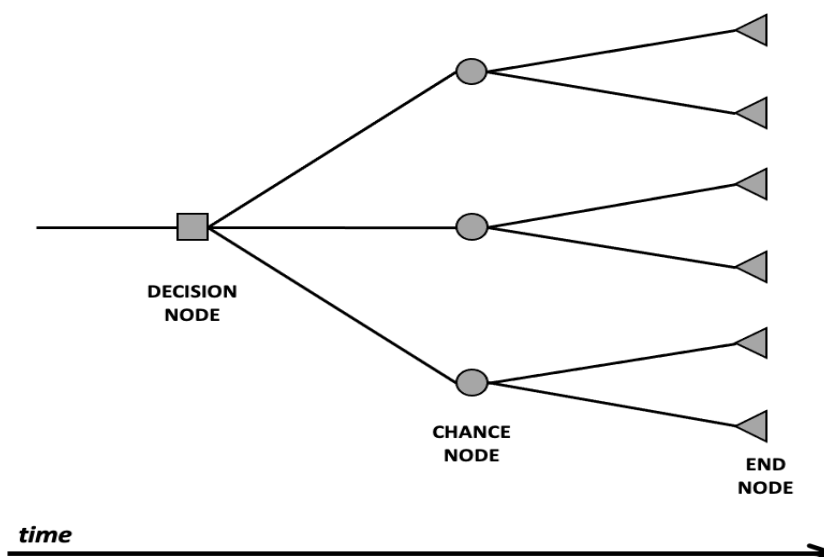


Figure 3.2-3. Components of a decision tree.

If the consequence (e.g., KES of income or kg/ha of yield or litres/day/cow) of each end node is known, and if the probability of each state of nature is known, the expected value of each decision option can be calculated by multiplying the values of each end node by the probability of its state of nature, and then adding the result across all states of nature.

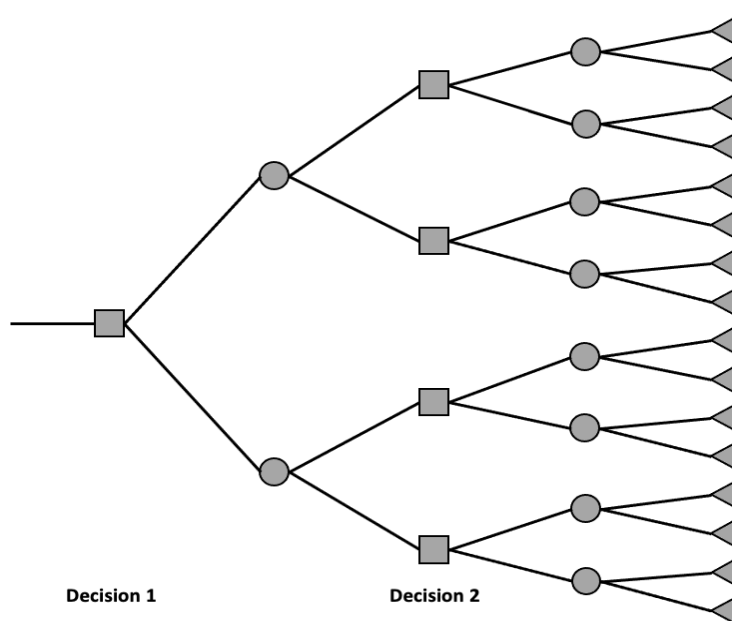


Figure 3.2-4. A decision tree that represents a sequence of two decisions.

A decision tree example

As an example, suppose a farmer faced the choice of whether to purchase crop insurance. (Note that the purpose of this example is to illustrate the interpretation of a decision tree. Insurance will be addressed later in Session 3.6.) Assume that income from crop production would be \$150 (US dollars) if seasonal rainfall were to fall in the below-normal tercile, \$500 if seasonal rainfall were near normal, and \$650 if seasonal rainfall were above normal. The insurance premium costs \$75, and pays out \$200 if seasonal rainfall falls in the below-normal tercile. The premium reduces income by \$75 for any state of nature, and increases income by

\$200 if rainfall is below normal. The probability of rainfall falling in any given tercile is 1/3, or approximately 0.333. This can be represented by the decision tree below (Figure 3.2-5).

Expected income can be calculated from the information in the decision tree:

- With no insurance, expected return is:

$$0.333 \times \$150 + 0.333 \times \$500 + 0.333 \times \$650 = \$433$$

- With insurance, expected return is:

$$0.333 \times \$275 + 0.333 \times \$425 + 0.333 \times \$575 = \$425$$

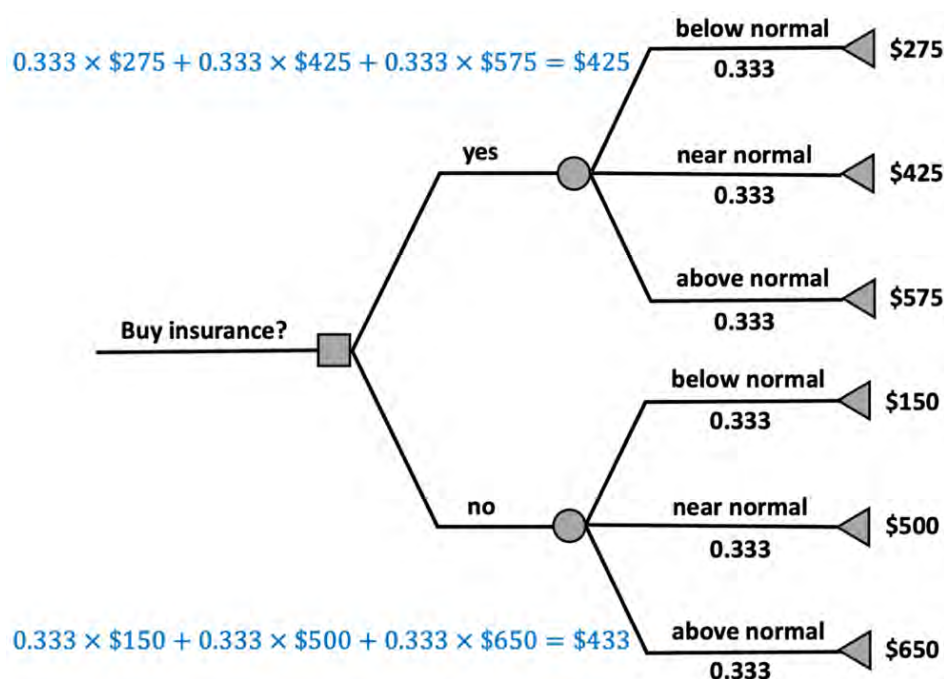


Figure 3.2-5. Decision tree representation of an insurance decision.

For a producer who wants to select the management option with the highest expected return, the decision tree can be simplified by replacing the chance nodes for each option with end nodes showing the expected value (Figure 3.2-6). In this case, the decision to purchase insurance is less profitable, on average.

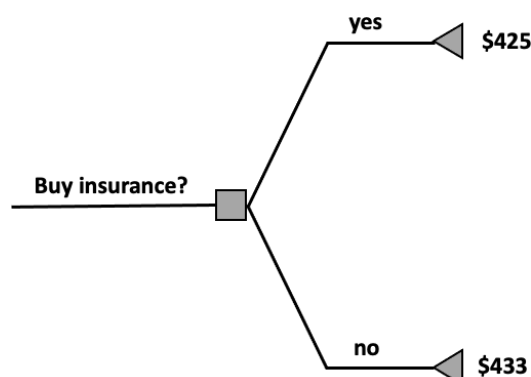


Figure 3.2-6. Decision tree representation of an insurance decision, with uncertain consequences replaced with expected returns.

Forecasts can change the probabilities that different states of nature will occur. In the insurance example, suppose there is a forecast of 25% probability of above normal, 30% probability of near normal, and 45% probability of below normal seasonal rainfall (Figure 3.2-7). In this example:

- With no insurance, expected return is:

$$0.45 \times \$150 + 0.30 \times \$500 + 0.20 \times \$650 = \$380.$$

- With insurance, expected return is:

$$0.45 \times \$275 + 0.30 \times \$425 + 0.20 \times \$575 = \$395.$$

The expected return from both decision options is reduced, and the expected return is higher with insurance than without, because of the forecast.

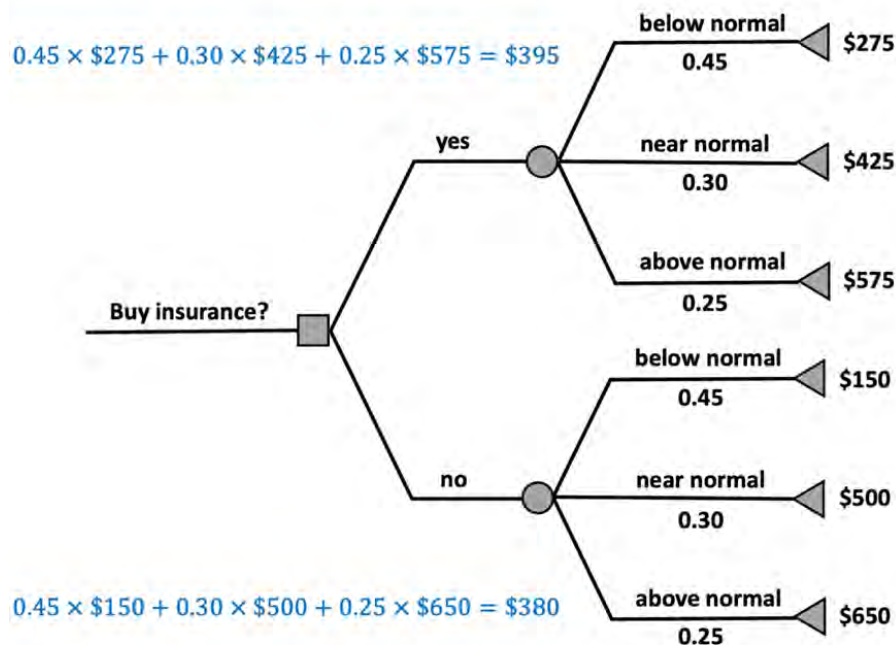


Figure 3.2-7. Decision tree representation of an insurance decision, with probabilities modified by a seasonal forecast.

Limitations of decision trees

Although decision trees can be a helpful way to describe decisions under uncertainty, they have several important limitations when they are applied to real decision problems. First, decision trees can only describe decisions with a small set of distinct options. Decisions such as what crop or cultivar to plant or which livestock breed to keep or fish species to farm can be described with decision trees. However, decisions such as how much fertilizer to use or what percent of available land should be planted with a particular crop have an infinite number of possible options. Second, decision trees can only describe risk with a small set of distinct states of nature. Climate variables such as rainfall amount or average temperature during a particular period can take on an infinite number of possible values. Although it is sometimes convenient

to use terms like above-normal, near-normal and below-normal – as national meteorological services often do when presenting seasonal forecasts – this may over-simplify aspects of climate variability that are important for a management decision. Third, decision trees easily become too complex to draw or analyse for realistic sequences of decisions, with their corresponding options, even if risk is represented by a small number of states of nature. In pastoralist contexts in particular, where extreme variability and instability are fundamental characteristics of socio-ecological systems, decision trees are generally inadequate capture the complexity and fluidity of real-world decision-making.



Exercise: Decision Trees

Working individually or in small groups:

- Draw a decision tree that represents the cultivar decision, the fertilizer rate decision, and the uncertain seasonal rainfall conditions. You may either use shapes and lines in PowerPoint, or draw neatly by hand and attach a photo. Use the returns listed in Table A3.2 below.
- Calculate the expected return for each decision option, and enter the values in the **climatology** column of Table A3.2-1.

Table A3.2-1. Returns (gross margin) from each decision option and state of nature (KES/ha). NOTE: Gross margins and varieties are hypothetical, not based on real data.

Variety	Fertilizer (kg N/ha)	Below-normal tercile	Near-normal tercile	Above-normal tercile	Expected return based on	
					climatology	forecast
SC411	0	1800	2300	2600		
	30	2200	3100	3500		
	60	2000	3400	4000		
SC621	0	2300	2600	3000		
	30	2500	3200	3400		
	60	2350	3100	3500		

- Draw a decision tree that replaces the chance nodes and states of nature with end nodes that show expected returns. What is the most profitable management option?
- Assume that a seasonal forecast shifts the rainfall probabilities to 50% dry, 30% middle and 20% wet for the upcoming season. Repeat steps 2 and 3 using the forecast probabilities, and enter the values in the **forecast** column.
- Briefly discuss how the forecast could influence the decision.

Session 3.3. Decision Making Under Uncertainty

This session expands on the idea that individuals, including farmers, tend to be risk averse. It will present concepts associated with risk aversion, and discuss how to identify management options that could be preferred by a range of farmers who have differing degrees of risk aversion.

By the end of this session, you will be able to:

- Explain the role of risk and risk aversion in agricultural management decisions.
- Explain the concepts, assumptions and limitations of *certainty equivalent* and *risk premium* as they relate to decision making under uncertainty.
- Use an E-S graph to describe risk-return tradeoffs, and identify the risk-efficient set, for a set of production management options.

Risk Aversion and Related Concepts

Session 3.1 introduced the concept of *risk aversion*. While producers generally prefer options that increase average production or income, risk aversion means that a producer also prefers options that reduce risk expressed as the year-to-year variability of production or income. Risk management involves managing trade-offs between the goal of maximizing expected production or income, and the goal of minimizing its variability. The relative importance of these two goals is a function of an individual's degree of risk aversion.

To explain *risk aversion* and closely related concepts, we will imagine a game in which you, as an agricultural professional, must choose between receiving an uncertain income, and receiving a lower but certain income. The “coin toss game” that follows is an unrealistic scenario, but a useful way to understand these concepts.

Imagine that your employer offers you a choice: Instead of getting your annual salary, in the form of a monthly pay check, you could play a game. Your employer will flip a coin and, if it lands on heads, you will get twice as much in each pay check for the next year. If it lands on tails, you will not receive any pay for the next year. If you do not play, you are certain you will receive your annual income (y). If you do play, there is a 0.5 probability of receiving two times your normal annual income, or $2y$, and a 0.5 probability of receiving an annual income of 0. Therefore, the expected value of playing the game is $0.5 \times 2y + 0.5 \times 0 = y$. Figure 3.3-1 represents this decision problem with a decision tree.

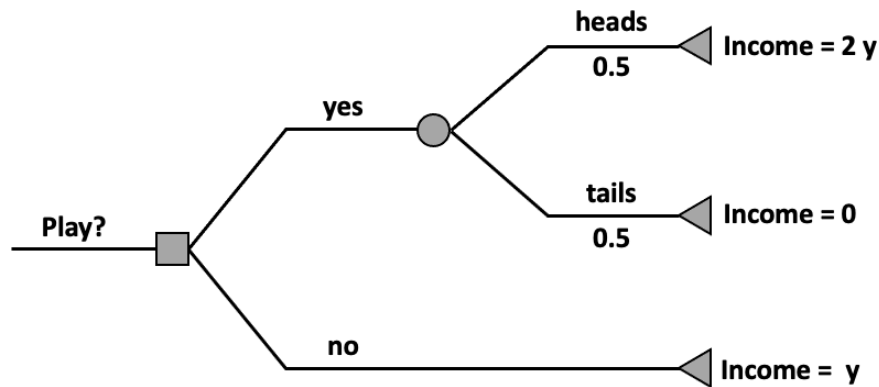


Figure 3.3-1. Decision tree representation of the "coin toss problem" (1 of 4).

Would you play the game? Why or why not?

Most people would choose not to, because the negative consequence of having zero income for the year is much greater than the added benefit of having double their annual income.

What if your employer would only give you 90% of your normal annual income if you decide not to play? In this case (Figure 3.3-2), the expected value of playing the game (y) is greater than the expected value of not playing ($0.9 y$). Would you play? Would you play instead of receiving only 80% of your annual income with certainty? ...or 70%, or 60% (Figures 3.3-2, 3.3-3)?

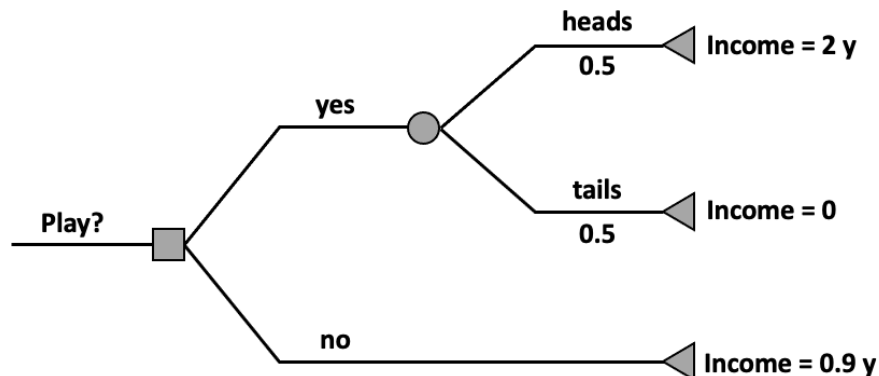


Figure 3.3-2. Decision tree representation of the "coin toss problem" (2 of 4).

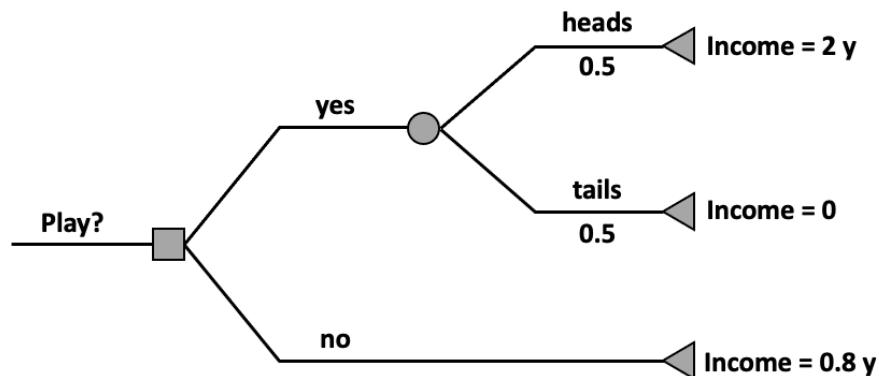


Figure 3.3-3. Decision tree representation of the "coin toss problem" (3 of 4).

At some point, you would be indifferent between playing the game, which gives you expected return equal to your normal annual income (y) with considerable risk, and obtaining a lower but certain return (Figure 3.3-4).

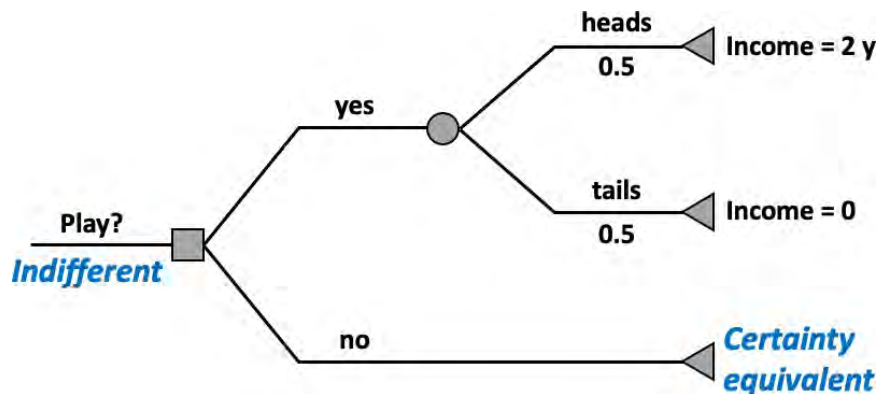


Figure 3.3-4. Decision tree representation of risk aversion “coin toss problem” (4 of 4).

This value is known as the *certainty equivalent*, or *CE*. The *CE* is a guaranteed return that someone would accept, rather than taking a chance on a higher but uncertain return in the future. The *CE* expresses the subjective value an individual places on an uncertain economic return, adjusted for their subjective cost of risk. If the *CE* is less than the expected value of a risky prospect, this indicates that the decision maker is risk averse. For a risk averse individual, uncertainty reduces the value of an option. On the other hand, if a decision maker is *risk-neutral*, meaning indifferent to risk, then for a given decision option their *CE* would be equal to the expected return of that option. According to decision theory, a decision maker who follows a particular set of assumptions will select the available management option with the highest *CE*.

The difference between the expected return and *CE* is known as the *risk premium*, or *RP*, defined as the amount of average return that a decision maker would be willing to sacrifice or, equivalently, the maximum amount that the decision maker would be willing to pay, to eliminate risk. *RP* is a measure of the cost of the combined effects of risk and risk aversion. Increasing either risk aversion or the risk (i.e., the variability) of returns will increase *RP*.

According to decision theory, a *rational* decision maker who follows a particular set of assumptions will select the available management option with the highest *CE*. The *CE* of a given management option, and hence its desirability to a producer, relative to other options, is a function of three factors: expected (or average) return, variability (or *SD*) of returns, and the farmer’s degree of risk aversion. If everything else is held constant, then for a given management option:

- Increasing expected return increases *CE*;
- Increasing variability of return decreases *CE*; and
- Increasing risk aversion decreases *CE*.

Expected utility

The coin toss game introduced the concepts of *CE* and *RP* in a way that can help an agricultural extension worker recognize the importance of risk and risk aversion in farm decision making. A brief introduction to *expected utility* is added here for an advanced learner who wishes to understand how risk aversion and *CE* can be quantified.

The standard framework in economics for accounting for risk preferences assumes that the decision maker seeks to maximize the expected value of a utility function, and conforms to a set of assumptions (or *axioms*) that define “rational” decision making in the face of risk (Anderson et al., 1977). Utility U is a unitless measure of subjective value of, or preference placed on, different levels of wealth w (e.g., stored grain, herd size, or money). The shape of U represents a decision maker’s preferences:

- Increasing U indicates that a decision maker prefers more rather than less – a condition that is assumed to hold for all individuals.
- A utility function U that is *concave* with respect to the horizontal axis (i.e., curved toward the right) implies aversion to risk.
- Linear U implies risk neutrality (i.e., profit maximisers).
- *Convex* (i.e., curved toward the left) U implies risk seeking (i.e., gamblers).

Most people are risk averse, and therefore have a utility function that is concave, as in Figure 3.3-5. The degree of risk aversion is related to the curvature of U ; the more concave the utility function, the more averse the decision maker is to risk. An economic interpretation attributes risk aversion to “*decreasing marginal utility of wealth*.” This means that a given change in wealth (e.g., receiving KES 100) has a greater impact on subjective wellbeing at low levels of wealth than at high levels of wealth. For example, a person in need of transportation will typically gain less benefit from a second or third car than from a single car. As a more relevant example, the benefit from an extra 500 kg maize grain in a good harvest year, relative to the long-term average, does not compensate for the hardship resulting from a deficit of 500 kg of grain in a poor year. Mathematically, the degree of risk aversion is represented by the second derivative of U which expresses its curvature, divided by the first derivative of U which expresses its slope.

Figure 3.3-5 illustrates the concept of expected utility for a simple risky prospect with two equally probable consequences, w_1 and w_2 . In this case, expected outcome $E\{w\}$ is the simple average, $(w_1+w_2)/2$. The vertical axis shows utility associated with w_1 and w_2 , and with the expected return $E\{w\}$. Because U is concave, the expected utility, $E\{U(w)\}$, is less than the utility of the expected outcome, $U(E\{w\})$. Certainty equivalent, CE , is the point on the wealth (horizontal) axis that corresponds to expected utility of the two possible consequences. If we know the shape of a decision maker’s utility function and the probability distribution of wealth at the end of a decision period for a given management option, then CE can be calculated as:

$$CE = U^{-1}(E\{U(w)\}).$$

Maximizing CE is equivalent to maximizing expected utility, $E\{U(w)\}$.

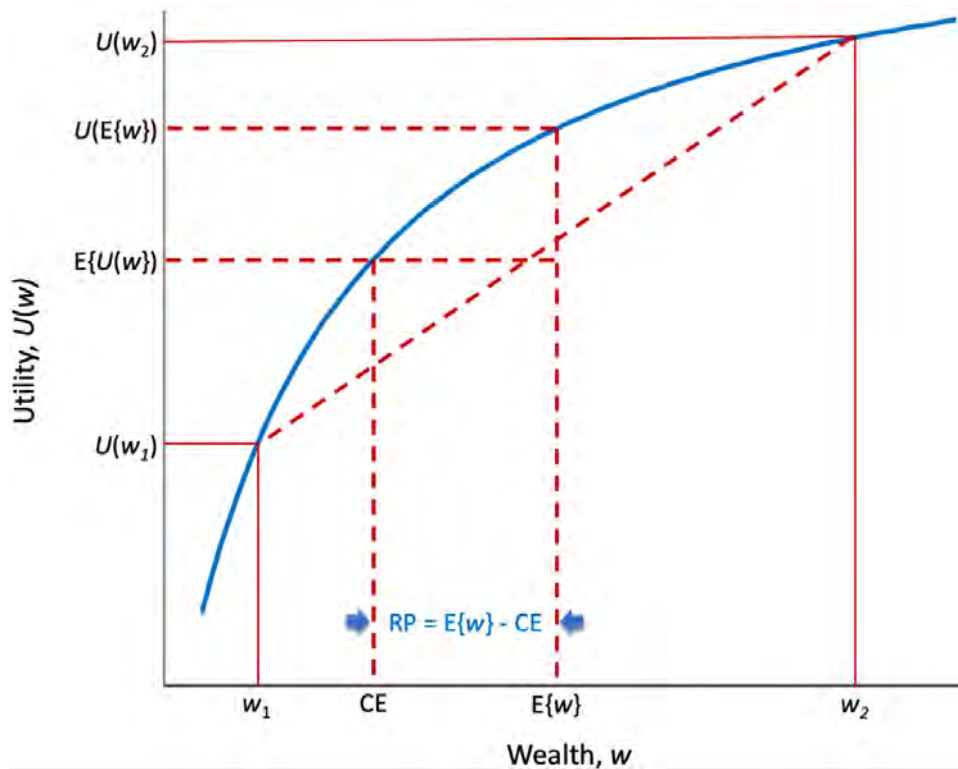


Figure 3.3-5. Illustration of expected utility concepts for a risk-averse decision maker faced with two equally-probable outcomes.

It would be possible to calculate the *CE* of each option, and hence identify the best management strategy if complete information were available about:

- the individual's level of risk aversion;
- the probability distribution of the consequences of each management option; and
- the farm household's assets, income sources and expenses.

However, this type of analysis is generally not used routinely for agricultural extension for three reasons. First, the math used for the analysis is complicated, and requires economic information about the entire farm household. Second, methods to measure individual risk preferences are complicated and time consuming. Third, management recommendations are made for many producers who may have differing economic circumstances and levels of risk aversion.

Assumptions and Limitations

Decision makers seek to maximize *CE* if they:

- know mean and variability of returns for each management option;
- prefer higher over lower expected return;
- do not prefer higher risk over lower risk; and
- have preferences that are rational and consistent.

Maximizing *CE* is a useful principle for guiding risk-averse decision makers to select options that are most consistent with their actual risks and with their goals and risk preferences. However,

there is considerable evidence that people often chose options that are inconsistent with their goals and risk preferences. Widespread challenges to making rational risk management decisions are related to:

- *ambiguity*: people have incomplete knowledge about the probabilistic consequences of decision options;
- *inconsistent preferences*: which involve preferring different options at different times, or depending on how a risky prospect is presented; and
- *cognitive biases* such as loss aversion, which involves putting greater weight on a decision consequence framed as a loss than a consequence framed as the equivalent final wealth.

Decision analysis when preferences are unknown

It is generally not feasible base to identify agricultural management practices that maximize *CE* for a target set of producers. However, simple *risk efficiency analysis* methods can be used to evaluate options for a group of producers who may have different risk preferences, based on a few general assumptions. Rather than identifying the best management option, risk efficiency analysis is used to group management options into a set of options that might be suitable for some decision makers, and a set that that no producer would prefer and that therefore should not be recommended to any.

The simplest type of risk efficiency analysis uses graphs to show trade-offs between expected return and risk. Expected return is expressed as the mean, and risk can be expressed as variance or standard deviation. It is sometimes referred to as E-V (expected return – variance) or E-S (expected return – standard deviation) analysis. E-S and E-V analysis assume that any decision maker prefers higher over lower expected return, and lower risk over higher risk.

The E-S graph in Figure 3.3-6 shows the mean and standard deviation of returns for six management options. A decision maker who wishes to maximize expected return would choose option **E**. A decision maker who wishes to minimize risk would choose option **A**. A decision maker who is somewhat risk averse might select option **C**, and a decision who is more risk averse might select option **B**. No decision maker who follows these assumptions would select option **F**, because options are available with higher expected return and lower risk (options **B**, **C**, and **D**). What about option **D**? This option has a higher return than options **A** and **B**, and lower risk than options **C** and **E**. However, the decision maker could obtain a better combination of risk and expected return by choosing a combination of options **B** and **C**.

To find the set of options that decision makers who meet the assumptions might choose, draw straight lines to connect the decision options that lie above and to the right of other options, as in Figure 3.3-7. These options are known as the efficient set. In this example, the efficient set consists of options **A**, **B**, **C** and **E**. The options that are not part of the efficient set in our example, options **D** and **F**, would not be selected by any decision maker, and therefore should not be included in recommendations.

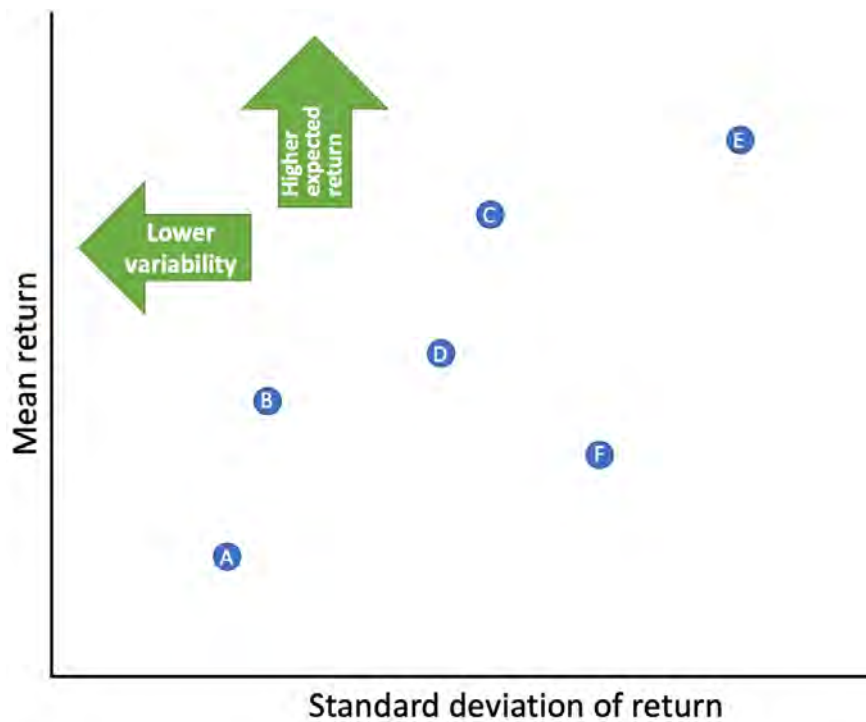


Figure 3.3-6. Risks and expected returns for a set of six management options, represented in a mean - standard deviation (E-S) diagram.

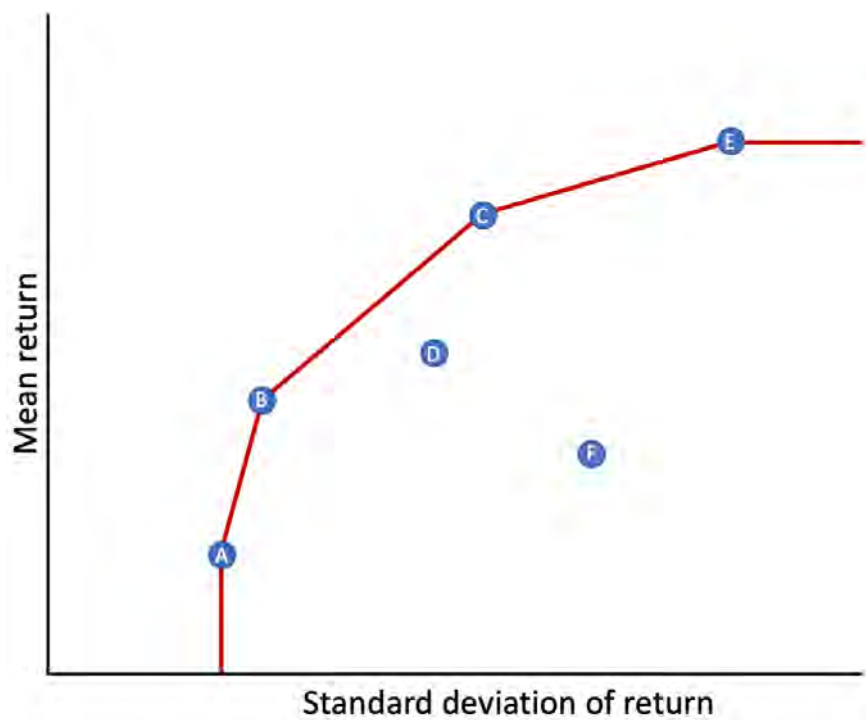


Figure 3.3-7. E-S diagram showing the efficient set of management options.

In addition to the four assumptions for maximization of CE, E-V and E-S analysis assumes that the shape of the probability distribution should approximate a normal distribution. Since real-world decisions often do not completely meet these assumptions, the results of E-V and E-S should be treated as an approximation.

Session 3.4. Tools to Analyse Climate-Sensitive Decisions

This session introduces tools that are useful for translating information about climate, soils, genetic characteristics and management into estimates of crop productivity and profitability.

By the end of this session, you will be able to:

- Describe the role and appropriate use of crop simulation models to estimate productivity.
- Use enterprise budget calculations to compare the profitability of crop and livestock management options.

When sufficient information is available, decision analysis can be used to identify which management options are best adapted to farmers' goals, attitudes towards risk, expected climate conditions and local environment. A rigorous analysis of agricultural management decisions typically includes the following steps:

1. Understand goals and constraints that influence farmers' decisions.
2. Describe the decision problem and management options.
3. Identify relevant climate uncertainties and how they influence production.
4. Estimate probability distributions of crop or livestock production for each management option, based for example on field experiments, crop simulation models, statistical models or expert knowledge.
5. Develop a realistic enterprise budget, and use it to estimate probability distributions of financial returns for each management option.
6. Using climate forecasts, if they are relevant, to modify probability distributions of production and returns for each management option.
7. Use risk analysis to compare management options and identify preferred options, based on based on:
 - Certainty equivalent if risk preferences can be estimated; or
 - E-S or other risk efficiency analysis when preferences are unknown.

Rigorous agricultural decision analysis requires access to good data about the production system, the environment, and farmers' goals and constraints.

As an agricultural extension worker, you may not perform these analyses routinely in your work with producers. However, understanding decision analysis concepts and tools will help you better understand the challenges that producers face as they make risky climate-sensitive decisions, and enable you to more effectively support them with climate information, training and technical guidance.

Estimating Productivity: Agricultural Simulation Models

A model is a simplified representation of a system. Crop simulation models are computer programs that use mathematical functions to mimic the growth and development of animals and crops. The models are based on existing knowledge of crop or animal physiology and ecology, and response to management practices and the environment. The early development of simulation models emphasized their ability to integrate knowledge of different processes, and to simulate interactions between genetics, environment and management, sometimes referred to as “G×E×M” interactions. As their ability to simulate these interactions advanced, models were increasingly seen as a tool to transfer results of traditional agronomic research results to locations other than where they were developed and tested, and to tailor production technologies to specific environments without having to replicate field research at every location. Their ability to simulate yield response to weather, soil, water, and management makes simulation models a useful tool for understanding and supporting climate-sensitive management decisions, when they are used appropriately, with an understanding of their capabilities and limitations.

Levels of analysis

The suitability of a crop model for a given environment depends in part on whether it represents the key determinants of production in that environment. For example, Rabbinge (1993) classified levels of crop production (or “levels of analysis”) by the factors that limit production (Figure 3.4-1). The evolution of crop models paralleled these levels of production. As crop models incorporate additional processes, they tend to grow in complexity and data requirements. In the first level, potential production, crop production is limited only by crop genetic characteristics, solar irradiance, temperature, daylength and CO₂ of a particular plant or organism. Early crop models incorporated basic physiological processes that determine potential production, including phenology, photosynthesis, respiration, and growth of the various plant parts. A second level of detail, attainable production, accounts for soil water and nitrogen availability. Soil water, N and organic C dynamics and uptake were added to crop models to simulate attainable production. This level is sometimes divided between water-limited and N-limited production. Many widely-used crop models are able to describe crop growth and yield with these assumptions. The third level, actual production, may be limited by a range of additional constraints such as pests, diseases, and various soil nutrient limitations and toxicities. Although no model simulates the full range of determinants of actual production, some crop models have attempted to address some determinants at this level, including P dynamics; and response to pests, diseases and various soil physical and chemical. Fish

production models incorporated basic physiological processes that determine growth potential and production.

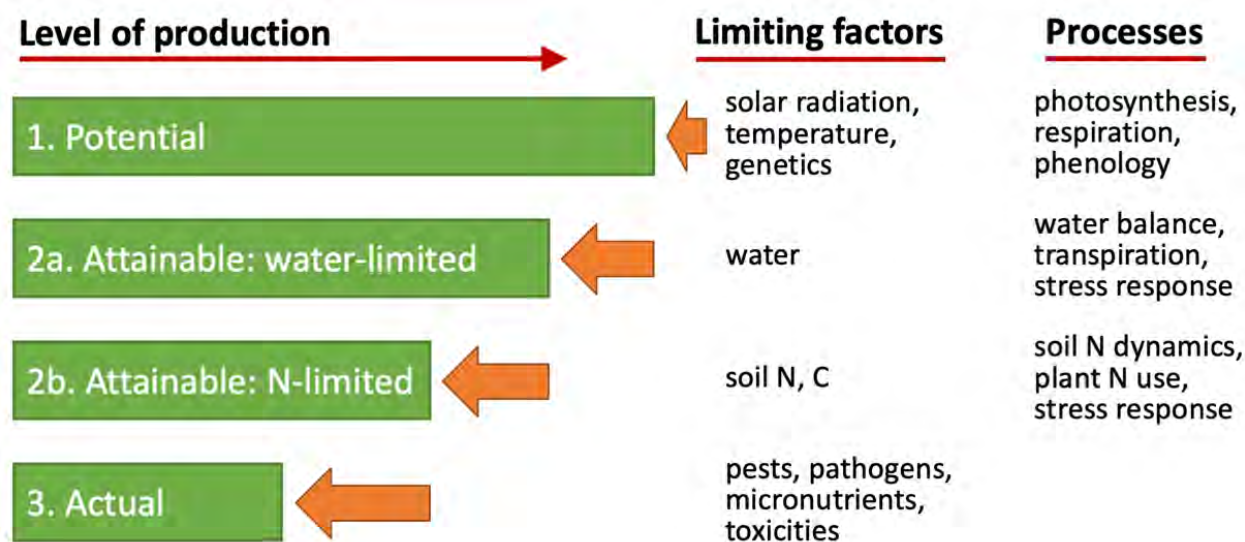


Figure 3.4-1. Levels of crop production.

Model processes

Most widely-used crop models simulate how a community of plants, with specific genetic traits, respond to their environment and management over time. They typically simulate the following processes (Figure 3.4-2):

- soil water and nitrogen balance,
- phenology, or crop growth stage,
- increase in biomass through photosynthesis,
- decrease in biomass through respiration,
- partitioning of crop biomass among parts of the plant (roots, shoots, leaves, grain or other harvested products), and
- loss of biomass through senescence.

Each day, or sometimes at shorter intervals, a typical crop model calculates rates of change in the state of the soil and plant in response to the environment, and calculates the new state of the soil and plant based on the rate of change. The process is repeated each day until the crop reaches physiological or harvest maturity.

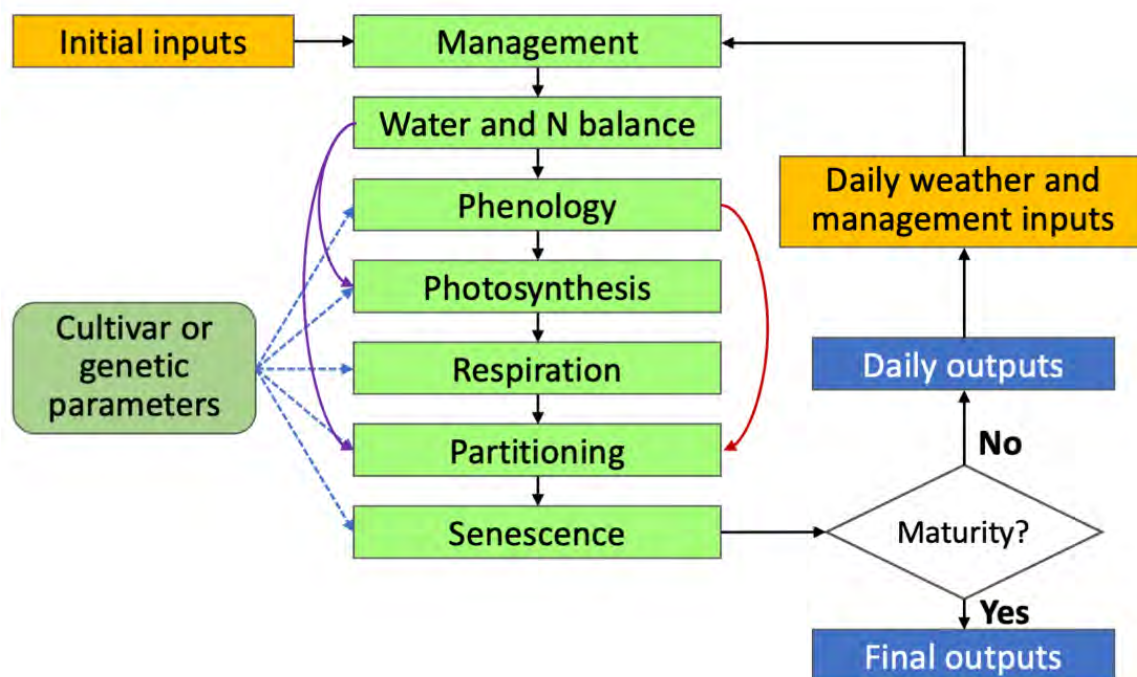


Figure 3.4-2 Simplified flow diagram of processing control for a crop production model operating on a daily time step. Blue and brown arrows indicate information flow. Dashed lines indicate genetic parameter inputs. Adapted from Plant, Cell & Environment 36(9): 1658-1672, DOI: 10.1111/pce.12119

Most of these processes are influenced by daily weather data (Table 3.4-1). Rainfall drives the soil water and nitrogen balance. Potential evapotranspiration is a component of the soil water balance and influences photosynthesis and crop water stress. Potential evapotranspiration is modelled as a function of daily minimum and maximum temperature, solar radiation, and sometimes humidity and wind data. Phenology is controlled by temperature, and for photoperiod- sensitive crops, by daylength. Solar radiation drives photosynthesis. The main physiological processes (phenology, photosynthesis, respiration, partitioning, senescence) are influenced by temperature, and indirectly by rainfall through the soil water and nitrogen balance. Crop simulation models typically require daily precipitation, minimum and maximum temperature, and solar radiation data. Some also use wind and either relative humidity or dewpoint temperature to provide more accurate estimates of potential evapotranspiration.

Table 3.4-1. Daily weather data that influence crop growth and development in crop simulation models (indicated by green shading).

Process	Rainfall	Temperature	Daylength	Solar radiation	PET
Soil water and N balance					
Phenology					
Photosynthesis					
Respiration					
Partitioning					

By simulating the complex interactions between daily weather, soil water and nitrogen dynamic, crop phenology and physiology, crop simulation models generally capture crop response to seasonal climate conditions better than statistical relationships (Figure 3.4-3).

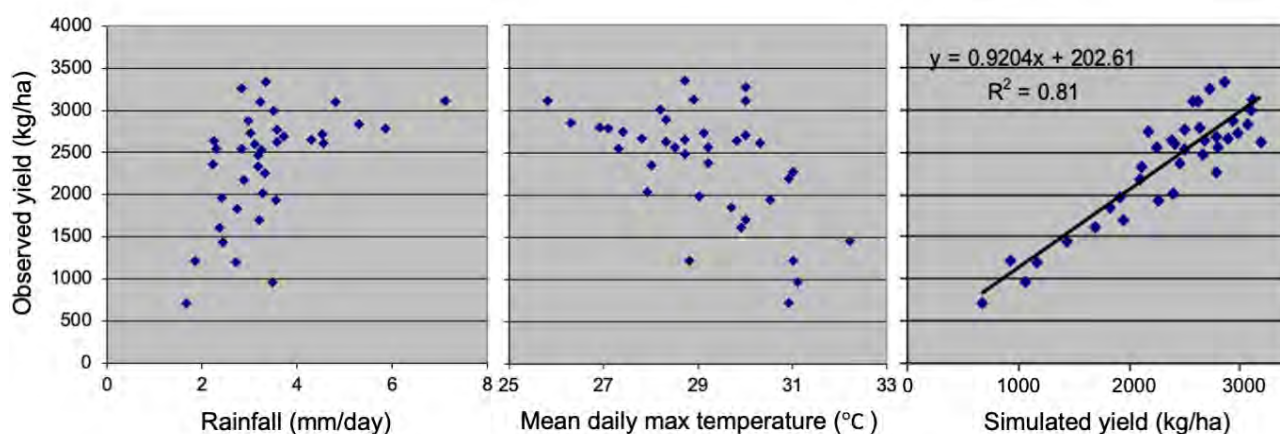


Figure 3.4-3. Observed soybean yields (Georgia, USA, variety trials) vs. seasonal rainfall, temperature, and simulated yields. Source: James W. Jones, University of Florida.

Estimating Profitability: Enterprise Budget Analysis

The profitability of farming depends not only on the income the producer receives from selling their products, but also on the cost of production. A producer will be unlikely to adopt a technology that increases costs more than income. Enterprise budget analysis is a useful tool for estimating the profitability of a farm enterprise, and for comparing the profitability of alternative ways of managing farm enterprises. It can also be used to translate probabilistic information about expected crop, livestock or fish productivity response to particular management options into economic terms that are more relevant to farm decision making. This session will present enterprise budget concepts and terms; how to derive a simple crop, livestock or fish enterprise budget; basic calculations; and how to derive probability distribution of economic returns for a set of crop management options.

An *enterprise budget* is a useful tool for estimating the profitability of a farm enterprise, and for comparing the profitability of alternative enterprise management options. An *enterprise* is defined as the production and marketing of a single crop, livestock or fish commodity that actually produces a marketable product. The enterprise is the lowest managed level in the hierarchy of agricultural systems, and the simplest to analyse. A diversified farm can include many production enterprises, and a farm household may be supported by a combination of farm and non-farm enterprises (Figure 3.4-4).

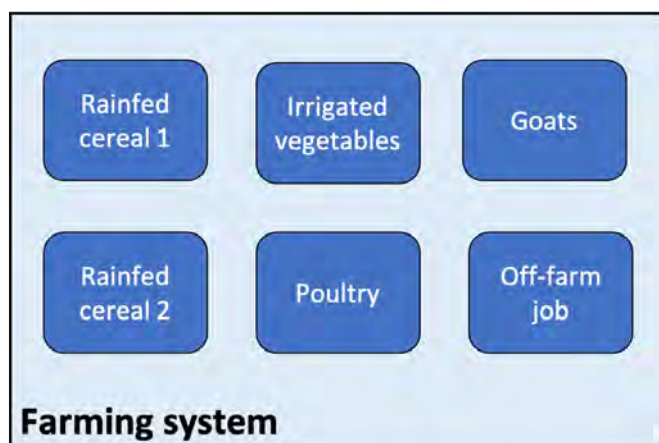


Figure 3.4-4. Illustration of a farming system with several crop, livestock and non-farm enterprises.

An enterprise budget describes the sources and amounts of income, costs and resulting profit associated with a farm enterprise, including:

- variable and fixed costs of production,
- expected yield or productivity,
- expected price of the farm commodity,
- income, or gross receipts, calculated as yield × price,
- gross margin: net income after production costs,
- *breakeven price*: minimum harvest price needed to cover costs, and
- *breakeven yield*: minimum yield needed to cover costs.

Enterprise budgeting involves two simplifications that make analyses simpler and more generalizable across producers. First, it looks at the smallest unit for which producers make management decisions that impact their livelihoods. Second, enterprise budgets are expressed on the basis of a unit of land (i.e., one hectare) or livestock (i.e., one animal or tropical livestock unit (TLU)) basis, so they can be scaled easily to different farm sizes. A *partial budget* further simplifies the enterprise budget by ignoring costs that do not change among the management options that are under consideration. Enterprise partial budgets can be used to compare different management options, as production management does not affect fixed costs. Because of these simplifications results can be interpreted relatively easily across producers employing similar technology under similar environmental (i.e., soil, weather, economic) environmental conditions.

Enterprise budget calculations

Gross margin, or *GM*, refers to the net return, or profit, that a producer would earn per hectare or per animal unit from a single enterprise in a given year. Profitability *GM* is the difference between income generated by the production enterprise, usually from the sale of a crop, livestock or fish product; and the costs incurred in producing the product.

For a crop enterprise *gross margin* can be calculated as:

$$GM = \text{yield} \times \text{crop price} - \text{production cost}$$

where *GM* is in KES/ha, *yield* in kg/ha, *farmgate price* is in KES/kg, and *production cost* is in KES/ha.

For a simple crop enterprise that includes expenses for seed, fertilizer, labour, harvest and post-harvest processing, *gross margin* is:

$$GM = yield \times crop\ price - \begin{aligned} & \text{– planting density} \times \text{seed price} \\ & \text{– fertilizer rate} \times \text{fertilizer price} \\ & \text{– labor used} \times \text{labor price} \\ & \text{– yield} \times \text{harvest and postharvest costs} \\ & \text{– fixed costs} \end{aligned}$$

For a livestock or fisheries enterprise, *gross margin* can be calculated as:

$$GM = animal\ weight \times price - production\ cost$$

where *animal weight* is in kg/animal, *farmgate price* is in KES/kg, and *production cost* is in KES/animal.

Yields and prices are typically the most important sources of uncertainty – in part because of climate variability – that affect farm decision making. When a farmer plants a crop, she does not know what the yield and price will be at the time of harvest. *Breakeven analysis* uses the results of an enterprise budget to identify the minimum yield needed to break even (i.e., not experience a net income loss) for a given farmgate price:

$$breakeven\ price = \frac{production\ cost}{yield}$$

or the minimum farmgate price needed to break even for a given yield:

$$breakeven\ yield = \frac{production\ cost}{price}$$

Practical considerations

The actual formula for an enterprise budget can vary depending, for example, on what aspects of management incur costs, which costs are assumed to vary with management and which are assumed constant, whether the production enterprise generates a single commodity or multiple sources of income, and whether the analysis accounts for the value of household inputs (land, labour) and consumption. Fixed costs, such as rental or tax on land, must be paid every year or season regardless of whether the enterprise is implemented or how it is management. Fixed costs are sometimes included and sometimes omitted from calculations. Tables are often used to list costs; show units, unit prices and quantities of inputs; and compare costs, gross receipts and gross margins for multiple management options. Institutions such as national agricultural research and extension organizations often have their own templates or guidelines for enterprise budget calculations and presentations.

Combining Simulation Models and Enterprise Budget Analysis

Process-based agricultural simulation models can be run with historical weather data to generate probability distributions of productivity. Enterprise budget analysis is often combined with simulation modelling to translate production risk into income risk. The resulting *stochastic enterprise budget* analysis offers a powerful tool for estimating how climate risk and management options impact the profitability of farming enterprises, as long as the input data and simulation results are properly validated.

Example: Maize management at a semi-arid location in Kenya

We use a published study potential use of seasonal forecasts for maize management in Kenya (Hansen et al., 2009) to illustrate the usefulness of combining crop simulation and enterprise budget analysis. The example below examines the influence of fertilizer rate and seasonal rainfall on the productivity and profitability of maize, using weather (1969-2002), soil and cultivar data from the Kenya Agricultural and Livestock Research Organization's National Dryland Farming Research Centre, at Katumani, Kenya (1°35' S, 37°14' E). The APSIM crop model was used to simulate maize response to 11 nitrogen (N) fertilizer application rates (from 0 to 120 kg N/ha) and four planting densities (2.2, 3.5, 4.5 and 5.5 plants/m²). Gross margins were calculated based on prices observed in the local market at the time of the study.

Yields and gross margins showed high year-to-year variability, largely in response to rainfall variability (Figure 3.4-5). Water stress led to complete crop failures in several years. The graph in Figure 3.4-6 shows how both average yield and average gross margin response to fertilizer rate. In this example, yields show a positive response to fertilizer rate at up to about 80 kg N/ha, and remain nearly constant at higher fertilizer rates. On the other hand, mean gross margin increases with fertilizer rates up to 60 kg N/ha, then decreases substantially with higher fertilizer rates. In general, the level of input use that maximizes profitability (expressed as gross margin) is lower than the level that maximizes productivity (expressed as yield). This suggests that fertilizer recommendations should consider cost and profitability, and not be based on maximizing yields.

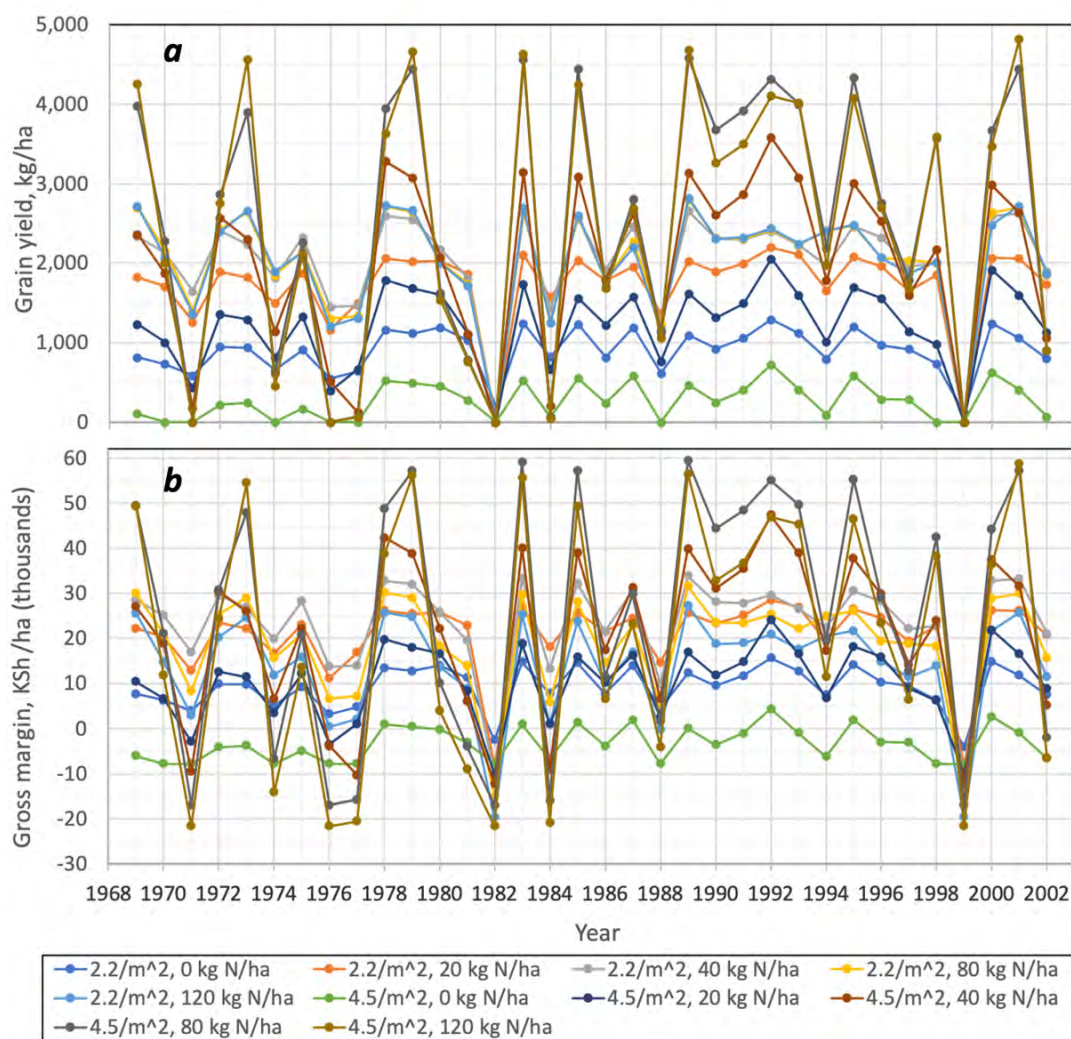


Figure 3.4-5. Maize yield (a) and gross margin (b) time series simulated with daily weather and soil data from Katumani, Kenya, for multiple fertilizer and planting density options. Simulation results from Hansen et al. (2009).

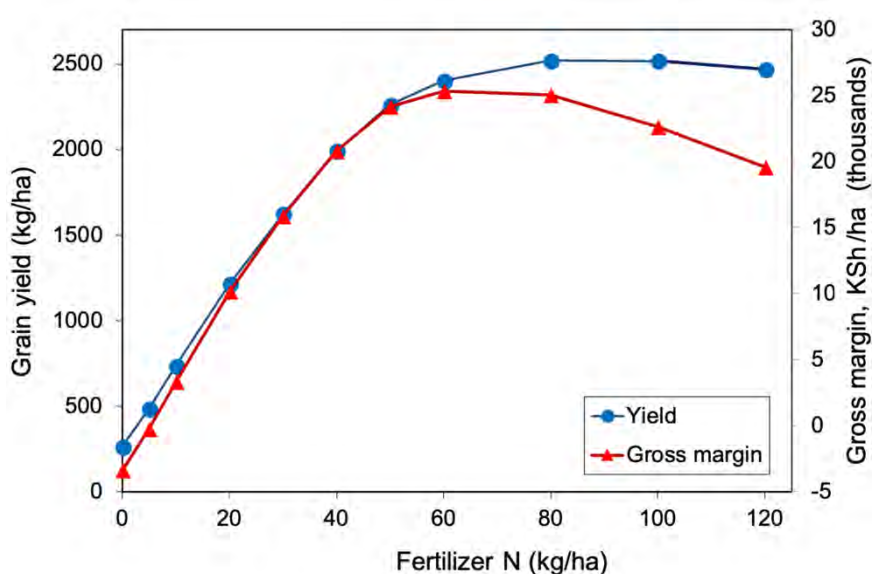


Figure 3.4-6. Mean Simulated maize yield and gross margin as a function of N fertilizer rate, average of all years of weather data. Simulations are based on simulated with daily weather and soil data from Katumani, Kenya, and a planting density of 4.5 plants/m², from Hansen et al. (2009).

To illustrate the interaction between fertilizer rate and seasonal rainfall, Figure 3.4-7 compares yield and gross margin fertilizer response curves averaged across seasons that fall in the dry, middle and wet. In this example, note that yields and gross margins are higher in years with high seasonal rainfall and lower in years with low seasonal rainfall, at every fertilizer rate. Furthermore, for every rainfall tercile, the fertilizer rate that maximizes expected gross margin is lower than the rate that maximizes expected yield. Finally, both the yield-maximizing and profit maximizing fertilizer rates increase with increasing rainfall and decrease with decreasing rainfall. It is often the case that the most profitable rates of production inputs tend to increase in years with favourable seasonal climate conditions and decrease in years with unfavourable climate conditions.

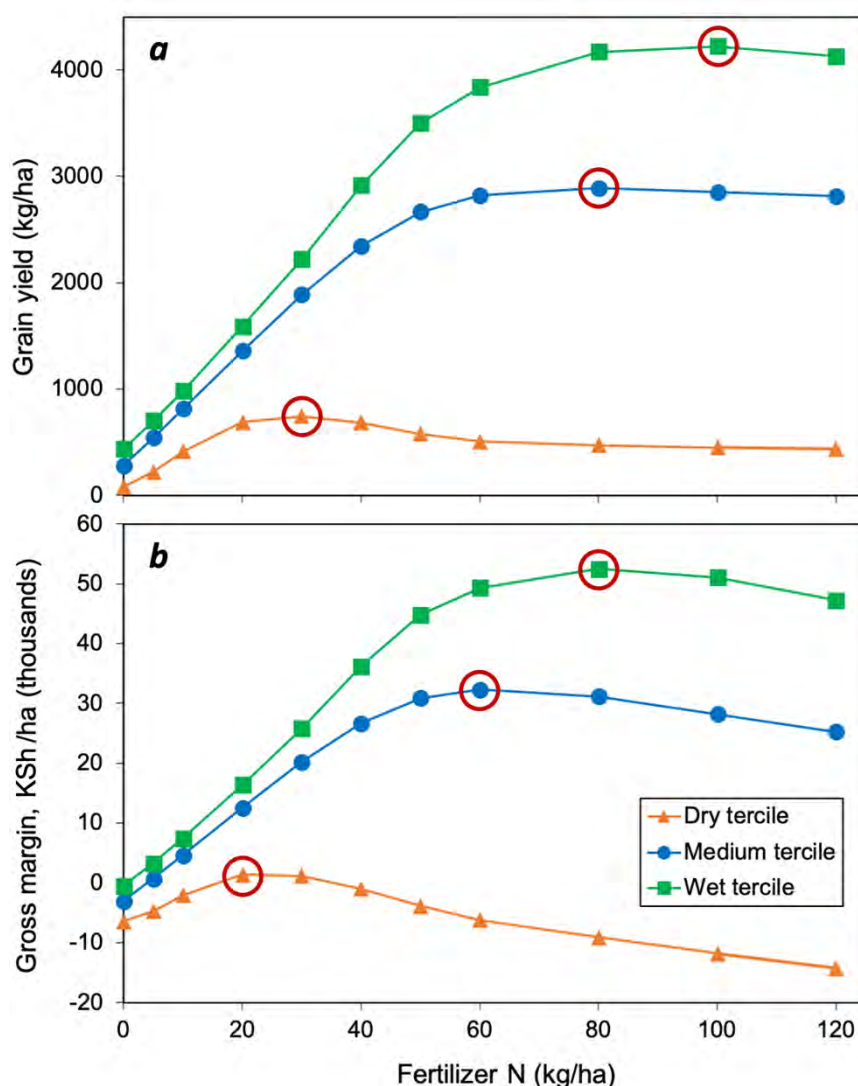


Figure 3.4-7. Simulated maize yield (a) and gross margin (b) as a function of N fertilizer rate, for each October-December rainfall tercile. Simulations are based on simulated with daily weather and soil data from Katumani, Kenya, and a planting density of 4.5 plants/m². Red circles show fertilizer levels that maximize average yield and profitability. Based on Hansen et al., 2009.

Decision Support Tools

Making good production management decisions requires producers to anticipate how crops or animals respond to management decisions, genetics, soils and uncertain future weather. These interactions between crop or animal genetics, the environment (soils, weather, water parameters) and management can be complex. For example, crop production is not a simple function of average climatic conditions during the growing season, but a response to dynamic interactions between weather, the soil and biotic environment, and physiology and phenology of the crop. The state of the environment prior to the growing season, particularly water and nutrients stored within the soil profile, can strongly condition crop response to weather during the growing season. A number of decision support tools combine data, modelling and enterprise budget analysis to help producers and their advisors understand these complex interactions and explore “what-if” questions about management scenarios, and identify promising management options. This session presents agricultural decision support tools, KALRO Selector tool and KAZNET, which are relevant to agricultural management in Kenya. It discusses the capabilities, limitations and appropriate use of modelling tools for decision support.

KALRO Selector

The KALRO Selector is a Big Data service designed to provide advice to producers on what is best to grow or keep on their land. Using advanced data analytics and location-specific information, the platform delivers personalized agricultural recommendations that boost productivity and promote sustainable farming practices. Producers can access the KALRO Selector through its intuitive web platform⁹ or Android application. By inputting key details such as their county, sub-county, ward, and specific GPS location, the tool analyses critical factors, including climate conditions and soil characteristics, to provide tailored, location-specific advisories.

The KALRO Selector offers recommendations for various agricultural decisions. Producers can choose between the crop or livestock selector to receive guidance on the most suitable crop varieties, pasture types, or livestock breeds adapted to their local environment. This empowers producers to make informed decisions, achieve higher yields, and adopt more sustainable farming practices. As a free digital service, the KALRO Selector is a transformative resource for improving agricultural outcomes in Kenya. Figure 3.4-8 shows KALRO Selector crop variety and animal breed recommendations for a ward in Embu County, for the short rains season.

⁹ <https://selector.kalro.org>

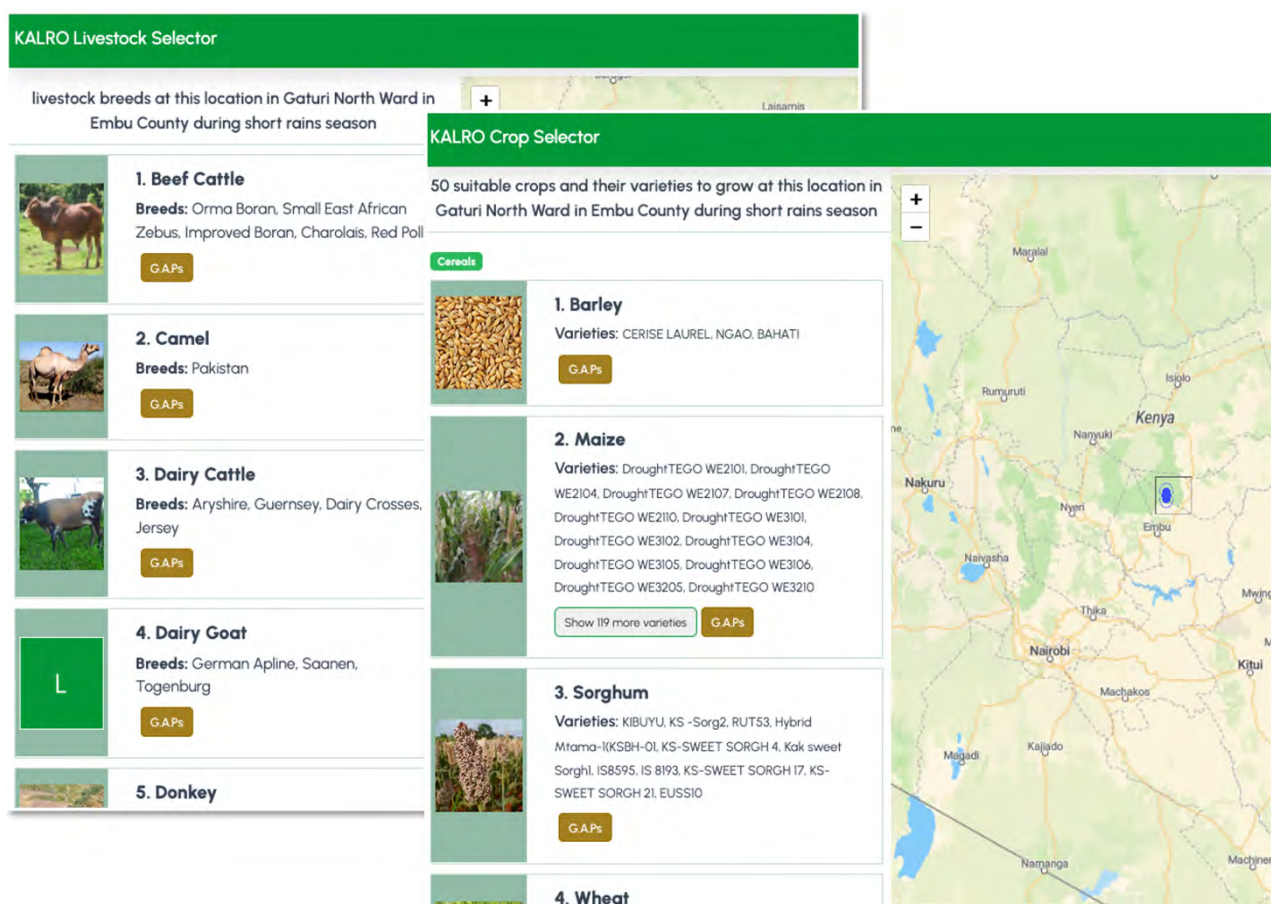


Figure 3.4-8. KALRO Crop Selector and Livestock Selector advisory screen captures for Gaturi North Ward, Embu County, during the short rains season.

KALRO Technology, Innovations and Management Practices (TIMPs)

KALRO's Technology, Innovations, and Management Practices (TIMPs)¹⁰ are digital tools designed to help agricultural extension providers and producers improve productivity, sustainability, and efficiency in the face of climate risks, through appropriate climate-smart agriculture (CSA) practices. The TIMPs system disseminates appropriate management practices, and supports producers to adapt practices through training, information and other support. TIMPs support the following CSA practices:

- *Climate-Smart Precision Agriculture* – Combines climate data (weather forecasts, historical trends) with real-time field data (soil moisture, temperature) to help farmers adjust their practices based on expected conditions.
- *Automated Monitoring and Early Warnings* – Uses weather stations and remote sensing to track environmental changes and predict risks like droughts,
- *Data Management and Climate Risk Assessment* – data management systems integrate climate data with farm-level data (e.g., crop yields, input use, and soil characteristics) to

¹⁰ <https://www.kalro.org/kcsap-timps/>

assess climate risks and vulnerabilities. This information can be used to develop tailored climate adaptation strategies for different farming systems and regions, and to provide farmers with climate risk assessments and guidance on appropriate adaptation measures, such as drought-resistant varieties, water conservation techniques, and diversification strategies.

- *Climate-Resilient Smart Irrigation Systems:* These systems incorporate climate data and forecasts to optimize irrigation scheduling and water delivery, maximizing water use efficiency and minimizing the impact of drought. For example, irrigation can be reduced or suspended during periods of anticipated rainfall, and water harvesting techniques can be promoted to capture and store rainwater for use during dry periods.
- *Integrated Pest and Disease Management (IPDM) under Climate Change:* IPDM, incorporating climate data, can help farmers and advisors anticipate changes in pest and disease dynamics and develop appropriate management strategies.

KAZNET

KAZNET¹¹ is an open-source digital platform that uses micro tasking to collect data from remote locations for dynamic monitoring of climatic shocks, informing early and anticipatory action, and enabling the dissemination of climate information services. KAZNET is an acronym for the Swahili word *kazi* (work) and *net* (internet). It was developed and piloted in 2017 by the International Livestock Research Institute (ILRI) to reduce the costs associated with traditional survey methods to monitor livestock market information and other socio-economic and environmental indicators in remote settings (Alulu et al., 2020; Chelanga et al., 2022).

By utilizing mobile phones, KAZNET efficiently gathers and disseminates livestock market data, enabling decision-makers – including pastoralists, governments, and NGOs – to access relevant information. The system operates on Open Data Kit (ODK) software, allowing offline data collection with submissions occurring when internet access is available. A web-based interface enables administrators to manage tasks, ensuring data accuracy and reliability. Its support for rapid data collection makes it particularly useful for monitoring climatic shocks, pandemics, or economic disruptions. Micro-tasking offers a cost-effective alternative to full-time enumerators. KAZNET's dynamic reward system incentivizes accurate data collection. Figure 3.4-9 shows details of some of the tasks available on the KAZNET app.

¹¹ https://play.google.com/store/apps/details?id=org.ilri.kaznet&hl=en_US

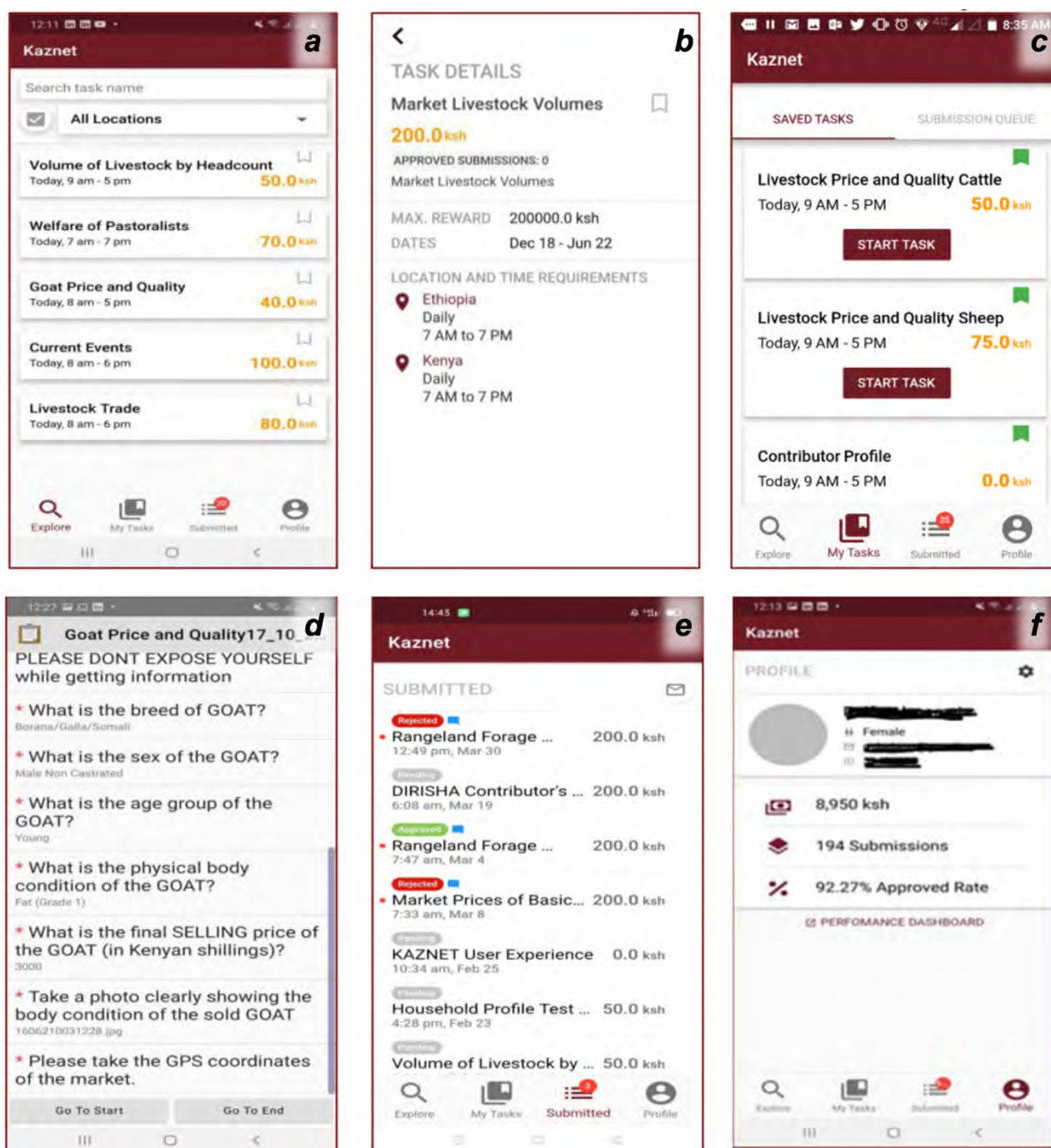


Figure 3.4-9. KAZNET app screen images showing: (a) available tasks for selected location, (b) task details, (c) downloaded tasks available for offline completion, (d) completing a goat price and quality task on ODK platform, (e) submission task status menu, and (f) KAZNET contributor profile. Source: Chelanga et al. (2022).

Appropriate use and limitations of model-based decision support tools

Because crop and livestock model-based decision support tools, such as KALRO selector or KAZNET, make it quick and easy to explore the consequences of a range of management alternatives under a range of historical or forecast weather conditions, it is appealing to use them to generate management recommendations for producers. However, such decision support tools should be used cautiously, with the guidance of experts who understand the assumptions, appropriate use and limitations of crop simulation models.

Crop simulation models have important limitations. They do not simulate many of the processes that can limit crop production, for example, soil micronutrients, soil toxicity, pests and diseases. As a result, they are likely to overestimate the yields that smallholder farmers experience on their fields. The accuracy of crop simulation results depends on the quality of the input data. Obtaining accurate input data is particularly challenging for soil properties, which can vary a great deal over short distances; and for initial soil moisture and nitrate content, which vary in space and in time.

If models have been tested in the environment in which they will be used, and if good input data and expertise is available, crop simulation models can contribute to extension recommendations in at least three ways. First, crop models can be used to screen potential crop management strategies for a particular environment, and identify a small set of promising candidates to test through field experiments or on-farm trials. Second, crop models can test how sensitive recommended crop management practices are across a greater range of range of soil and weather conditions than can be sampled through field experiments. This can indicate whether a particular cultivar or management practice can be recommended with confidence across a wide range of soils and climatic conditions, or if it should be adjusted for specific conditions. Finally, and perhaps most important, decision support tools that employ crop models provide a useful way for farmers and their advisors to learn principles of climate risk management. Such tools support learning through accelerated experience and experimentation with decision scenarios. When these tools are used in a group setting to experiment with management options under different climate scenarios or other environmental conditions, they sometimes challenge the existing beliefs of farmers, advisors and even researchers, leading to new ways to think about their risk management challenges. For this reason, these crop model-based tools are sometimes referred to as “discussion support tools.”

The modelling and decision support tools presented in this session focus on the management of individual production enterprises. However, producers also make many decisions that impact more than one enterprise, for example:

- allocation of farm land among crops, pasture, fallow or other land uses;
- household labour allocation among farm and off-farm enterprises, and household care responsibilities;
- leasing or purchasing land;
- allocating money among consumption, precautionary savings, and investing in the farm;
- borrowing and loan repayment; and
- major capital investments such as land, farm structures, equipment, and education.

Analysing the economic consequences of these decisions requires more complex whole-farm analysis. Furthermore, analysing a single farm enterprise does not give a complete picture of the risk that a producer faces. This is because diversification reduces risk (Session 3.5). For a diversified farm, the variability (expressed as coefficient of variation) of household income can

be much lower than the average variability of gross margins from individual production enterprises if the different sources of farm income are not strongly correlated. Any non-farm income also tends to reduce the variability of overall income of a farm household. For these reasons, fully understanding the consequences of the management options that a producer faces would require analysing income, expenses and assets from all sources. The complex analyses needed to capture such farm-level decisions are beyond the scope of this course.

An assessment of the first 1-1/2 decades (since the late 1980s) of the early pioneering use of climate-informed, model-based agricultural decision support tools in Australia found that farmers benefited – not by implementing the actions that the tools identified, but by better understanding and anticipating climate risks, exploring new management options, and updating their own “rules-of-thumb”. This evidence led to a shift in focus: from “decision support” to “discussion support,” and towards using these tools to support co-learning among producers and agricultural advisors (McCown et al., 2012; Nelson et al., 2002). Based on the early Australia experience and more recent assessments (Duncombe, 2018; Tsan et al., 2019), digital decision support tools are expected to most effective when they feed into farmers’ decision-making processes, strengthen social learning among producers and agricultural advisors, and aim to strengthen rather than replace institutional advisory services.



Exercise: Analyse Crop Management Options

- *Work in small groups.*
- *This activity will provide experience using crop simulation and enterprise budgets to analyse agronomic management options. You will perform a basic crop gross margin calculation, examine gross margins for a range of management options, and conduct a graphical E-S analysis of those options, using outputs from a published maize management simulation study from a semi-arid location in Kenya.*
- *Instructions are in activity sheet, **A3-4 Analyse crop management options.docx**.*
- *The exercise requires Excel spreadsheet, **A3-4 Katumani maize enterprise budget.xlsx**.*

Session 3.5. Climate Information and Agricultural Decisions

This session discusses a few important examples of use of climate information to inform agricultural management decisions. It covers adapting agricultural management strategies to the local climate based on historical data analyses, seasonal forecasts for seasonal farm planning, and planting decisions in rainfed annual cropping systems.

By the end of this session, you will be able to:

- Describe ways historical climate data can be used to adapt agricultural systems to local climate conditions.
- Describe opportunities for farmers to use seasonal climate forecasts for planning.
- Recognize and identify solutions to common challenges to using seasonal forecasts for agricultural decision making.
- Describe climate-related factors that influence decisions on crop, livestock and fish production systems, and information that can inform those decisions.

So far, this module covered climate impacts on agricultural production and producers (Session 3.1), principles of decision making under uncertainty (Sessions 3.2 and 3.3), and tools and approaches to analyse consequences of agricultural management decisions in the face of climate risk (Session 3.4). Recall that the time scale of climate information should match the time horizon of decisions, if climate services are to be useful for risk management decisions (Session 3.2). This session discusses a few examples of climate-sensitive crop and livestock management decisions, and the types and time scales of information that can inform these decisions.

Adapting agricultural systems to historical climate

Historical climate data are the main source of knowledge about the seasonality, variability and trends that define the local climate. This knowledge is foundational to developing agricultural systems that are well adapted to their local climate, particularly when that climate is changing.

Targeting appropriate species, varieties and production technologies

The use of historical meteorological records, directly and with the aid of simulation models, to analyse risk and support decision-making is well established in agricultural research and practice. Historical climate analyses can inform a range of agricultural planning questions, such as:

- *What crop varieties, and fish and livestock species and breeds, are suited to what locations?* Crop breeders use climate data to match variety characteristics to local climate conditions. Relevant spatial climate information includes mean onset, cessation and length of the rainfed growing season. Thermal time to maturity, crop water requirements, and optimal temperature ranges are also relevant for targeting crops and varieties to local climatic conditions.
- *What fertilizer rates should be recommended to farmers?* Crop response to chemical and organic fertilizers is a complex function of crop, soil, and climate characteristics, and stand density (see illustrative example in Session 3.4). Using spatial soil and climate data to produce location-specific fertilizer recommendations is expected to improve agricultural profitability and increase technology adoption relative to blanket fertilizer recommendations over large areas.
- *What areas are best suited to irrigation development?* Historical climate data analyses can provide information about where rainfall is adequate to support optimal crop production, how much additional water would need to be supplied by irrigation to meet any rainfall deficit, and how these vary from year to year. As discussed earlier (Session 3.1), a soil water balance model can capture the dynamic interactions between water supplied by rainfall, plant demand for evapotranspiration, and development of the plant. A soil water balance model is essential for calculating seasonal indexes such as the Water Requirements Satisfaction Index (WRSI), but can also provide additional information about the timing of water deficits and resulting plant stress.
- *Where do particular climate-sensitive diseases threaten crop, livestock or fish production?* Weather conditions influence the multiplication and spread of many agriculturally important pests, disease organisms, and animal disease vectors. Variables such as temperature, relative humidity, precipitation and (for spread of disease organisms) wind can indicate whether conditions are favourable for an outbreak or infestation. Knowing where climate conditions are favourable or unfavourable for these biological threats may inform decisions about where to develop new agricultural products and value chains, and where to prioritize investment in monitoring and control measure.

Detecting and understanding change

Because of climate change, crops, pastures, livestock and fish species, and production practices that were well adapted to local climate conditions a few decades ago might not be adapted to current climate conditions. For example:

- Hazards such as droughts, flooding or heat waves may have increased or decreased.
- The timing of the onset or cessation of the rainfed growing season may have shifted.
- Crops and fish likely mature earlier due to increasing growing season temperatures.
- Changes in temperature or humidity may have changed risk of climate-sensitive pest or disease threats to crops or livestock.
- The rising water levels in lakes and ocean is changing fish habitats; this affects breeding grounds and fishing ground.

Any of these changes may warrant changes in agricultural practices, to adapt to new local climate conditions.

In traditional rural communities, agricultural production systems may have been refined and passed down from parent to child over generations. While this trial-and-error process can be very effective at adapting agricultural systems to stable local environments, it cannot keep pace with rapid changes in land use, technologies, or market conditions; and in recent decades, in the climate itself. Traditional rural communities also learn by experience to understand their local climate and use observable indicators to anticipate upcoming weather conditions. But traditional climate knowledge can be biased, confounded by changes in land use or soil quality, or eroded by rapid climate change. Traditional agricultural systems may be poorly adapted to the current climate as a result. Poor agricultural investments and maladaptation can result if either:

- real climate change is not recognized; or
- changes in agricultural performance are misattributed to climate change when another driver is the underlying cause.

Analysis of historical meteorological records offers a way for producers and other decision-makers to check their perceptions about change, or lack of change, against objective measurements. This may correct either type of error: either raising awareness of real trends in aspects of climate that impact their farms; or suggesting whether perceived changes are caused by anthropogenic climate change, natural low-frequency climate variability, or some other driver of change such as land use change or soil degradation.

Adapting farm management

While agricultural research and extension organizations are responsible for developing appropriate agricultural production technologies and farmer advisories, producers are ultimately responsible for making adoption and management decisions that are consistent with their goals, constraints and level of risk tolerance. At the farm level, historical climate analysis can inform questions such as:

- *Are my crops, fish, and livestock adapted to my local climate?*

- *Are my farm and family resilient to climate change hazards?*
- *Am I taking advantage of years with good climate conditions?*

Participatory Integrated Climate Services for Agriculture (PICSA) is an example of a successful approach for adapting farm management to local climate conditions. PICSA is a systematic workshop process, facilitated by trained intermediaries, that guides farmers to adapt their farming and livelihood system to their local climate based on local historical climate time series graphs, and participatory resource mapping, activity calendars and budgeting activities. PICSA and other participatory communication approaches are discussed in Session 4.1.

Forecast-based seasonal farm planning

Role of seasonal forecasts in farm management

Although farmers make management decisions many times throughout the year, the period shortly before the main agricultural season is a particularly crucial time when farmers must make many strategic decisions. Seasonal forecasts are potentially relevant to a wide range of agricultural production systems and decisions. However, seasonal forecast use has been most studied, and evidence suggests it is most widespread, in the case of rainfed annual crop production. Across sub-Saharan Africa, available evidence shows that a large proportion of crop farmers who have access to seasonal forecasts adjust at least some of their management decisions in response despite the challenges that they face (Vaughan et al., 2019). Adoption rates are often lower for livestock production decisions.

The benefit from seasonal forecast use for crop, livestock and fish production management is a function of interactions among seasonal climate conditions, management options, prices of inputs and farm commodities (i.e., crops, livestock, fish products), productivity and profitability. In general, it is profitable to increase investment in production inputs (e.g., fertilizer application rates, seed, weed control, animal feeds) when favourable climate conditions are anticipated, and reduce investment in production inputs when rainfall deficits or other adverse conditions are anticipated. The Kenya maize fertilizer modelling study presented earlier (Session 3.4, Figure 3.4-7) illustrates this interaction. In that example, the profit-maximizing fertilizer rate varied with seasonal rainfall total:

- 80 kg N/ha in the wettest 1/3 of years;
- 60 kg N/ha in the middle 1/3 of years; and
- 20 kg N/ha in the driest 1/3 of years.

If seasonal forecasts are skilful (meaning they provide significantly more information about the upcoming season than the historical climate distribution), and if producers interpret seasonal forecast correctly and incorporate them into their decision making, they are expected to lead to better decisions that improve producer wellbeing on average. However, because seasonal forecasts are probabilistic, producers will not necessarily benefit every year.

How do Kenyan farmers use seasonal forecasts?

In Kenya and across Africa, a large proportion of farmers who have access to seasonal forecasts change at least some of their management decisions in response despite the challenges that they face. A few studies offer insights into how Kenyan farmers respond to seasonal climate forecasts.

In an early study, Ngugi et al. (2011) surveyed 240 farmers and agropastoral households across three agroecological zones in the Machakos District in 2001 to assess awareness and potential use of seasonal forecasts. Respondents identified different types of decisions they would change, depending on whether they anticipated above-normal, near-normal, or below-normal growing season rainfall (Figure 3.5-1). The most frequent management responses related to soil conservation, and cultivar selection if wet conditions were anticipated; and to crop and cultivar selection, early planting, and feed and fodder conservation if dry conditions were anticipated.

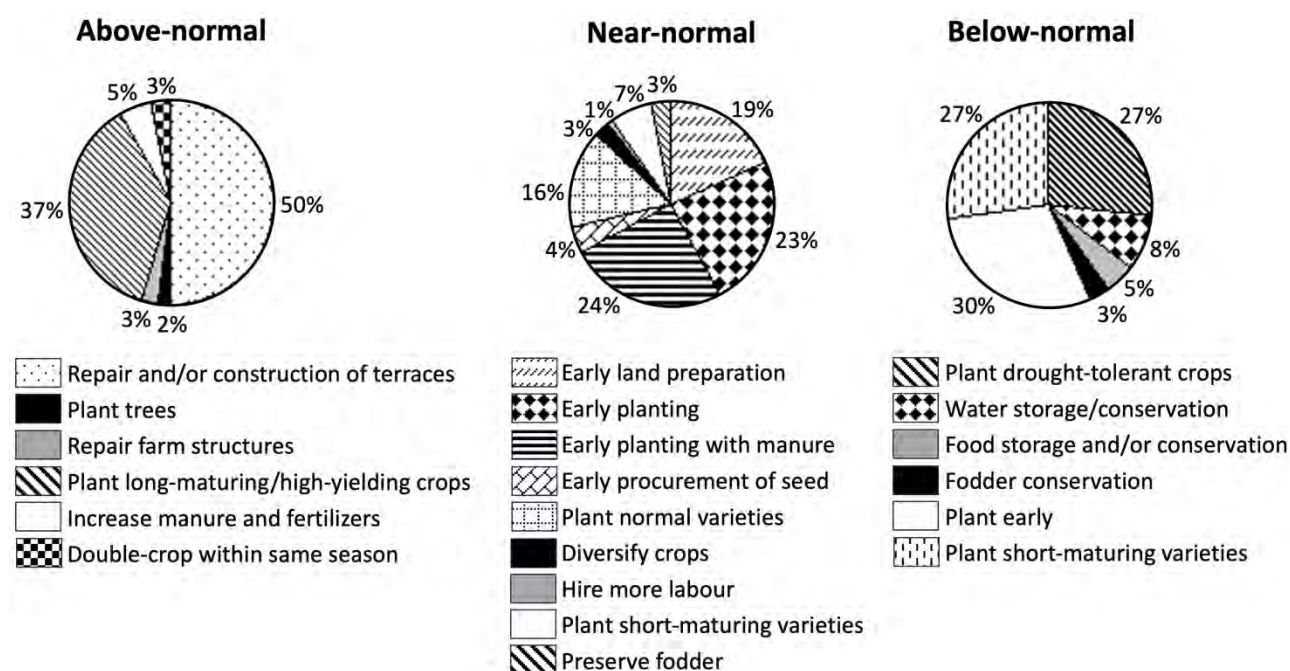


Figure 3.5-1. Management decisions that surveyed farmers in Machakos district would change in response to increased likelihood of above-normal, near-normal, and below-normal growing season rainfall. Adapted from Ngugi et al., 2011.

More recently, Guido et al. (2020) surveyed 501 smallholder farmers on the western slope of Mount Kenya in central Kenya in 2018 to understand their response to KMD forecasts. More farmers (51.7%) acted on the March-May long rains forecast than on the October-December short rains forecast (41.3%) (Figure 3.5-2). The most common management responses to seasonal forecasts were changing planting date, followed by crop selection and cultivar selection.

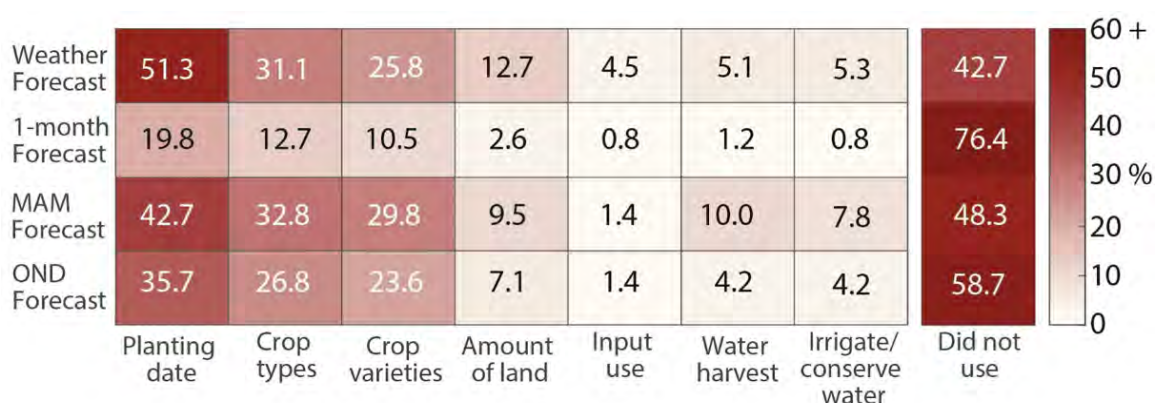


Figure 3.5-2. Management decisions that surveyed farmers in central Kenya would change in response to weather and climate forecasts. Source: Guido et al., 2020.

Common challenges and solutions

Producers may encounter several common challenges when using seasonal climate forecasts. A good understanding of these challenges suggests ways that agricultural extension workers can help producers overcome them and make better use of seasonal forecasts. The discussion below draws on Hansen et al. (2011; 2022).

First, resource constraints can limit the capacity of relatively poor smallholder farmers and pastoralists to act on forecasts. For example, a high-yielding hybrid might perform much better than the usual cultivar in a season that is predicted to have longer growing season with higher rainfall than normal. Yet smallholder farmers cannot change cultivars if seed is not available, or if they cannot access credit to purchase the seed. Although such constraints can reduce the options available, particularly for relatively poor smallholder farmers, available evidence from across Africa shows that the majority of crop farmers who access seasonal forecasts change some management decisions in response (Hansen et al., 2011; Vaughan et al., 2019). Although severe resource constraints can exclude relatively poor smallholder farmers from some forecast-based management options, adjustments to allocation of land and labour among farm activities, and to the timing of farm operations, are less likely to be affected by resource constraints. When availability of key inputs, such as seeds or credit, limit farmers' ability to benefit from seasonal forecasts, agricultural institutions and value chain actors might be in a position to take actions that alleviate farmers' constraints to acting on forecasts.

A second challenge involves the concern about how a "wrong" forecast could impact the wellbeing of relatively poor, vulnerable producers. The possibility that a producer could experience worse net income or production in some years, as a result of acting on seasonal forecasts, is an important challenge. However, this concern reveals a problem with how seasonal forecasts are sometimes communicated and interpreted. If forecasts are skilful, then they should improve farmers' wellbeing, on average, if producers interpret the forecast distribution accurately, and if they make decisions in response to the forecast in a way that is consistent with the way they make decisions in response to historical climate uncertainty. However, a producer might respond to seasonal forecasts in a way that is inconsistent with their goals and risk tolerance if:

- probabilistic information is lost or distorted somewhere in the forecast generation, communication or interpretation process;
- the producer has difficulty understanding new information formats; or
- agricultural advisories or policy interventions promote particular management responses that are inconsistent with farmers' goals or risk tolerance.

Errors can be avoided and producers' welfare can be protected by communicating the probabilistic nature of seasonal forecasts, and training producers to understand and act on probabilistic seasonal forecasts, in a manner that is consistent with how they understand and act on seasonal climate variability in the absence of forecasts.

Third, common conventions for presenting seasonal forecasts do not align well with farmers' needs. The most widely used convention expresses a seasonal forecast as probabilities that rainfall in the upcoming season will fall in "below-normal," "normal" or "above-normal" categories, defined as the lowest, middle, and highest third of the distribution of seasonal rainfall amounts from the past 30 years (Session 1.4). Experience with producers across many countries and contexts has revealed several weaknesses that limited the usability of these forecasts for local agricultural decision-making:

- Coarse spatial forecasts do not provide information about expected climate conditions at farmers' location.
- Forecast categories are often misunderstood as something other than terciles.
- Tercile probability shifts (e.g., "*above-normal probability of below-normal rainfall*") are complex and prone to misinterpretation.
- The 33rd and 67th percentiles of historical distribution that define terciles are arbitrary, and not necessarily relevant to particular farm decisions.

These constraints reflect conventional practice, and not inherent characteristics of seasonal forecasts. Most of these weaknesses can be reduced by switching to objective forecast methods, using local historical climate data to calibrate and downscale forecasts, and presenting probability distributions of the forecast along with the climatological distribution (Table 3.5-1). The Flexible Forecast Maproom presentation (Session 2.3, Figures 2.3-5 and 2.3-6), which KMD and a few other African NMS are adopting, address the main weaknesses of the tercile convention by using local historical climate data to calibrate and downscale forecasts, and presenting the forecast as probability distribution graphs alongside the historical distribution for the same location, season and variable. Downscaling the forecast onto local climate data, and presenting the climatological distribution alongside the forecast distribution, in physical units (e.g., mm rainfall), provides all of the information needed to anticipate upcoming seasonal climate conditions at the local scale of decision-making. Presenting the full forecast distribution provides forecast quantities or probabilities associated with any decision-

relevant threshold, and avoids misinterpretations that are common to categorical probabilistic forecasts. The ability to compare the shapes and position of the forecast and climatological distributions conveys the degree of uncertainty of the forecast relative to climatology, and hence the skill of the forecast, more clearly than tercile probability shifts. Assuming hindcast residuals are used to calibrate a forecast distribution, the narrower the forecast distribution, the greater the accuracy of the forecast system.

Table 3.5-1. Tercile seasonal forecast usability challenges, and solutions available through NextGen forecast methods and Flexible Forecast presentation. Adapted from Hansen et al., 2019.

Challenge	Solution
Lack information about local climate	Downscale forecasts
	Bundle forecasts with local climatology
Categories are difficult to understand	Provide full forecast probability distribution
Categories don't match decisionmaker thresholds	
Limited relevance of seasonal averages	Forecast additional variables
	Translate into impacts, options

Fourth, different producers may make very different decisions in response to the same forecast. If agricultural extension or national meteorological service workers attempt to top-down recommendations about how producers should act on seasonal forecasts, the failure to consider producer differences can create a challenge. Allocation of scarce farm land, household labour and finance (e.g., savings, credit) are quite sensitive to differences in resource availability, to changes in expected commodity and input prices, and to producer goals and level of risk aversion. Results of a model-based study of the value of ENSO information for a simple crop mix problem in Argentina (Messina et al., 1999) illustrate the sensitivity of seasonal farm land allocation decisions to risk preferences and prices (Figure 3.5-3). For such decisions, advisories should be tailored to varying producer characteristics and contexts. An effective approach is to support farmers' understanding and use of seasonal forecasts with participatory communication and planning approaches (Session 4.3).

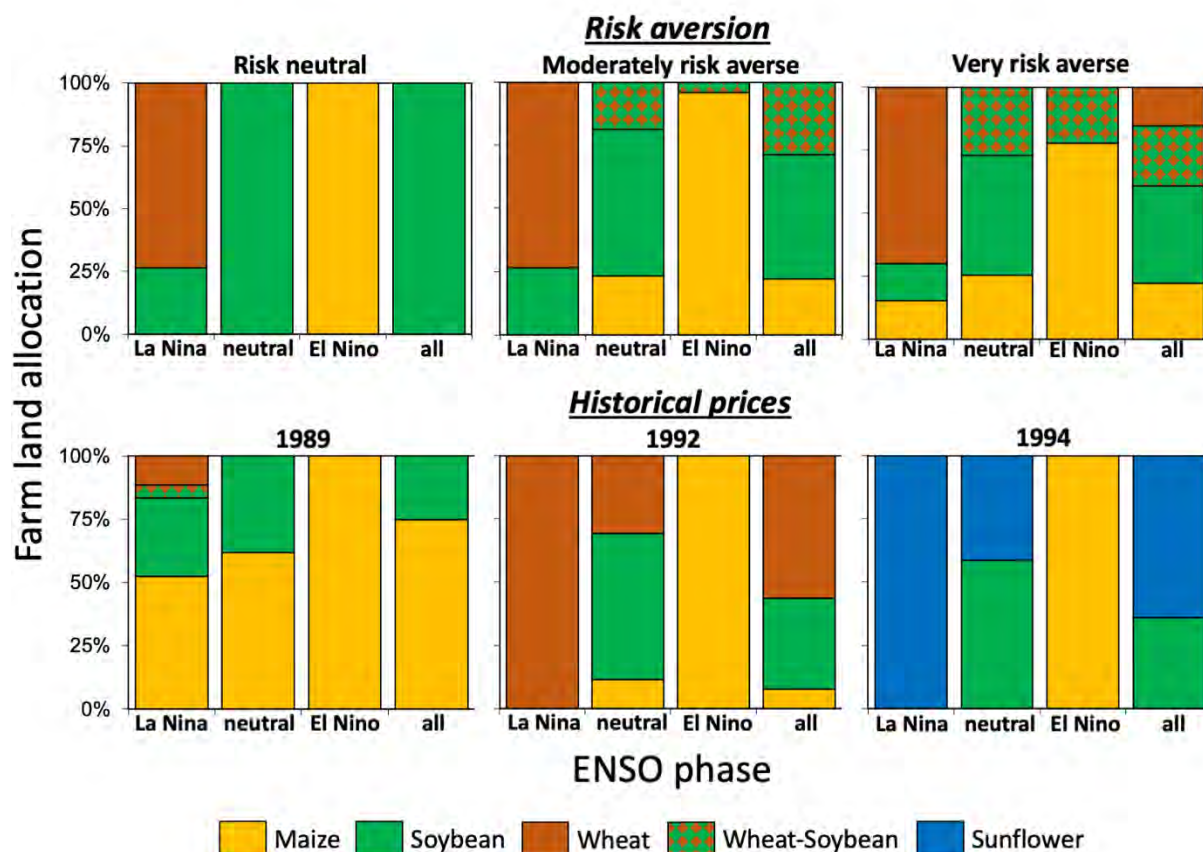


Figure 3.5-3. Modelled farm land allocation responses to ENSO-based seasonal forecast information, as influenced by risk preferences and prices, Pergamino, Argentina. Based on Messina et al., 1999.

Planting and stocking decisions

In rainfed annual cropping systems in sub-humid and semi-arid climates, decisions about what to plant and when to plant are particularly sensitive to climate condition, and particularly important for managing climate-related risk. Sowing too late can reduce yields by reducing the time in which the crop can convert CO₂ and solar radiation into biomass and harvest product. Sowing too early increases the risk that there will not be enough water in the soil profile to establish the germinating seedlings. Although farmers may replant when this occurs, replanting increases cost of labour and seed, and may reduce yields by delaying crop establishment. For a given crop and variety, the sowing date also influences what weather conditions the crop will be exposed to as it matures. While sowing date is an important decision in rainfed annual cropping systems, it is also a challenging decision because the timing of the start of the rainfed growing season is variable.

Rainfed growing season onset definitions

The onset of the rainfed growing season has been defined in several ways, including the first time, within a window of possible onset dates, that:

- available moisture exceeds a threshold fraction of available water holding capacity in the upper soil;

- the soil wetting front exceeds a threshold depth;
- rainfall amount in a short period (e.g., 3 days) exceeds a threshold; or
- cumulative rainfall amount in a short period exceeds a specified fraction of potential evapotranspiration.

Building on ICRISAT research in Sahelian West Africa in the 1980s, the most widely used convention in sub-Saharan Africa defines onset as the first day, after a given date well before the normal onset, when rainfall total over a short period (typically 2-3 consecutive days) exceeds a given amount (typically 15-30 mm), and when no dry spell exceeding a given length (typically 7-21 days) occurs in the subsequent period (typically 3-4 weeks). This definition uses rainfall data to answer two separate questions:

- *Has sufficient rainfall occurred to support germination?*
- *Will rainfall be adequate to support seedling growth until roots are deep enough, and rainfall is consistent enough, to establish the crop?*

The second criterion is used to determine whether an early germinating rainfall event constitutes a true onset leading to successful crop establishment, or a false onset leading to failed crop establishment.

It is straightforward to determine when these conditions were met, for any location and prior year for which daily rainfall data are available. However, three factors limit the usefulness of this onset definition to guide farmers' planting decisions. First, using rainfall data in a 2- or 3-day period to assess whether the upper soil profile contains enough water to germinate the seed does not account for stored soil moisture from earlier rainfall events, or differences in soil hydrological properties. Second, using observed rainfall to assess onset does not help a farmer anticipate or plan in advance of the onset date. Finally, a farmer must wait a few weeks to determine whether a germinating rainfall event signalled the actual onset of the rainfed growing season, or whether a dry spell results in a false onset.

It is important to select appropriate thresholds when using this onset definition, to ensure that calculated dates of germinating rain, and estimates of whether subsequent rainfall is sufficient for crop establishment, match field conditions as closely as possible. The KMD growing season onset and cessation date Maproom allows users to modify these thresholds.

Farmer planting decisions

Recall from Session 3.2 that decisions under uncertainty have characteristic planning horizons – the period from when the decision is made until the consequences of that decision are experienced. In the case of rainfed annual cropping systems, decisions about what to plan and when to plant are affected by factors on several time scales.

Consider three questions that a farmer might ask near the start of the growing season:

- *When should I prepare my fields and inputs for planting?*
- *Should I plant now?*
- *If I plant now, what crops and varieties are best suited to expected weather conditions late in the growing season?*

These questions, and the information that can help answer them, have different time scales. Variety selection, which interacts with planting date, has a seasonal time horizon. Preparations for planting may benefit from forecasts of onset timing, which are often integrated with seasonal forecasts. Determining whether there is enough water for germination involves monitoring, and short-term weather forecasts. Determining risk that crop establishment will fail involves anticipating rainfall at a sub-seasonal lead time. We expand on each of these questions in the discussion that follows.

When should I prepare?

Farmers typically know the normal range of onset dates, and prepare their fields and inputs before the earliest anticipated onset. Mean onset date (Figure 2.2-14), and variability around the mean (Figures 2.2-15 and 2.2-16), are available from KMD Maprooms. Farmers might benefit from anticipating whether the onset is likely to occur earlier or later than normal, for example, to contract labour for sowing, or till their fields close enough to the sowing date to avoid weed buildup. Forecasts of the timing of rainfall, included in seasonal forecasts issued by KMD (Figure 3.5-4), are available to help farmers anticipate and prepare for years when the season starts substantially earlier or later than normal.

Should I sow now?

The decision about whether conditions are suitable for sowing involves two different questions:

- *Is there enough water in the soil to grow my seed if I sow now?*
- *If I sow now, what is the probability that seedlings will die from lack of water before the roots grow deep enough and rain becomes frequent enough to establish my crop?*

The first question, “*Is there enough water in the soil to germinate my seed if I sow now?*”, is relatively easy to answer using farmers’ observations of the depth of the soil wetting front or local rainfall, and short-term weather forecasts. The second question, “*I plant now, what is the probability that my crop will die from lack of water before it is established?*”, is more challenging. The critical 3-4-week period between sowing and crop establishment is longer than the lead time of weather forecasts. Sub-seasonal forecasts, with lead times up to four weeks, are a relatively new innovation. Experimental sub-seasonal forecasts exist, but they are generally not yet operational in Kenya or elsewhere in sub-Saharan Africa. In the absence of forecasts of dry spell risk at a sub-seasonal lead time, historical climate analysis offers relevant information.

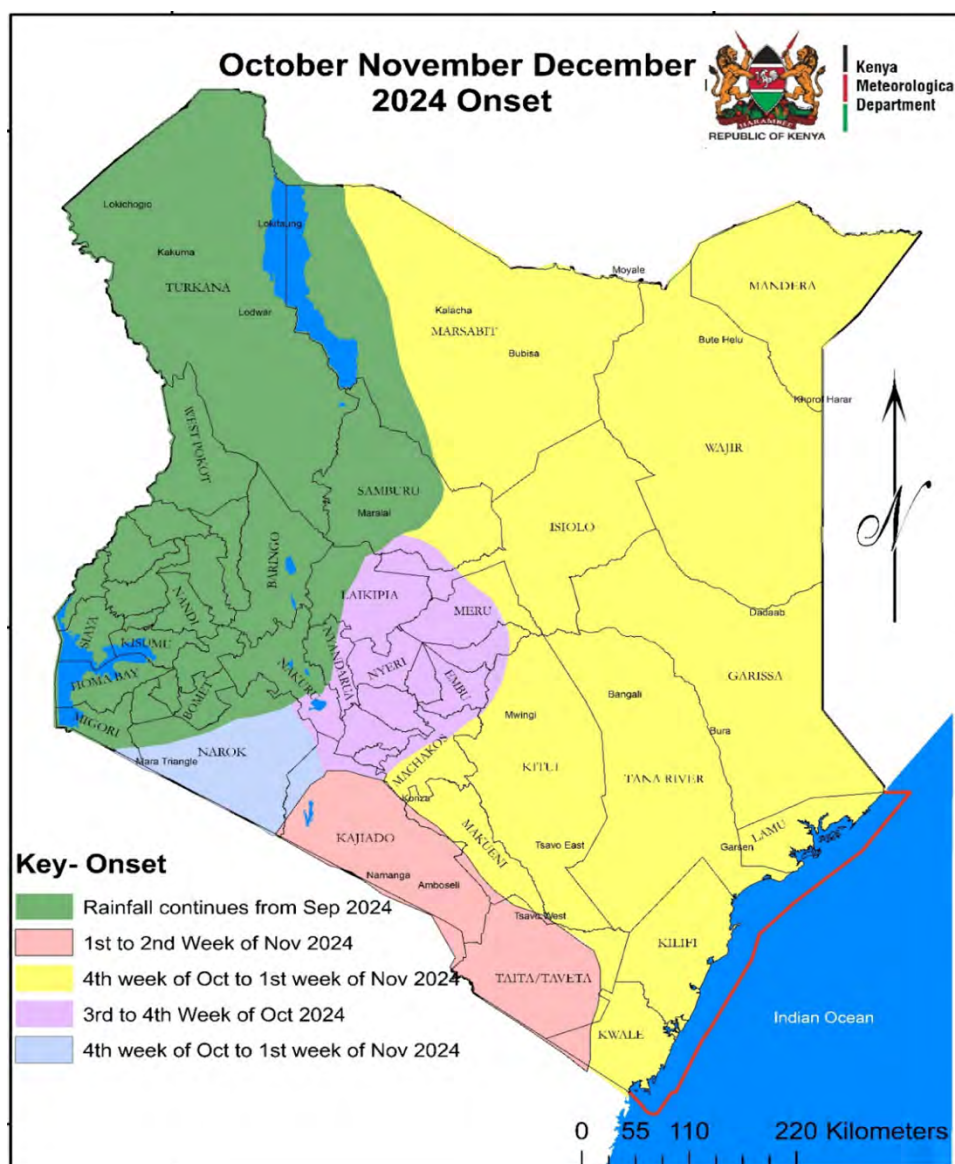


Figure 3.5-4. KMD 2024 October-December short rains forecast onset map, issued September 2024.

Source: <https://meteo.go.ke/sites/default/files/forecast/seasonal-forecast/OND%202024%20Seasonal%20Weather%20Forecast.pdf>, accessed 31 October 2024.

What variety should I plant?

The use of historical climate information to select varieties that match growing season length was discussed earlier in this session. However, because rainfed growing season length at a given location can vary considerably from year to year, a variety that is adapted to average growing season length may not be best in some years. What crops and varieties to plant, and when to sow are interacting decisions. Sowing date can influence whether a particular variety will mature at the right time to take full advantage of the length of the suitable growing season and avoid harvest losses from either drought stress or excessively wet conditions late in the season. If the onset date in a particular year occurs much earlier or later than normal, then information about average and forecast rainfall cessation dates, and analysis of historical weather conditions late in the growing season, could inform decisions about what to plant. At the time of writing, KMD does not provide forecasts or historical analysis of rainfed growing

season cessation dates. Changing to a longer- or shorter-seasonal variety or crop species might improve production if sowing occurs much earlier or later than normal, in a given year.

Crops or varieties that have high photoperiod sensitivity may be an exception to this generalization. For example, pearl millet landraces in Sahelian West Africa have been selected, over many generations, to flower and mature at roughly the same time each year in response to changing daylength, regardless of sowing date. This climate risk adaptation allows farmers to take full advantage of years with early onset dates and long growing seasons, while still obtaining a harvest in years when onset is delayed.

Animal stocking decisions

The questions that a livestock or aquaculture farmer might ask before the start of an agricultural season parallel decisions about planting in cropping systems:

- *When should I prepare my pasture or aquaculture unit, and inputs for stocking?*
- *Is this the right time to stock?*
- *What livestock or fish species and breeds are best suited to expected weather conditions later in the growing season?*

Livestock and aquaculture producers may be confronted with an additional decision to destock to reduce losses when adverse conditions are anticipated.

Animal production depends on seasonal climate cycles in much the same way as crop production. Animal production is closely to plant production – either on-farm fodder or pasture production, or rangeland conditions for extensive livestock systems. Livestock breeding calendars, especially in dry areas, are planned to coincide birthing with the onset of rains to ensure sufficient availability and quality of feeds, fodder, pasture and water. In aquaculture stocking season are planned to consider with warm rainy seasons to ensure adequate temperature and water supply for the entire growth period of fish.

Climate conditions also influence the choice of livestock or fish species and breeds. In livestock production, the decision on what breed to keep should be guided primarily by the agro-ecological zone and prevailing climatic conditions for adaptability and tolerance to endemic diseases and pests. In fish production, the decision on species and strain to grow should be guided by the climatic conditions in a specific agroecological zone to favour tolerance to climatic conditions.

Managing Risk Valley fever risk to livestock

Rift Valley fever (RVF) is a mosquito-borne viral *zoonotic* (i.e., transmittable from animals to humans) disease that mainly affects cattle, sheep, goats and camels. Young animals are most susceptible to the disease, with almost 100% mortality rates. Animal-to-animal RVF virus (RVFV) transmission can occur when susceptible animals come into direct contact with infectious

excretions such as aborted material. Animal morbidity, mortality and abortion reduce livestock production, income generation, draught power and other livestock-based livelihoods. International animal trade embargoes, implemented for biosecurity, also impact livestock value chain actors, such as traders, transporters, abattoir workers and butchers. The 2006/2007 outbreak in Kenya caused socioeconomic losses of USD \$30m (Rich and Wanyoike, 2010). Humans can contract the disease when they come into direct contact with infectious tissues such as blood and foetal tissues from infected animals, or via infectious mosquito bites, resulting in a severe haemorrhagic syndrome with a high mortality rate.

While RVF is endemic in several regions in Kenya, its outbreaks occur more frequently in pastoral areas (Figure 3.5-5). These regions are characterised by high climate variability, generally flat terrains and savannah grasslands, extensive livestock systems and inadequate public and animal health services (Hightower et al., 2012). Incidences of intense rainfall and flooding, whose frequencies seem to have increased with climate change, provide favourable conditions for RVF outbreaks. The high livestock population turnover in these ecosystems also limits the build-up of herd immunity that would dampen the disease spread.

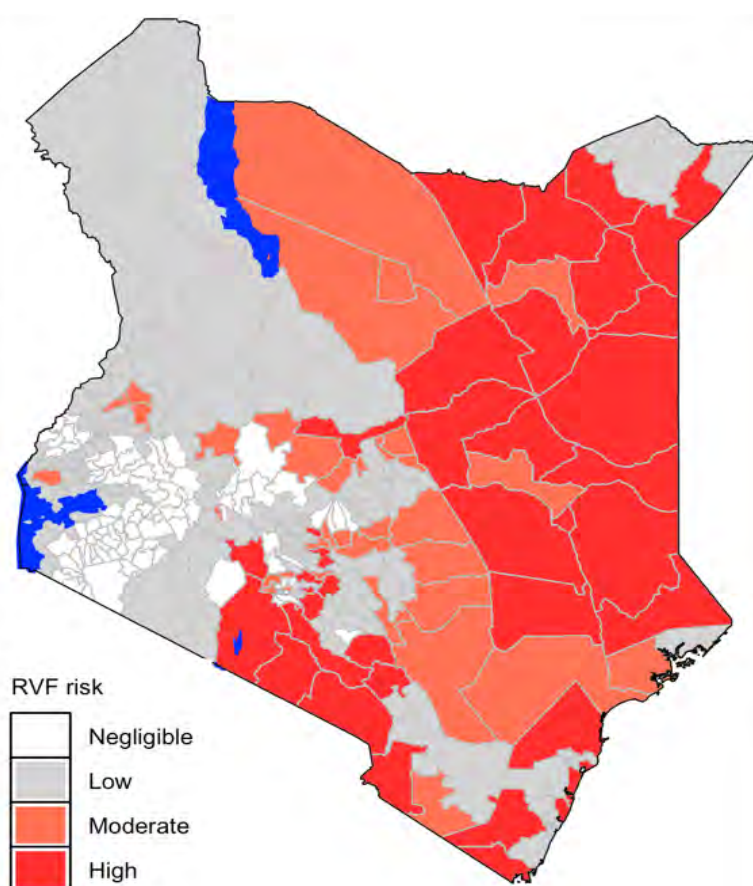


Figure 3.5-5. Map of RVF risk in Kenya, by subcounty, based on the analysis of historical data on outbreaks that occurred between 1990 and 2024.

Climate-informed RVF early warning

RVF outbreaks are sensitive to rainfall and temperature. A Previous analyses have shown that rainfall anomalies accompanied by an increase in temperature precede RVF outbreaks by 2-6

weeks. While specific thresholds for these events haven't been identified, the statistical association between past outbreaks and climate conditions has contributed to the development of early warning systems. Monitored precipitation data, available at a ~4 km from KMD Climate Monitoring Maproom (Session 2.3), and rainfall and temperature forecasts from weather to seasonal lead times, can therefore provide an early indication of whether climate conditions are likely to be conducive for an outbreak in susceptible locations.

The observed statistical relationships have prompted efforts to develop predictive RVF early warning and decision support tools. For example, the UN Food and Agriculture Organization (FAO) developed a preliminary tool¹² based on a statistical model published by Anyamba et al. (2009). That early model used the normalised difference vegetation index (NDVI) as a proxy for rainfall and other ecological features that correlate with RVF outbreaks, and provides predictions 2-6 weeks ahead of potential outbreaks.

The role of climate in RVF transmission and infection is, however, quite complex, and specific thresholds for climate parameters have not been established. Transmission involves multiple animal hosts and multiple *Aedes* and *Culex* mosquito vector species – each influenced by differing environmental and biological factors. Rainfall influences transmission by flooding mosquito breeding sites, allowing dormant infected eggs in dry soil to hatch and adult mosquitos to multiply quickly. However, this water ponding is also influenced by localized factors such as topography, soil type, land cover, irrigation and aquaculture development, and soil water content prior to recent rains. Temperature has differing effects on mosquito hatching, development, egg-laying, survival and biting rates (Mpeshe et al., 2014). This complexity has made it challenging to develop accurate RVF forecast models, and creates considerable uncertainty when using simple statistical or qualitative relationships with meteorological data. Yet ongoing research is improving understanding of the system, and is expected to improve climate-driven early warning tools.

Improving RVF risk mitigation

Timely and appropriate intervention, informed by appropriate early warning information, is crucial for preventing severe livelihood and health impacts of RVF outbreaks. An assessment of the 2006/2007 RVF outbreak in Kenya and Tanzania showed that the severity of the outbreak was exacerbated by delays in recognising risk factors and in implementing decisions to control the disease (Jost et al., 2010).

A decision support framework has been developed to guide early, effective assessment and response to anticipated RVF outbreaks (Bett and Mariner, 2014). The framework identifies four main decision-making phases:

¹² <https://data.apps.fao.org/catalog/dataset/rift-valley-fever-decision-support-tool/resource/b587f662-fc91-44b1-b4e4-b006be7755dc>

1. *Inter-epidemic period*: to cover the interval between outbreaks (repeats, following the *recovery* phase);
2. *Pre-outbreak*: involving early warnings, and alerts of localised rain, flooding and mosquito swarms as sub-stages;
3. *Outbreak*: classified into suspected and confirmed outbreak sub-phases; and
4. *Recovery*: including a 45-day period when no new further livestock cases are observed and a period on post-outbreak recovery and reflection.

It identifies specific actions that policy and institutional decision makers can implement at each decision-making phase, depending on available information and circumstances of the current phase. These actions are classified into:

- capacity building and training;
- communication, advocacy and public awareness;
- national and regional coordination;
- early warning;
- surveillance, based on climatic and other indicators of risk;
- disease prevention, such as mass livestock vaccination campaigns, mosquito vector control, and other infection prevention and control measures;
- case management;
- regulation of trade and markets for livestock;
- resource mobilization;
- establishing or strengthening institutions and policies; and
- research.

Local communities, including livestock owners, can collaborate with policy and institutional decision makers in RVF risk mitigation. Engaging policy makers with livestock producer communities would enrich RVF control interventions, and provide feedback that can be used to improve the content of the decision support system. Producer communities could play additional roles in early warning and response, for example:

- *Making online risk maps accessible*. Because RVF is a trade sensitive disease and access to data on its occurrence patterns are controlled by line ministries, sharing with pastoralist and livestock farming communities would require government approval.
- *Data sharing*. Functionality could be embedded in an online RVF decision support system to allow real-time sharing of data on environmental risk factors, and animal and human health symptoms. Such crowd-sourced data could be used to supplement surveillance and for model validation.

Climate information challenges in pastoralist decision making

Decision making system

For pastoralists, decisions are deeply shaped by climate variability and uncertainty in relation to vegetation dynamics, water availability and livestock health. In extensive grazing systems, climate-sensitive decisions are not isolated, one-time choices, but part of an ongoing process of observation, negotiation, and adaptation. They are shaped by a suite of other factors including access to grazing lands, strength of kin networks, herd composition, cultural values and broader institutional and market dynamics. In managing variability, pastoralists may also consider:

- *Reciprocity and social capital.* In areas regularly impacted by drought, and other intersecting crises, tight bonds of obligation and trust are critical. Sharing and redistributing resources across other community members means opening multiple channels of potential future support.
- *Inter-generational continuity.* Both livestock breeds and larger herds are not only means of subsistence, they are also security for future generations. Even in times of drought, herders may avoid selling certain animals to preserve valuable breeds and safeguard long-term family well-being and herd recovery.
- *Conflict dynamics.* The availability of good pasture for livestock does not always lead to a straightforward decision to move. Herders weigh up potential risks associated with conflict (often in border areas), and may opt to move stock to lower quality grazing lands with less risk of conflict.

Key climate-sensitive decisions include:

- *Seasonal mobility,* shaped by real-time observation of local ecological conditions. Even when accurate forecasts are available, hyper-local rainfall patterns in the drylands require dynamic and adaptive strategies attuned to a range of environmental indicators. It is rainfall timing and specific distribution (i.e., not just overall quantity) that determine when and where rangelands are viable for livestock.
- *Herd composition and diversification.* Across multiple timescales, from the decadal to the seasonal, pastoralists make climate sensitive decisions about what stock to keep. For example, in many dryland areas impacted by climate change, pastoralists are reducing cattle numbers and increasing camel numbers as a means of managing shifting ecological characteristics.
- *Timing of breeding and livestock sales.* Pastoralists control breeding in relation to climatic factors. During periods of environmental stress, and particularly when most stock have not already stopped breeding due to nutritional stress, it is common for herders to heavily control the breeding of their livestock in order to avoid pregnancies that will result in

death of the pregnant animal. Similarly, the sale of livestock is often timed for the wet season, when livestock are in good condition and fetch high prices.

- *Emergency strategies.* During times of acute environmental stress, pastoralists often rely on dry-season reserves – i.e., areas of forage protected through communal institutions for use during emergencies. In extreme emergencies, livestock are sold, or split across kin networks to be distributed across different geographical areas.

Challenges to climate information use

Pastoralists can in principle, and often do, consider information such as seasonal forecasts, weather forecasts, and remote sensing of vegetation conditions and watering points when making these decisions. The value of this information, however, depends not just on accuracy, but on timing, trust, and relevance to pastoralists' decision systems and culture. Efforts to promote climate services for pastoralist decision making face challenges from both the strengths of their traditional risk management strategies, and the significant constraints that this population faces.

The traditional pastoral livelihood system has evolved over millennia to manage the very high level of climate variability and recurrent drought risk in East Africa's drylands. Several of their traditional risk management strategies tend to limit the use and value of climate-related information that is available from KMD and other provider institutions. First, out of necessity, pastoralists have evolved expertise at observing the environment to assess evolving risks. Their heavy reliance on their own observations of evolving environmental conditions, and indigenous indicators of future conditions can reduce demand for and receptivity to scientific forecasts. Spatial information about vegetation and surface water resources from satellite remote sensing is somewhat redundant with pastoralists' and agro-pastoralists' reliance on scouting, which is increasingly aided by mobile phones, to guide herd movements.

Second, pastoralists' flexible and complex risk management decisions often do not align with or benefit from available forecast information. The high variability of rainfall in the drylands, across both space and time, has led to herd migration decisions that are made more in response to real-time assessments of shifting social, economic and environmental conditions than to predictions or fixed calendars. They interpret climate information within a wide set of decisions relating to risks such as conflict or disease. Planning too far in advance leads to decisions that are too rigid in the face of multiple changing risks.

Third, animals are viewed more as a source of wealth and precautionary savings, than a source of income. The long-term value of animals and the time required to restock herds are disincentives to destocking in advance of a drought when forecasts of drought severity, and impacts on grazing and water resources, are uncertain.

Pastoralists also face significant constraints that can reduce their ability and willingness to use available climate information, even when it is relevant to their decisions. The mobility that characterizes the pastoral livelihood system limits access to institutional communication

channels, while the remoteness of the drylands, and limits the relevance of location-specific climate information. On average, education opportunities and literacy rates are lower in pastoral communities than in sedentary farming communities, which creates barriers (discussed in Session 4.2) to accessing and using some information products. A history of top-down interventions by development organizations and government that marginalized pastoralism in favour of sedentary agriculture may have reduced trust in official institutions, including meteorological and agricultural extension providers.

When pastoralist communities do use climate information effectively, it usually involves considering scientific forecasts alongside local observations and knowledge systems. Enhancing climate services for pastoralists requires improving accessibility (through, for example, local language radio, mobile platforms and community intermediaries), supporting interpretation, and ensuring information is actionable within pastoralists' flexible and adaptive decision-making systems. Pastoralists typically access and share information through informal channels, such as meetings at a watering point, during community barazas, under the shade meetings, and exchanges in markets, schools, mosques and churches. Customary greetings among pastoralists, which include discussions about animal health, feeds, migration and security, allow a great deal of information about rangelands to be shared through informal networks.

Session 3.6. Other Farm-Level Risk Management Options

This session addresses some strategies that are available to farmers to manage climate-related risk – beyond using climate information to adjust management (covered in Section 3.5) – including climate smart agriculture technologies and innovations, diversification, and index-based agricultural insurance.

By the end of this session, you will be able to:

- Explain what makes a particular agricultural practice “climate-smart.”
- Explain how different types of agricultural production technologies reduce climate-related production risks.
- Identify opportunities to use diversification to reduce risk for a given farming system.
- Explain basic agricultural insurance concepts, including its main roles, key differences between indemnity-based and index-based insurance, and contract structure.
- Identify circumstances in which farmers are likely to benefit from index insurance.

Climate-Smart Agriculture Practices

Climate-smart agriculture (CSA) is an approach for reorienting agriculture in the face of climate change. CSA is not defined by a particular set of practices, but by changes in practices that lead to sustainable increases in productivity, resilience, and where possible, greenhouse gas (GHG) mitigation (Lipper et al., 2014). These are sometimes referred to as the three pillars of CSA:

- *Productivity*: CSA aims to sustainably increase agricultural productivity and incomes, which in turn will raise food and nutritional security.
- *Resilience*: CSA aims to reduce negative impacts, and build farmers’ capacity to adapt and prosper, in the face of short-term risks and long-term stresses. At a landscape scale, CSA often gives particular attention protecting and enhancing ecosystem services that are essential for maintaining productivity in the face of a changing climate.

- *Mitigation:* CSA aims to reduce or remove greenhouse gas (GHG) emissions, or at a minimum, enhance productivity and resilience without increasing net GHG emissions per unit of food, fibre and fuel produced.

A production technology or practice is “climate smart,” in a given context, only if it improves these three pillars relative to existing practices. Crop, fish and livestock production technologies vary widely in their productivity, profitability, sensitivity to climate conditions, and contribution to GHG emissions.

The discussion below, which draws from Hansen et al. (2019) and references therein, focuses on the resilience pillar, and highlights a few agricultural production practices that have proven, widespread risk reduction benefits. Because the risk benefits of particular production technologies are often quite context specific, it is important to draw on local expertise when selecting or recommending available technologies, and to do adequate field testing across a range of climate conditions when developing new technologies. More complete and context-specific information about appropriate climate-smart agriculture technologies and practices can be obtained from the Kenya Agricultural and Livestock Research Organization (KALRO) and the country’s agricultural universities.

Stress-tolerant crop varieties

The Green Revolution, which dramatically increased production of staple cereals and reduced rates of hunger and poverty over roughly the last third of the 20th century, was largely driven by new high-yielding crop varieties. These early improvements in crop genetics targeted high-potential environments, and were supported by resource-intensive water, soil fertility and pest management packages. However, the productivity and welfare gains from Green Revolution technologies largely bypassed large, marginal rainfed agricultural regions, where the impacts of climate variability are greater, and where high rural poverty and hunger rates have been more persistent. International research and breeding programs responded by increasing attention to tolerance to climate-related stresses, which led to advances in drought-tolerant maize varieties in sub-Saharan Africa, and rice varieties with increased tolerance to drought, flooding and salinity across regions. In sub-Saharan Africa, drought-tolerant maize cultivars consistently outperform commercial varieties under drought conditions in field trials, but their performance relative to standard commercial varieties under non-stressed conditions is mixed. In field experiments in Asia, drought and flood tolerant rice experienced no significant yield penalty under non-stress conditions.

Early successes in drought-tolerant maize and stress-tolerant rice have been extended to other crops. Through the AICCRA project, in 2022 ICRISAT partnered with the governments of Kitui, Makueni and Taita-Taveta counties to pilot demonstration farms for high-yielding, drought-tolerant and early maturing varieties of pearl millet, sorghum, and pigeonpea.

Conservation agriculture

Conservation agriculture (CA) aims to sustainably improve and stabilize production through a combination of reducing soil disturbance from tillage, maintaining soil cover with organic material, and crop diversification through intercropping or rotations. CA is not a fixed technology, but a varying bundle of practices that sometimes include additional soil fertility, water or weed management practices. The yield and risk reduction benefits of CA are associated with a combination of improved water infiltration and retention, accumulation of soil C, and reduced heat stress due to the presence of organic residues. Where these benefits have been observed, they generally increase over time, and may not be realized in the first few years.

The effectiveness of CA varies with context. Some studies have concluded that CA shows greater risk management and productivity benefits in more drought-prone environments. Other studies show more complex interactions between CA practices and environmental conditions. The complexity of CA, competing demand for organic residues and the time lag before yield benefits are experienced have contributed to highly variable adoption rates and cases of dis-adoption in sub-Saharan Africa.

Agricultural water management

Irrigation has the potential to dramatically increase productivity and reduce the risks associated with rainfed agriculture in dryland (i.e., dry sub-humid and semi-arid) environments. In addition to reducing risks to rainfed crop production, irrigation may allow farmers to grow a second crop during the dry season.

The storage capacity of an irrigation system largely determines its capacity to buffer the agricultural impacts of climate variability. Large reservoir-based irrigation systems that can store enough water to meet demand for multiple agricultural seasons can protect crops from major droughts. However, large reservoir-based systems are expensive to build, operate and maintain. Existing systems are typically the result of major government or donor infrastructure investments, and often serve multiple water demands such as industrial, municipal and hydroelectric power generation.

Small-scale agricultural water management alternatives have lower capacity to buffer the impacts of prolonged or severe droughts, but are generally more accessible to small-scale farmers due to their lower initial cost. Small-scale agricultural water management options include on-farm water harvesting and groundwater irrigation. Groundwater irrigation, using electric, gasoline or diesel pumps, often an option where the water table is sufficiently high and reliable. Efforts to reduce greenhouse gas emissions from agriculture and the diminishing cost of solar panels have resulted in increasing attention to solar-powered groundwater irrigation. Rainwater harvesting is an alternative where groundwater irrigation is infeasible or impractical.

In most cases adopting irrigation requires significant initial investment, either by farmers or of public funds. Where this responsibility falls on farmers, secure land tenure, and access to

finance with favourable terms, are important requirements for smallholder farmers to adopt irrigation. Investment in irrigation is most likely to be cost-effective when it enables farmers to switch from subsistence-oriented rainfed staple crops to higher-value crops such as horticultural crops.

Integrated animal health, feed, and herd management

An integrated herd health package is a coordinated set of interventions designed to improve the health, productivity, and resilience of livestock herds – by combining animal health, nutrition, genetics, management, and welfare practices (Båge et al., 2020). It is important to address livestock health and feed management strategies in an integrated manner, as climate risk directly or indirectly impacts all elements of the integrated herd health package. This approach is particularly important in regions facing significant resource constraints, and evolving climate and disease risks. Animal health has major consequences for how animals use their resources, including feed and water, and poor health will tend to increase inputs, including medication, and reduce outputs (Perry et al., 2018). Thus, there is a direct positive association between animal health and efficiency (de Vries and de Boer, 2010), which should translate into lower emissions (Kyriazakis et al., 2024). This approach is particularly important in regions facing climate change, resource constraints, and evolving disease risks. Limited productivity restricts opportunities to enter profitable markets and undermines the long-term resilience of communities.

In addition to enhancing productivity and resilience, integrated animal health, feed, and herd management reduce greenhouse gas emissions, and therefore contributes to all three CSA pillars. Sick animals emit more methane and nitrous oxide, increasing the greenhouse gas (GHG) intensity of livestock products. For example, parasitism in lambs can lead to a 33% increase in methane yield (g CH₄/kg of feed) (Fox et al., 2018). Preventing abortions in cattle could lower milk GHG emission intensity (EI) – the amount of GHG produced per unit of meat – by 4.6%, while in goats, the reduction could reach as high as 15.8%. Halving calf mortality would reduce EI by 3%, and eliminating calf mortality would therefore reduce by 6% (Gurmu et al., 2024).

Precision livestock feeding can decrease livestock environmental impacts by optimizing the use of dietary nutrients and animal nutrient utilization efficiency which results in less nutrient excretion. For example, precision feeding in pig production can cut costs by more than 8%, lower protein and phosphorus intake by 25%, reduce excretion by 40%, and decrease greenhouse gas emissions by 6% (Pomar and Remus, 2019).

Animal breeding programs increasingly target traits such as heat tolerance, disease resistance, and feed efficiency. The use of local or resilient breeds can enhance the environmental and social sustainability, animal welfare, and production, compared with the introduction of cosmopolitan breeds with uncertain adaptation in uncontrolled environmental areas (Colombi et al., 2024). Hence, indigenous breeds (e.g., Nguni, Tuli, Tswana cattle) are increasingly used in crossbreeding to improve adaptability and productivity. Genetic gains through selective

breeding mean fewer animals can produce the same amount of product, thereby reducing greenhouse gas emissions and improving climate resilience. Modern breeding programs are designed to deliver improved breeds that are more productive, nutritious, and resilient to climate and environmental challenges. Climate-resilient livestock traits can be achieved through genomic selection and gene editing, with some programs reporting up to 40% reduction in enteric methane through selective breeding. Rapid uptake of improved breeds is essential for overcoming climate impacts and building sustainable livelihoods. Good genetics tailored to local objectives (milk, meat, growth, adaptation) and high-quality feeds are central to resilience and productivity.

Participatory Rangeland Management

Participatory rangeland management (PRM) builds the capacity of communities to better plan, manage and govern their lands (ICPALD, 2024, Figure 3.6-1). Communities lead the process, and a rangeland management institution is strengthened or established as the responsible authority for PRM within a rangeland management unit. Other stakeholders may need to be involved in decision-making processes in relation to community lands. There may be secondary and tertiary land users who access rangeland resources at different times of the year. There may also be others with interests in the land, including government, investors and conservation organizations.

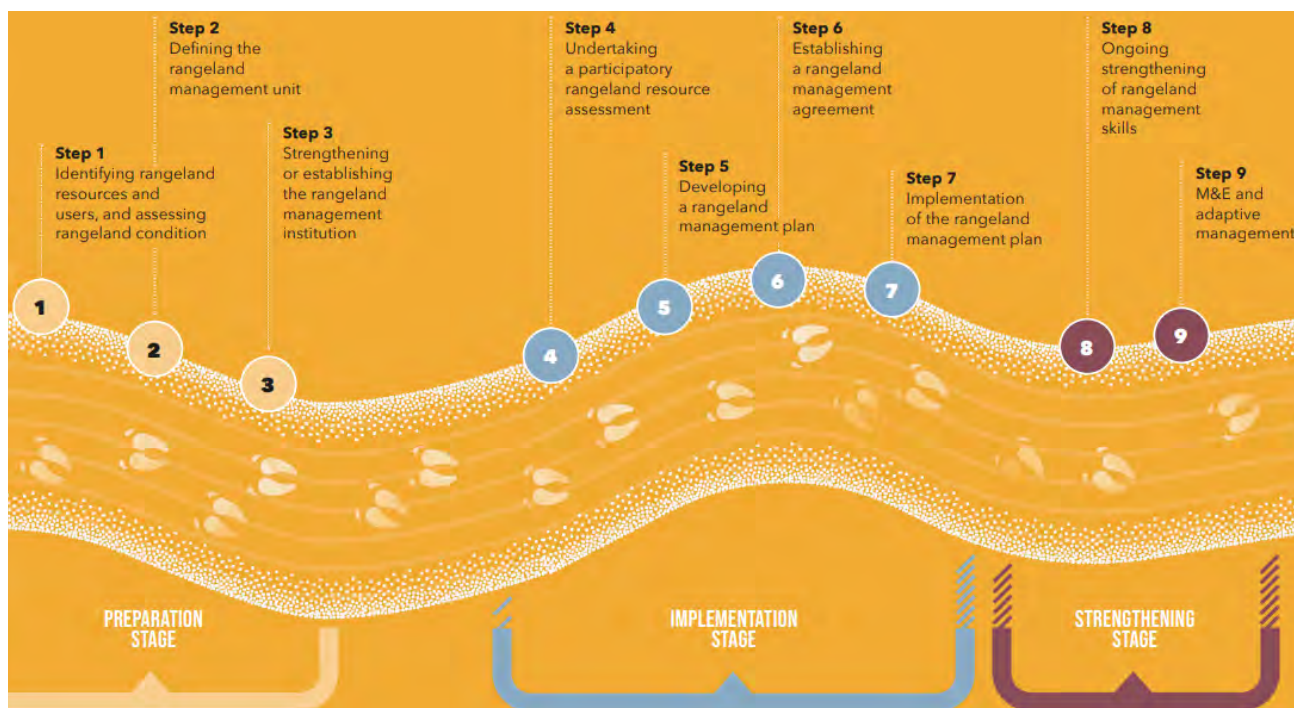


Figure 3.6-1. Stages and steps of the PRM process. Source: ICPALD, 2024.

Ideally, PRM is carried out where communities have clear and secure rights to their land (e.g. a landholding certificate). This gives communities a greater incentive to invest their time and resources in the PRM process and to improve or restore land productivity. However, in pastoral areas, communities often do not have secure and clear rights to their land. In these circumstances, PRM can contribute to greater tenure security by increasing the legitimacy of

community land use through mapping, documentation and use. A rangeland management agreement between the local community and government can follow. Ultimately, PRM promotes the sustainable use, management and governance of healthier rangelands, maintaining biodiversity and providing for more resilient livestock-based livelihood systems.

Climate-smart aquaculture systems

Regenerative aquaculture enhances aquatic ecosystems while producing fish and other food sources. Sustainable methods include seaweed and microalgae farming, which reduce carbon footprints. Techniques like Integrated Multitrophic Aquaculture (IMTA) lower costs by reducing reliance on fish feed. *Recirculating Aquaculture Systems (RAS)*

Recirculating aquaculture systems (RAS) are closed and semi- closed systems that intensively cultivate fish and reuse a large proportion of naturally treated culture water to reduce water consumption and the release of nutrients into the environment. They recycle water, cutting consumption by up to 99% while reducing waste and improving fish health. RAS enables year-round fish production, making aquaculture more efficient and environmentally friendly.

Diversification

Diversification is a well-known strategy for managing risk in fields as diverse as financial investments and agricultural production. Producers can often use diversification to reduce their income and consumption risk, even if resource constraints limit their access to other risk management options. Education in agricultural sciences, on the other hand, might not emphasize diversification, but focus instead on how to use technologies such as crop and animal genetics, agronomic practices, sanitary, phytosanitary practices and veterinary care to manage risks for individual production enterprises.

What can producers diversify?

Farmers and pastoralists have a range of options for diversifying their livelihoods, including farm and non-farm income sources, fish species, livestock species and breeds, crop species and cultivars, field locations and topography, and timing of production and marketing activities.

Increasing the number of crop species does little to mitigate climate risk if all of the crops respond similarly to climate stresses, as their yields and returns are likely to be strongly correlated. Correlations of yields among crops or cultivars can be reduced, and risk reduction benefits increased, if timing of sensitivity to climatic stresses is different due to differing phenology or planting dates. This is because the impact of short-term drought or heat stress within the growing season is reduced if only a portion of the plants cultivated are at a critical stage (e.g., anthesis or grain set) at the time. Growing crops in different fields with differing soil and hydrological environments can also reduce correlation and overall variability. A traditional strategy for managing risk in extensive dryland farming systems, particularly in the West African Sahel, is to divide crop cultivation between depressional areas, which collect and retain water

during short drought periods; and upland areas, which are less susceptible to waterlogging during periods of heavy rain (Brouwer et al., 1993).

Livestock provides additional options to reduce risk through diversification. Where livestock production has traditionally been dominated by a single animal species – particularly cattle – diversifying production to include, e.g., goats, sheep, poultry, pigs and/or rabbits may increase resilience to droughts, heat waves and climate-related health problems; and provide more continuous supply of meat, milk and income through the year. Furthermore, the differing roles that animals and crops play in mixed farming system can be exploited to reduce the impacts of climate shocks. Livestock and fish, like crops, are a source of income and subsistence consumption. However, in addition to providing a source of income and household consumption, livestock are often treated as a form of savings, and slaughtered or sold at strategic times. When farmers sell animals or fish to fill a gap in income from crop production, the income from crop, fish and livestock sales is negatively correlated. The flexibility to use livestock or fish as a buffer during periods of stress may therefore make diversification between crop- and animal-based farm enterprises an effective risk management strategy.

Example: Camels in pastoralist systems

For pastoralists across many contexts, and particularly in the drylands, camels are becoming increasingly central to livelihoods. Over recent years, historically cattle-dependent pastoralist areas in northern Kenya and southern Ethiopia have seen a marked increase in camel ownership. In many areas, camels have been incorporated into already diverse herd compositions. This is in response to increased occurrence of drought, a breakdown in the seasonality of rainfall patterns and rising temperatures. Unlike many other livestock species, camels can survive on sparse forage and are adapted to water scarce environments. They are well known for their capacity for milk production far into the dry season, a time when many other species struggle. Alongside this increase in camel numbers, new economies have grown and expanded. In particular, diaspora communities in towns and urban centres have created a burgeoning demand for camel milk, the provision of which provides a good source of income for many pastoralists. Their adoption, and growth in number, represent an increase in the diversity of herds and income sources, and reflects pastoralists' ongoing processes of adaptation to their shifting constraints and opportunities.

Example: Integrated aquaculture systems

Integration of finfish, shellfish species, and aquatic plants at different trophic levels helps in the mitigation of climate risk by maximizing utilization nutrients available in a fish farming unit which may vary due to climate change. This allows fish in the middle of the trophic level to benefit from the nutrients which are produced by other fish species which are top of the food web. The nutrients released by the fish are utilized by the plants and shellfish at lower trophic levels in a multitrophic integration. An example is the Rabbit fish, seaweed and sea cucumber integrated farming in the Kenyan coast. Aquaponic systems including combined hydroponic and fish farming (Figure 3.6-2) (Bhanja et al., 2024). It is also important for an aquaculture

venture to invest in a complete loop of the aquaculture value chain to have control over the systemic challenges in the sector that could lead to potential failure or exposure to production and management risks. Integration is also done with rice, livestock and poultry.

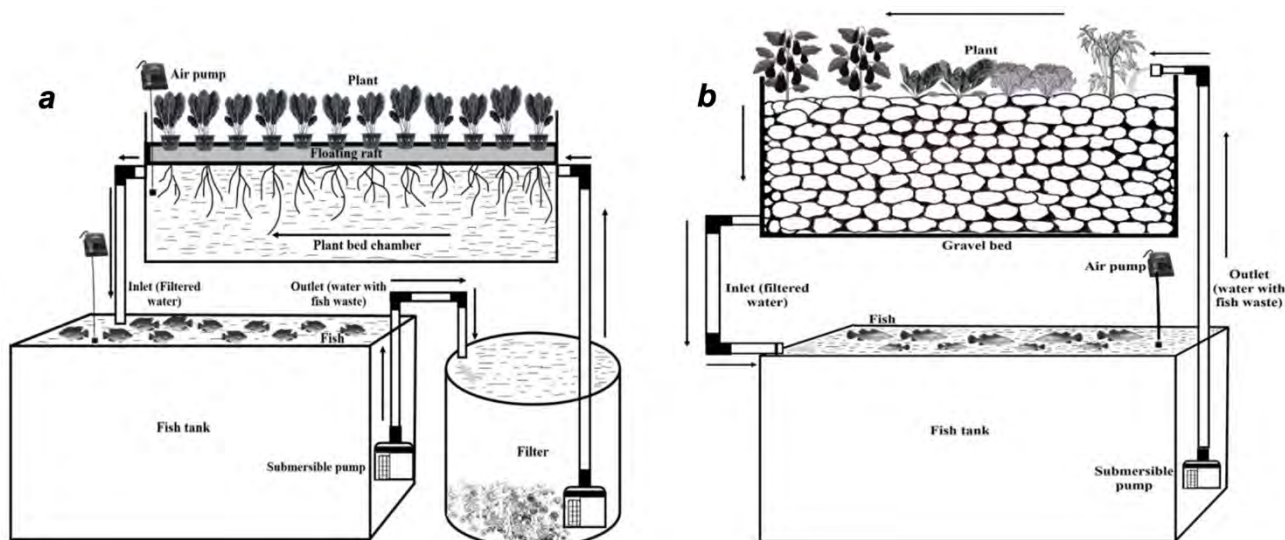


Figure 3.6-2. Schematics of (a) deepwater culture and (b) media based (gravel) aquaponic systems.
 Source: Bhanja et al. (2024).

Relationship between diversification and risk

Diversified farming systems are not always more resilient to climate risk, as environmental and market constraints may limit the range of viable farm livelihood options or the benefits of diversification. In an Africa-wide study, Waha et al. (2018) used data from 28,000 households in 18 countries to study the relationship between climate, diversification and food security. They found that households with more diversified production systems were generally better able to meet their consumption needs. However, the benefit from farm diversification was influenced by factors such as household market orientation, livestock ownership, non-agricultural employment opportunities, and available land resources. The authors concluded that the greatest opportunities for diversification of food crops, cash crops, and livestock are located in areas where annual rainfall has a mean in the range of 500-1000 mm, and a coefficient of variability of annual rainfall in the range of 17-22%.

The risk benefits of diversification depend on the number of activities or income streams, and on how correlated they are in time. Figure 3.6-3 shows the standard deviation of annual incomes from portfolios of different hypothetical income sources, combined in equal proportions, as a function of number of uncorrelated activities (Figure 3.6-3a) and income correlation between two activities (Figure 3.6-3b). Increasing the number of activities or income sources reduces risk. Decreasing the correlation among income sources also reduces risk. Risk reduction is greatest when the different income streams are weakly or negatively correlated. Combining income from two sources that are perfectly correlated has no effect on risk.

Recall from session 3.3 that a decision maker who follows a set of rationality assumptions would select options that fall on the frontier to the left (i.e., lower risk) and top (i.e., higher returns) of

an E-S graph. Figure 3.6-4 shows a mean-standard deviation (or E-S) graph of returns from two hypothetical enterprises, A and B, with the specified mean, standard deviation and cross-correlation, and for mixes of the two at 10% increments. The parabolic shape of the curve in Figure 3.6-4 is characteristic of E-S graphs of diversified portfolios. Under the assumptions in this example, a rational decision maker would never select 100% enterprise A because combining A with up to 40% enterprise B would reduce risk and increase expected return. Whether a diverse mixture exists that has lower risk than the least risky individual enterprise depends on the mean, standard deviation and correlation of the individual options.

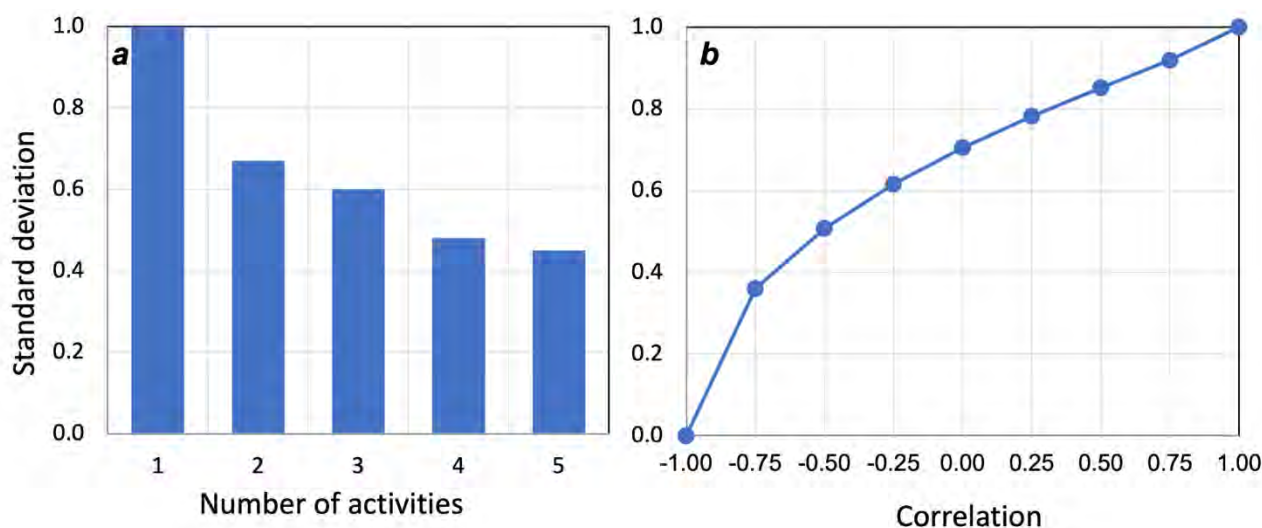


Figure 3.6-3. Standard deviation of average income as a function of: (a) number of uncorrelated income streams, and (b) correlation among 2 income streams; each with standard deviation of 1.0.

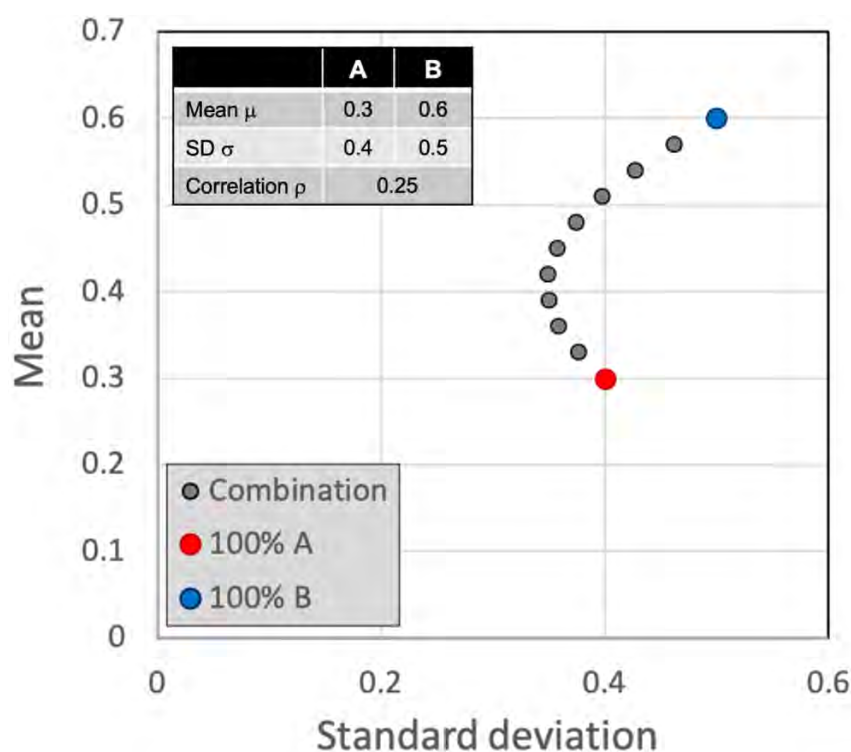


Figure 3.6-4. Mean-standard deviation (E-S) graph of returns from combinations of two hypothetical enterprises with specified means, standard deviations and correlation.

Guidelines for using diversification to manage risk

Understanding how diversification influences risk suggests a few guidelines for using farm diversification as a climate risk management strategy.

- First, a key goal for farm diversification is to combine income or food sources that have low or negative correlation. For crops, correlation may be reduced by selecting crops or cultivars with differing phenology, staggering planting dates, and selecting different fields with different topographic characteristics. Diversifying crop commodities can reduce income risk if farmgate prices are weakly or negatively correlated, even if yields are strongly correlated.
- Second, in mixed farming systems, the complementary roles of crops, fish and livestock integration can be exploited. Livestock and fish serve as a form of savings. Crops must be harvested and generally sold at a particular time of year. Livestock and fish, on the other hand, can be sold for income to compensate for loss of income or staple food production when a harvest fails.
- Third, consider all potential sources of production and income, not just on-farm production. Farm households often have other sources of income than farm production, such as off-farm salaried employment and day labour, remittances from extended family, social protection programs, and emergency humanitarian assistance.
- Fourth, if a farm household's production and income are already diversified, look for opportunities to adjust portfolio of activities and incomes to better meet the particular farmers' goals and risk preferences.
- Finally, consider whether the portfolio should be adjusted as new climate and market information become available.

Index-Based Agricultural Insurance

Role of agricultural insurance

Index-based agricultural insurance, also known as "index insurance," is a relatively new innovation that has overcome major challenges to providing insurance to smallholder farmers and pastoralists. Like other forms of insurance, agricultural insurance protects policyholders from specific types of risks by providing a monetary payout when a covered loss occurs. In the case of agriculture, insurance can contribute to the wellbeing of producers in two ways.

First, insurance protects producers from losses. An extreme climate event, such as a drought or flood, can have long-term impacts on livelihoods. For example, a farmer who does not harvest enough to repay loans, due to a drought or flood, may lose the ability to borrow money for farm inputs in the future. Likewise, it can be difficult for a pastoralist to recover their herd if a drought depletes grazing resources to a point where many animals die. Insurance payouts can help producers avoid coping strategies that deplete their productive assets, or replace lost assets, resulting from an extreme climate event.

Second, insurance can promote farmers' livelihoods by improving the adoption of improved production practices and access to credit. By providing payouts after an extreme event, insurance not only protects producers from resorting to coping strategies that threaten their livelihoods by depleting productive assets, it can also unlock investments that are more risky but more profitable on average. For smallholder farmers, the risk of an infrequent but severe event, such as a flood or a drought, is a disincentive to investing in improved seeds, fertilizer and other costly agricultural inputs. Risk also has a negative impact on the development of rural financial services and the availability of credit to smallholder farmers. Knowing that insurance will provide payouts in the event of extreme climate conditions increases farmers' confidence to invest in improved agricultural practices, and increases the confidence of credit providers to lend to smallholder farmers. In this way, farmers can benefit from insurance even in years when they do not receive a payout.

What is index-based insurance?

Understanding *index-based insurance* requires recognizing how it differs from traditional *indemnity insurance* (Table 3.6-1). With any insurance, the producer or other client pays an agreed amount, known as a *premium*, on a regular basis. If a specified hazard is experienced, the client receives a monetary payout. The amount and timing of the premium, the conditions under which a payout is made, and the amount of the payout are all specified clearly in a contract, well in advance of experiencing the particular hazard.

Table 3.6-1. Contrasts between indemnity-based and index-based insurance.

Characteristic	Indemnity insurance	Index insurance
Payouts based on:	Measured loss	An index that is correlated with loss
Farm visits needed?	Yes	No
Incentive for good production management?	No: poor yield leads to payout	Yes: yield not directly related to payout
Advantages	Payouts based on actual loss	Quicker payout Lower operating cost allows lower premium or higher payouts More accessible to smallholder farmers and pastoralists
Limitations	High operating costs lead to high premium or low payouts Slow payouts	Basis risk: some losses may not have payouts

Indemnity insurance insures against a specified loss, and requires farm visits to verify that the loss occurred. This type of insurance has sometimes worked for large-scale farms. However, a few challenges have made this type of insurance generally infeasible for smallholder farmers and pastoralists. *Moral hazard* refers to the incentive for producers to neglect good risk

management in order to receive payouts. *Adverse selection* refers to the tendency for insurance to be purchased preferentially by producers who experience more frequent losses. Moral hazard and adverse selection increase the cost of insurance. Third, the need for farm visits to verify claims results in high processing costs and long payout delays.

Index-based agricultural insurance triggers payouts based on an index that is correlated with agricultural losses, rather than actual losses. Indexes include rainfall or temperature during a defined period, yields sampled over a larger region, and remote sensing of vegetation conditions or flood extent. Index insurance seeks to cover specific threats, and for a number of producers, that can be captured by the selected index.

Basing payouts on an objectively measured index, rather than the performance of individual producers, reduces the incentive for producers to neglect good risk management (*moral hazard*), or to base their decision to purchase insurance on the losses they expect to experience (*adverse selection*). Without the need to process claims and verify losses, payouts can be made quickly and with low administrative cost.

The main limitation of index-based insurance is *basis risk*, which represents the imperfect relationship between farmers' losses and the index that triggers payouts. As a result, producers who pay an insurance premium might not receive a payout when they experience significant crop or livestock loss, or they might receive payouts when they did not suffer actual losses. Both forms of basis risk can reduce the benefits producers receive from insurance.

There are three main types of index-based agricultural insurance programs:

1. *Weather index insurance* is based on meteorological variables such as rainfall or temperature, or sometimes the result of a soil water balance model driven by meteorological data.
2. *Area yield insurance* is based on yields estimated over a specified region, using statistical sampling from many farmers' fields.
3. *Index-based livestock insurance* is either based on livestock mortality data estimated over a specific region, or on vegetation remote sensing data. Vegetation remote sensing data is a useful index of livestock mortality where drought impacts on grazing resources are a major cause of livestock mortality.

Index insurance contract structure

Figure 3.6-5 illustrates how a simple weather index insurance contract is structured. This example index is based on rainfall, and is intended for use in drought index insurance schemes. A *contract window* is the specific range of dates when the insurance covers a particular risk. A well-designed weather insurance contract provides protection during critical phases when the crop is particularly vulnerable to the particular weather hazards. Timing is perhaps one of the most important factors to consider when designing a rainfall-based index for agricultural index insurance. The *trigger* is a pre-identified threshold value of the index that

triggers the beginning of a payout, and the *exit* is a pre-identified threshold that triggers the maximum payout amount. Weather index insurance contracts often increase payouts linearly when the index value falls somewhere between the trigger and the exit.

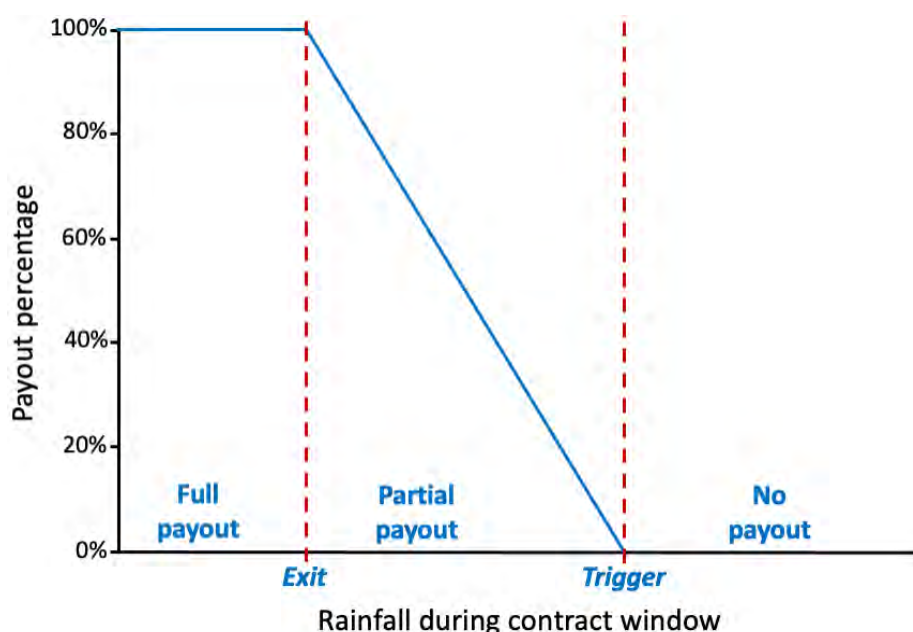


Figure 3.6-5. Components of a simple rainfall index insurance contract.

Index insurance in Kenya

Although index-based agricultural insurance in Kenya has seen growing adoption, as of 2022, less than 1% of smallholder farmers were protected by some form of insurance. However, several initiatives have expanded access in recent years. Index-based agricultural insurance in Kenya is characterized by use of satellite data, weather stations, and geospatial technology to reduce basis risk; collaboration among government agencies, international organizations, insurance companies, and agribusinesses to expand reach and affordability; and bundling of insurance with other agricultural inputs or services to increase adoption. Several of these programs use mobile applications and money transfer services for registration, premium payments, and claim settlements. The Kenyan government subsidizes 50% of premiums for some programs, making insurance more affordable for smallholder farmers.

Major initiatives include:

- *Kenya Agricultural Insurance Program (KAIP)*. Launched in 2015 by the Kenyan government in collaboration with the World Bank, KAIP uses satellite data for crop area and crop conditions to insure farmers and pastoralists from climate-related risks. KAIP is implemented by seven insurance companies in 33 selected counties and covers potato, onions, sorghum green grams and maize.
- *Agriculture and Climate Risk Enterprise (ACRE)* is the largest input-linked, mobile-enabled index insurance program in Africa, covering more than 1,700,000 farmers across Kenya, Tanzania, and Rwanda as of 2018. ACRE uses meteorological station data as a basis for indexes covering losses from drought, excess rain, and storms.

- *Bima Pima*, by Acre Africa, is a micro-insurance product that covers more than 70,000 farmers across 15 counties. It uses scratch cards sold at local agri-dealers, and allows premium payments in small amounts over time.
- *Gender-sensitive Agricultural Index-based Insurance (GAIINS)* is a new project launched in 2022, and implemented by RCMRD in partnership with NASA and USAID, that aims to help women farmers understand and access agricultural insurance.
- *Index-based livestock insurance (IBLI)* is a donor- and government-funded initiative designed to protect pastoralists in arid and semi-arid lands (ASALs) from drought-related livestock losses (Agency for Rangeland Information and Development in Kenya, 2018). Operated by the International Livestock Research Institute (ILRI) and delivered through private insurers, IBLI uses satellite data to monitor pasture conditions every 10–16 days. These data feed a statistical livestock mortality prediction model. If forage availability falls below a critical threshold, indicating high mortality risk, insured pastoralists receive payouts to sustain their livestock through feed, water, and other essentials. Pastoralists purchase IBLI policies annually, with premiums based on the risk associated with sustaining livestock during drought. The insurance covers camels, cattle, sheep, and goats. Policies are sold before Short Rain (August/September) and Long Rain (January/February) seasons to prevent adverse selection (Figure 3.6-6). Payouts are determined at the end of each season, based on the IBLI index.

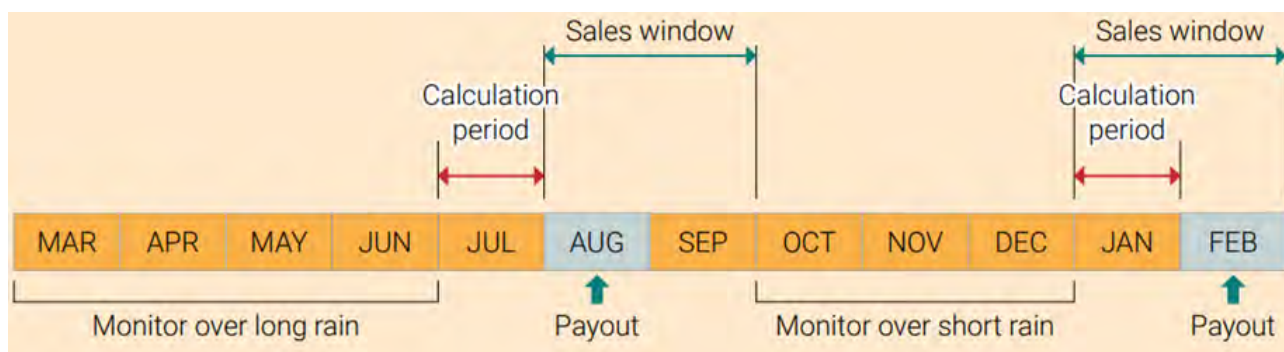


Figure 3.6-6. Index-Based Livestock Insurance (IBLI) contract windows and payout calendars. Source: Boresha Consortium (2022).

Is index insurance worth the cost?

Insurance is both an effective way to manage some risks, and an expensive way to manage risk. For commercially viable insurance, the premiums that insured producers pay must cover several costs. Part of the premium is saved towards payouts that the company owes insurance holders when the covered hazard occurs. Part of the premium is used to cover operating costs and provide profit to the insurance company that is assuming that risk. Since insurance premiums must cover the average cost of payouts, operating costs, and insurance company profits, producers can expect to pay more for premiums than they receive back in the form of payouts, when averaged over many years.

Recall from Session 3.3 that a decision maker who follows a particular set of assumptions will select the available management option with the largest certainty equivalent (*CE*). Insurance is likely to be successful in the long term only if the benefits outweigh the costs to the producer. For this to happen, *CE* of farm income must be higher with insurance than without insurance. It is useful to consider three cases in which this might happen:

1. The positive effect of reduced variability outweighs the negative effect of reduced average income on *CE*.
2. Insurance leads to management changes that increase net income.
3. Premium subsidies reduce the cost of insurance.

Case 1: Risk reduction effect outweighs reduced income effect

If we assume that (a) insurance premiums are not subsidized, and (b) insurance does not change agricultural management practices, then insurance has two opposite effects on *CE*. First, insurance reduces average net income, which tends to reduce *CE*. This is because the average payout is less than the annual premium. Second, insurance reduces variability of income, which tends to increase *CE*. Recall that combining sources of income that are negatively correlated reduces variability of income (session 3.5). Because insurance payouts occur in years when production is very low, income from payouts is designed to have a strong negative correlation with agricultural income and hence reduce variability of farm net income.

Since insurance has two opposite effects on *CE*, it is possible that insurance will benefit some producers but not others when the two assumptions (no premium subsidy and no effect on agricultural management) hold. Insurance is most likely to increase *CE* of farm income when:

- risk is very high;
- risk aversion is very high;
- insurance greatly reduces an important risk or prevents a shock from reducing future income through loss of productive assets; and
- insurers' operating cost plus profit margin is a small percentage of the premium cost.

One example where these conditions are likely to hold is pastoralism. Pastoral communities who depend on rangelands in semi-arid to arid lands across Africa are among the most vulnerable population to drought risk. In this system and environment, if a household's herd size falls below a threshold, it is impossible for them to generate enough income to rebuild their herd without outside assistance. This creates a poverty trap that can be triggered by herd mortality during a drought. Index-Based Livestock Insurance (IBLI) was pioneered by International Livestock Research Institute in northern Kenya in 2010, and has since been adapted in several other countries. Normalized Difference Vegetation Index (NDVI), based on satellite remote sensing, is a good indicator of rangeland conditions, and is strongly correlated with livestock mortality in drought conditions. IBLI is designed to protect pastoralists against herd loss and resulting poverty traps during severe drought, by triggering payouts when NDVI

in traditional grazing areas falls below a threshold. The initial design and calibration of the index and triggers took advantage of herd mortality data available in Kenya.

Case 2: Insurance leads to management changes that increase net income

The second case, in which insurance increases expected farm income, is possible if insurance leads to change in farm management, which increase average farm income. Several index-based agricultural insurance initiatives were designed to overcome risk as a barrier to adoption of improved agricultural management or market opportunities. Insurance can lead to improved management if it either enhances farmers' willingness to adopt improved practices, invest scarce household capital or borrow; or enhances the willingness of lenders or value chain actors to provide services to producers. In the case of crop-based farming systems, experience suggests that the benefits from enabling improved management practices are generally more important than the benefits from reducing income variability.

Factors that determine insurance cost

Since insurance is effective in the long term only if the benefits outweigh the costs, it is important to design insurance programs that are cost-effective. Several aspects of index insurance contract and program design influence the cost to producers:

- *Payout size and frequency:* For a given premium, producers face a trade-off between the frequency and the magnitude of payouts. The frequency of payouts in an index insurance contract should closely reflect the frequency of extreme events that lead to serious losses that exceed a household's coping capacity or that may lead producers to default on loans. Index-based crop insurance often covers the cost of production inputs to protect farmers' access to credit or to allow replanting if an early-season dry spell kills the germinating crop. Insuring the full harvest value of a crop would be much more expensive.
- *Operating costs:* The higher the operating cost per producer, the higher the premium. Low transaction cost is one of the main advantages of index-based agricultural insurance relative to indemnity insurance. Operating costs per producer typically decrease as the number of producers who adopt a particular insurance product increase and fixed costs can be spread among more client producers. Once an insurance program has been designed and implemented, the operational fees and profit margin set by insurance companies are usually not negotiable.
- *Uncertainty:* If an insurance company does not have enough data to estimate the insured risk accurately, companies will increase the cost of insurance to protect themselves from that uncertainty.
- *Subsidy:* In some countries, governments subsidize insurance premiums to reduce the cost to producers and thereby stimulate adoption. However, subsidies that are not implemented carefully have the potential to discourage other means of managing risk, create dependence on future subsidized assistance, and distort incentives for insurers and banks.

Index insurance good practice

High cost, basis risk, heterogeneity of farmers' needs, and trust in insurance are key challenges to achieving the potential benefits of index-based agricultural insurance. Recognizing these challenges suggests some practices that address those challenges (Table 3.6-2).

Table 3.6-2. Good-practice solutions for common index-based agricultural insurance challenges.

Challenge	Good-Practice Solutions
Cost-effectiveness	Insure only low-frequency, high impact risks that cannot be covered through other risk management options, exceed coping capacity, or threaten future livelihood potential.
	Design insurance to provide benefits in years when payouts do not occur, e.g., by bundling with credit or input packages that improve farmers' productivity and income.
	If insurance is subsidized to reduce cost and stimulate adoption, use only smart subsidies that: (a) serve a well-defined policy objective, (b) target a well-defined set of beneficiaries, (c) are informed by monitoring and evaluation, and (d) have either a clear exit strategy or a viable long-term financing strategy.
Basis risk	Use high quality, long-term data to design and validate indexes and calculate risk.
	Use agrometeorology tools and expertise to design indexes that are strongly correlated with agricultural losses – also considering issues such as understanding and trust in the product, vulnerability to manipulation, and availability of data.
	Validate index performance against objective data (e.g., historical production statistics, experiment station records or remote sensing data) and farmers' experience.
Varying farmer needs	Design insurance to meet needs of specific farmer groups, recognizing that the benefits might not outweigh the costs for some types of farmers.
	Involve farmers in the design process to ensure that products align with their demand and constraints, and cover the risks that they consider important.
	Verify that the index captures the risks that are most important to the farmers.
Trust in insurance	Support insurance with a strong legal and regulatory environment that enforces contracts that both buyer and seller can trust.
	Invest in transparent communication and farmer education to enable farmers to understand contract terms, the basis for payouts, and the reason why it is possible to experience a loss without a payout.
	Market insurance through existing distribution channels that farmers use and trust.



Exercise: IBLI costs and benefits

This exercise uses a hypothetical, quantitative index-based livestock insurance (IBLI) example to provide experience in assessing factors that influence whether insurance would increase or decrease a pastoralist's expected net income over a ten-year horizon.

*Working in small groups, follow the instructions in activity sheet **A3-6 Index-Based Livestock Insurance.docx**:*

- *Use premium and payout formulas to fill out the table.*
- *Calculate the sum assured for two hypothetical herders in Wario and Abdulahi.*
- *Calculate contract contribution for Wario from Kinna division and Abdulahi from Central Isiolo division and report on their answers.*



MODULE 4

Delivering Climate Services to Farmers

MODULE 4 | DELIVERING CLIMATE SERVICES TO PRODUCERS

Module 4: Delivering Climate Services to Producers equips extension staff to bring climate services into the services that they provide to their client farmers or pastoralists. Integrating climate services into agricultural extension activities and responsibilities can improve the effectiveness of both types of services. Delivering climate services to producers involves much more than disseminating information. It requires understanding farmers' diverse needs, strengthening their capacity to interpret and act appropriately on new types of information, and communicating farmers' demands and feedback to those who produce climate information and agricultural advisories. Communication processes are therefore crucial to enabling producers to benefit from climate services.

By the end of this module, you will be able to:

- Understand why *weather* and *climate* information time scales require different communication strategies.
- Formulate a climate service communication strategy for a given context.
- Recognize the factors that lead to inequitable benefits from climate services, and potential solutions.
- Lead a group of producers through a basic seasonal forecast communication and planning workshop process.

Session 4.1. Rural Climate Service Communication Strategies

Delivering climate services to farmers involves much more than disseminating information. Effective services must begin with understanding farmers' diverse communication and capacity needs. The different channels by which rural communities access information have differing roles, strengths and limitations. This session discusses different communication needs and communication channels that are relevant to rural climate services. It guides learners to consider how communication channels can be combined strategically to support the climate service needs of rural communities.

By the end of this session, you will be able to:

- Understand why *weather* and *climate* information time scales require different communication strategies.
- Explain how group participatory processes help farmers understand and use probabilistic climate information.
- Identify strengths and limitations of digital and broadcast media communication channels.
- Formulate an appropriate communication strategy to deliver climate services to farming communities in a given context.

Differing Needs for *Weather* and *Climate* Information

To review: *Weather* refers to the state of the atmosphere at a particular time and place. Examples include forecasts of daily or hourly weather conditions for up to about ten days into the future, and records of recent daily or hourly weather conditions. *Climate* refers to statistical information about weather. Examples include seasonal rainfall or temperature forecasts for the coming 3-5 months, and summaries of historical data showing seasonal cycles, variability and trends.

Weather is relatively simple straightforward to understand and factor into decision-making because people experience weather every day. In contrast, climate is a more abstract statistical concept and climate information is inherently probabilistic. Since climate information is more challenging to understand and act upon, different communication processes and more support are required to use it appropriately.

Practical considerations

Several differences between weather and climate information have practical implications for how the information would be best communicated to a given community of farmers or pastoralists.

Weather information is used frequently throughout the agricultural calendar, particularly the growing season and, because of its short lead time, must be communicated quickly. On the other hand, climate information tends to be used infrequently, at particular times during the year. For example, seasonal forecasts are consulted shortly before the rainfed growing season, to plan crop production strategies, obtain inputs or plan movement of the animals. Producers would likely consult historical climate information less frequently, to assess whether the crop farming and herding system is adapted to the risks, trends and seasonal cycles of their local climate.

Weather information is relatively simple to understand. Frequent repetition helps producers learn to understand weather information, assess its accuracy, and act appropriately on the information. Climate information is more challenging to understand because the information is more complex and inherently probabilistic. Because climate information is consulted and at most a few times each year, decision makers – when they are first introduced to a new type of climate information -- must depend on statistical descriptions instead of personal experience, to assess its accuracy and be trained to interpret and act appropriately on the information.

To illustrate this, suppose a decision maker needs to experience accessing and acting on a forecast, in order to assess its accuracy, and learn – through trial-and-error – how best to use it for a particular management decision. (Thirty repetitions is a very approximate rule-of-thumb that is sometimes applied to making reliable statistical estimates, and to making good intuitive assessments and decisions, from probabilistic information.) A farmer might consult and make decisions based on thirty weather forecasts in a single agricultural season, but would require most of her farming career to experience using thirty seasonal short-rains (i.e., October-December) seasonal forecasts.

Table 4.1-1. Differences between weather and climate information that have implications for communication needs.

<i>Weather information</i>	<i>Climate information</i>
Used frequently, needed quickly	Used at particular strategic times
Relatively simple information	Complex, probabilistic information
Users learn to interpret and act on information through repetition	Users need training and support to interpret and act on information
Simple messages, frequency of information fit mobile phone, broadcast media channels	Timing, training and support needed fit group participatory processes

Psychological considerations

Psychological research describes two different systems that the human brain uses to process decisions that are based on uncertain information:

- *Analytical processing* refers to the system our minds use to process information that is in the form of a statistical description, such as a probability distribution, or the probability of experiencing an outcome within a particular category such as above-normal seasonal rainfall.
- *Experiential processing* refers to the system our minds use to process information that is obtained through repeated experience. Experiential processing relates current situations to memories of one's personal experience, or the stories of other people's experience.

The brain's experiential processing system is likely to play a major role when people interpret weather information, because they experience weather conditions on a daily basis and have many memories of positive and negative experiences with weather. Producers, in particular, are likely to have strong memories, including some that are quite negative, from their experience with weather and its impact on their crops, animals and families. Since climate refers to statistics (i.e., averages, variability, seasonal cycles and trends) that are typically described with graphs or statistical summaries, and not to events that people experience at particular times, analytical processing is likely to play a major role when people interpret climate information. When people are able to relate abstract new information to their own experience, and hence integrate their analytical and experiential processing systems, they are more likely to act on that information and more able to avoid some of the errors that are commonly associated with making decisions with probabilistic information. This understanding of how the human mind processes complex information suggests that communication strategies that help producers relate climate information to their own experience is a key to enabling them to use new climate information effectively (Marx et al., 2007).

Based on these practical and psychological considerations, weather and climate information require different communication strategies. Mobile phone and broadcast media channels, for example, are a good match for the simple content, and the frequency and time-sensitive nature that characterize weather information. Structured training and group participatory processes are a good match for the degree of learning and support that are needed to understand and act appropriately on climate information. The next session will discuss communication options and strategy to support rural communities with climate services.

Participatory Climate Communication Processes

Participatory communication processes with groups of producers can be effective at increasing their understanding and willingness to act on complex, probabilistic climate information. They provide opportunity for formal training and social learning, and they help overcome the cognitive difficulties that people experience when processing and using uncertain information.

People generally have difficulty interpreting probabilistic information and tend to make several common errors when using that information for decision making; particularly when this information is presented and processed as statistical summaries. However, those difficulties are reduced when people combine analytical and experiential processing when they make decisions based on climate information (Marx et al., 2007). Furthermore, experiential processing tends to have greater influence than analytical processing on decision-making because it is connected to a person's memories and emotions. Participatory communication processes that incorporate group activities can help producers relate statistical climate information to their personal or collective experience. Examples include:

- Games that provide accelerated experience with simulated decisions;
- Activities that relate climate information graphs to farmers' memory of recent agricultural seasons;
- Group discussion of experience with traditional climate indicators; and
- Group discussions of hazards, opportunities and decision options associated with seasonal climatic conditions (e.g., above- or below-normal rainfall) they have experienced in the past.

Several participatory climate communication processes include useful training and guidance materials.

Participatory Scenario Planning (PSP), developed by CARE International's Adaptation Learning Program, brings together local governments and a range of stakeholders to incorporate seasonal forecasts into their planning (Ambani et al., 2018). PSP is designed to support access, understanding and collective interpretation of seasonal climate forecasts for decision-making by farmers and other decision makers. The process is closely tied to the tercile convention for presenting seasonal forecasts, and includes discussion of hazards, risks, opportunity and potential decisions associated with each rainfall tercile scenario. One- or two-day PSP workshops convene all relevant actors – KMD, value chain stakeholders, government departments in climate-sensitive sectors (e.g., agriculture, water, energy), and local communities – prior to each rainfall season to co-produce climate services that are responsive to user needs. PSP participants produce consensus management advisories for crops, livestock and other climate-sensitive sectors (Figure 4.1-1). PSP has been implemented in most of Kenya's counties, with support from the Agricultural Sector Development Support Program (ASDSP) (Miriti and Bullock, 2023).

Seasonal Participatory Planning for Agricultural Risk with Climate Knowledge (SPPARCK) is a participatory workshop process that the IRI developed to help farmers relate downscaled seasonal forecasts in probability-of-exceedance format to their own memory of historic climate variability (Hansen et al., 2022). It specifically supports the use of the Flexible Forecast Maproom presentation (Session 2.2), although it was developed before National Meteorological Services

started adopting this format. While the goal of this approach is to equip producers to understand and use seasonal forecasts for their planning, most of the time is spent using local historical climate data to understand the concept of probability and the risks that seasonal forecasts modify. SPPARCK is presented in Session 4.3.

Livestock Sector Advisories

1. Harvesting and storage of pasture/fodder
2. Creation of a seed bank
3. Strengthening of Grazing Management committees
4. Controlled grazing"
5. Self-destocking
6. Separation of sick herds
7. Develop watering schedules to avoid mixing of herds
8. Reactivation of ward peace committees

Health Sector Advisories

1. Have a basic emergency kit ready,
2. Educate communities on water contaminations
3. Boiling of water before consuming or use bottle water if available
4. Seek medical check-up and treatment
5. Stay Informed and Monitor weather updates
6. Report any sign and symptom of widespread infections/diseases
7. Initiate early exclusive breastfeeding and continue breastfeeding up to 2 years
8. Household nutrition screening such as family MUAC
9. Household food diversification
10. Community nutrition early self-referral

Agriculture Sector Advisories

- 1) Messaging of opportunity for planting drought tolerant seeds.
- 2) Early land preparation
- 3) Early harvesting of farm produce
- 4) Safe disposal of crop wastes and residues
- 5) Supplementary irrigation
- 6) Water harvesting structures
- 7) Dissemination of drought early warning information
- 8) Continuous monitoring and surveillance
- 9) Use of PPE
- 10) Use of appropriate TIMPS
- 11) Peaceful coexistence
- 12) Soil sampling and testing
- 13) Opening of farm access roads
- 14) Prepositioning of subsidized fertilizer at the wards

Peace and Security

- 1) Conducting Surveillance by grazing and peace committees
- 2) Key messages on resource-based conflict
- 3) Accommodating fellow pastoralists
- 4) Reporting of migration details to elders and chiefs
- 5) Sensitization to maintain peace on local radio talk shows
- 6) Reporting of migration details to elders and chiefs
- 7) Reporting to nyumba kumi chairperson
- 8) Informing KWS offices in case of invasion by wildlife
- 9) Avoid wildlife corridors
- 10) Preserve foodstuff
- 11) Practice kitchen gardening
- 12) Selling of livestock to buy foodstuff and reduce the herd
- 13) Pastoralist to avoid encroachment of livestock to farms
- 14) Water corridors not to be closed

NB:

These advisories should be used in conjunction with weekly and monthly forecasts including updates and alerts issued by this department

For any enquiries please contact:



KENYA METEOROLOGICAL DEPARTMENT

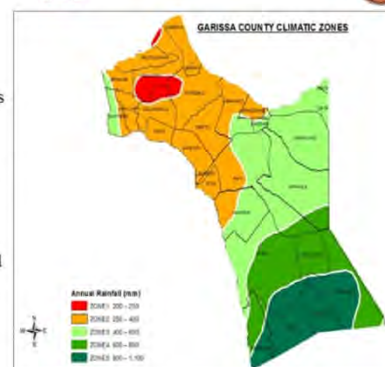
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GARISSA COUNTY
OCTOBER-NOVEMBER-DECEMBER
2024 RAINFALL FORECAST

KENYA METEOROLOGICAL
DEPARTMENT

IN COLLABORATION WITH

ASAL-Adapt program implemented by
Mercycorps - Kenya



Figure 4.1. Example of a PSP advisory from Garrisa County. Source: KMD.

Participatory Integrated Climate Services for Agriculture (PICSA) is a structured participatory climate communication, training and planning process, developed by the University of Reading (Dorward et al., 2015). PICSA combines location-specific climate information with participatory activities including resource mapping, activity calendars and budgeting activities to empower farmers to make better-informed crop, livestock and livelihood decisions. PICSA has a strong focus on using historical climate information to understand risks that are important for agriculture. PICSA includes the use of seasonal forecasts, based on the older tercile forecast convention. Like the seasonal planning workshop covered in the next session, PICSA makes extensive use of graphs of the local climate.

Participatory Rural Appraisal (PRA) is a "bottom-up" planning and implementation process that engages community institutions and leaders, and other relevant stakeholders (e.g., local government, agricultural extension staff, NGOs), to identify problems, needs, and

opportunities. PRA is used to diagnose a community's current situation (*Exploratory PRA*), address a specific area of concern (*Topical PRA*), or diagnose a problem and identify solutions (*Problem Solving PRA*). In the context of climate risk management, Problem Solving PRA can be used to engage affected rural communities and other relevant stakeholders to understand climate-related challenges, diagnose constraints (e.g., climate information and communication gaps, needs of rural women and other disadvantaged groups), and identifying appropriate solutions.

The *Farmer Field School* approach, which FAO developed initially to support integrated pest management, convenes farmers frequently through an agricultural season for training and shared learning. Climate services, and management of climate-related agricultural risk, has been incorporated into farmer field school programs and curriculum in Indonesia, The Philippines, and recently East Africa (*Climate Resilient Farmer Field School*, Osumba et al., 2021; p'Rajom et al., 2020). Because they go into detail about a range of topics and specific agricultural management issues, farmer field schools are the most detailed and time-consuming of the participatory communication approaches for climate services. Recently, the traditionally crop-focused farmer field school concept has been expanded to pastoral livelihoods, as an innovative capacity development strategy. The *Pastoral Field School* concept is guided by several principles including: practical problem-solving learning, rangelands and the herds as the primary learning resources; discovery based learning and trained facilitators as the guide to deliberate learning (FAO, 2013).

Digital and Media Climate Communication Channels

Agricultural extension services and climate services use a range of communication channels to reach their clients. Agricultural extension services traditionally emphasized face-to-face communication processes (e.g., farm visits, training workshops, farmer field schools) and broadcast media. In response to expanding mobile phone coverage and cost considerations, agricultural extension services increasingly use digital communication channels.

Broadcast media

In much of rural Africa, rural radio remains the communication channel that offers the greatest reach at the lowest cost. It is used widely and effectively for weather information, and for awareness and education campaigns around agricultural innovations that are widely applicable for producers in a given region. Television programming can be more engaging and informative, but is generally less available to smallholder farmers and pastoralists. Broadcast media allow information to be disseminated without local presence of extension agents or meteorologists, but offers limited opportunities to respond to demand or incorporate feedback from users. For reasons that were already discussed, this is an advantage for time-sensitive weather forecasts and extreme weather alerts, but may be a disadvantage for information at a climate time scale.

Although broadcast media (radio, and in some regions television) is generally a one-way dissemination channel, several innovations can make communication more interactive, and hence better able to engage producers and meet their context-specific needs. Community listening groups combine the reach of radio with the benefits of group interaction and social learning. Radio listen groups can be effective at fostering change in farm practices, and have been part of several efforts to support rural climate services in Africa. Creative programming that involves producers and experts in village dialogs, radio drama and reality television programs helps producers relate new information and concepts to their experience. For example, the popular “*Shamba Shapeup*” television program in Kenya uses a reality show format to educate farmers about improved farming methods, including climate risk management and the importance of gender and financial inclusion.¹³ The *Shamba Shape Up* production team travels to smallholder farms (“*shambas*”) across Kenya, educating farmers about topics such as weather forecasting, drought-tolerant seed, fertilizer, irrigation, multiple cropping, pest and disease management, livestock management, nutrition and access to finance. Viewers can ask questions about a range of issues and concerns by texting or calling a call center that is staffed with agronomists, livestock experts and a veterinarian. An evaluation found that *Shamba Shapeup* effectively motivated widespread positive change in farming practices through a combination of entertainment, empathy with featured farm families, and interaction among farmers and with credible experts (Clarkson et al., 2018).

Mobile phone channels

New digital services that use mobile phones have potential to address both the limitations of broadcast media and the resource and scaling challenges of traditional face-to-face communication channels. If information is available about farmers’ locations and characteristics, it is possible to tailor climate and extension messages to their needs. Interactive mobile phone channels exist that enable on-demand access to content and two-way information flow.

Mobile phones are used in several ways. Broadcasting messages to all subscribing producers, in the form of short text (SMS) or audio messages, is an efficient but supply-driven communication channel. This can be an efficient way to disseminate time-sensitive information that is relevant to many individuals, such as daily weather forecasts or emergency warnings of extreme weather conditions. More demand-responsive mobile phone strategies allow users to request SMS or audio messages from a menu of options, through interactive voice response (IVR) or Unstructured Supplementary Services Data (USSD) menu applications. Call centers that allow a user to talk with an expert are the most demand-driven but also the most expensive mobile phone communication strategy.

¹³ <https://agrilinks.org/post/edutainment-model-shakes-and-shapes-international-development-communications>

A growing suite of mobile phone services in Kenya provide weather and/or climate-related information for producers, often bundled with other information and services. These services include a mix of project-based, public-sector and commercial services. As a public sector example, the *Kenya Agricultural Observatory Platform* (KAOP)¹⁴ is an online platform, developed by the Kenya Agricultural and Livestock Research Organization (KALRO), that uses geo-data from satellites to generate real-time, location-specific information and advisories for producers. For all wards across Kenya's 47 counties, forecasts from a company based in the USA, and agronomic advisories are uploaded onto KAOP for dissemination to producers through SMS or via the online portal.¹⁵ As a commercial example, DigiFarm is a service that Safaricom bundles with its mobile services, which offers farmers free services including farm inputs at discounted prices, production input loans, access to markets, weather information and educational content on farming.¹⁶ DigiFarm offers additional value-added services such as crop insurance, and extension services through remote agronomists located at the DigiFarm call center or on ground DigiFarm Village Advisors (DVA).

Internet tools and digital applications

For producers who have access to data service, and either smartphones or computers, digital apps and web-based tools offer powerful and flexible options to access climate-related information. Digital apps and web-based tools can provide information that is tailored to particular decision makers and locations, and in multiple formats (text, visual, audio).

In Kenya and across sub-Saharan Africa, a growing set of agricultural development projects and private sector agricultural technology companies is developing website content and smartphone tools to support producer decision making and agricultural extension providers (Dittmer et al., 2022). The iCow App and iShamba App smartphone applications provide climate-related information services through SMS to dairy and small-scale farmers. These Apps provide essential information about livestock management including breeding, nutrition and health. iCow also features a cow gestation calendar and links to the nearest veterinary service providers. Relevant web-based tools in Kenya include KMD's suite of Climate Maprooms (Sessions 2.2-2.4), the AgData Hub under development through the AICCRA project (Session 2.1), and KALRO's Kenya Agricultural Observatory Platform.

Extension videos

Short training videos by lead producers or extension workers can be an effective way to share concepts and information with producers. Short videos can be shared with groups of crop and

¹⁴ <https://kaop.co.ke>

¹⁵ <https://allianceforscience.org/blog/2023/04/kenya-smallholder-farmers-benefit-from-online-climate-tool-that-sends-location-specific-weather-advisories-to-their-phones>

¹⁶ <https://www.safaricom.co.ke/media-center-landing/frequently-asked-questions/digifarm>

livestock farmers, using for example a portable projector; made available on demand on computer monitors or projectors at local government offices, training centres or other community facilities; including community Barazas, livestock water points or played on smartphones, tablets or laptop computers during gathering such as in market place.

Institutional Networks

Institutions represent a third type of communication channel, in addition to group participatory processes and digital communication channels. In Kenya, producers and other local stakeholders access climate and other types information through many different institutions. These institutions include several national and country-level government agencies, NGOs, CBCs (water committee, health committee, disaster preparedness committee, etc.), producer organizations, and a very active private agricultural technology sector. They play differing roles in the generation, translation, transfer and use of climate information. As a result of this diversity, it might not be obvious to an end user whether an institution that provides them with information generated that information, or whether it is transferring information that they obtained from another institution.

Public sector support for climate services in Kenya became more localized and generally better integrated across meteorological and agricultural institutions since the 2010 constitution decentralized much of the government's authority, finance and services to the county level. As a part of this restructuring KMD began shifting much of its service delivery to the county level. The Adaptation Consortium (ADA), led by the National Drought Management Authority (NDMA), provided technical and financial support to develop climate services in a set of pilot counties. This led to the establishment of county climate service plans, County Meteorology Directors employed by KMD, and installation of meteorological stations and creation of CBCs. ADA has adopted Participatory Scenario Planning (PSP) (Ambani et al., 2018) as a way to structure regular multi-stakeholder meetings to consult seasonal forecasts, formulate plans, and produce agricultural advisories (Adaptation Consortium, 2014). The process is integrating climate services and agricultural extension services at the county level. A 2014-15 evaluation in Kitui County showed that the resulting decentralization of climate services bundled with advisories resulted in higher incomes for agricultural and non-agricultural households (Barrett et al., 2021).

Aside from NGOs, CBCs and government bodies, farmers' institutionalised groups, such as women groups and SACCOS, youth groups, livelihoods-based groups, and the council of elders are another structure that facilitate sharing and dissemination of climate information and other disaster related information. Beyond information sharing, these local institutions provide labour and other resources for responding to shocks and stress, and ensures continued solidarity and sharing (Mohamed, 2023).

Although some of the institutions that are involved in agricultural climate services in Kenya provide mandated services on a sustained basis, many are involved in climate service activities

through time-bound projects. Projects can increase farmers' access to key institutions, during the project lifecycle. As a result, the institutions that interact with producers vary in space and time. Producers tend to have greater awareness, access and capacity to act on climate information in locations where climate service projects have been active.

The diversity of institutions involved in climate services presents both opportunities and challenges. In terms of challenges, when information passes through a network of institutions, there is a risk that the information will be distorted. Loss of information about the probabilistic nature and inherent uncertainty of the information is a particular concern in the case of climate information. Furthermore, the diversity of institutions raises the risk that producers will receive conflicting information from different institutions. This is particularly challenging when the source and the quality of the information is not communicated, or when producers are given conflicting management recommendations.

The diversity of institutions also presents opportunities. First, institutions that producers already know and trust may be very effective at introducing new types of information, and building farmers' confidence and capacity to act on that information. Trust in a messenger is an important requirement for acceptance and use of information. Second, women's organizations and other non-governmental organizations that serve disadvantaged groups may be well positioned to reach those groups of producers with climate services and strengthen their capacity to understand and act effectively on the information. Third, agricultural extension and advisory service providers, and agribusiness organizations have the potential to bundle climate information with other types of information or services in a manner that exploits their synergies and increases uptake. Finally, institutions who work with producers have the potential to amplify the producers' influence on providers of information and services.

Combining Communication Channels to Support Climate Services

The various communication channels that are available in a given location play different roles in support of rural climate service. Examples of climate service communication activities include:

- raising awareness of available services;
- *climate literacy*: educating producers about climate risks and their management;
- adapting farming systems to the local climate based on historical data;
- forecast-based planning for the next agricultural or migration season;
- accessing daily weather monitoring and forecasts;
- disseminating weather hazard warnings;
- providing customized information, advisories and decision support tools;
- bringing farmers' feedback into the co-production of climate services: and
- supporting extension workers' access to climate information, advisories, resources and decision support tools.

Some communication channels are better suited than others to support these particular activities. For example, videos, and radio and television programs are well-suited to building awareness, reinforcing concepts introduced through participatory processes, and delivering frequent forecasts and advisories at a weather time scale. Mobile phones can push location-specific weather forecasts and alerts of extreme events as SMS or voice messages; and provide targeted information on demand. Group processes are effective for initial learning and seasonal planning around complex information at a climate time scale, and provide an opportunity for the learning and feedback that are needed to design effective services.

A simple matrix offers a practical approach to developing a CIS communication strategy for a given agricultural community and context. The columns represent the channels for accessing information that are available to the community, and rows represent the CIS functions that require communication for that community. Then for each cell, rate how useful the given channel is to support the given function. Table 4.1-2 provides a highly generalized example, using a scale of 1 (not useful) to 3 (very useful). However, the climate service activities and the communication channels available to support them vary with local context.

Table 4.1-2. Suitability of different communication channels for climate service communication functions (1 = not useful, 2 = somewhat useful, 3 = very useful). Adapted from Hansen et al., 2019.

Function	Communication channel			
	Group meetings	Broadcast media	Mobile phone	Internet, smart-phone
Awareness of services	2	3	1	2
Climate literacy	3	2	1	2
Adapting to local climatology	3	1	1	2
Forecast-based seasonal planning	3	2	1	2
Weather monitoring and forecasts	1	3	3	2
Extreme weather alerts	1	2	3	2
Customized information, advisories	2	2	3	3
Producer feedback	3	1	2	3
Provide information, support to extension staff	1	1	1	3



Exercise: Rural climate service communication strategy

- *Work in small groups from the same region.*
- *This exercise uses a PowerPoint template, **A4-1 Rural climate service communication strategies.pptx***
- *Agree on a specific familiar rural context.*
- *Identify relevant communication needs and available channels.*
- *Modify the table in slide 4. Modify rows to include your list of communication needs, and columns to include channels relevant to your location.*
- *Fill the cells in the table to indicate suitability of the channel for the function: 1 = not useful, 2 = somewhat useful, 3 = very useful.*
- *Report to plenary.*

Session 4.2. Gender and Social Equality in Climate Services

Inequality is deeply built into the way societies, economies and governments are structured. These structural inequalities can make it challenging to provide climate services that are accessible and benefit everyone. Even though climate services have the potential to improve the lives of rural farmers, they risk reinforcing existing inequalities if service providers fail to understand and address the unique needs and constraints of women, youth, and other historically marginalized populations, as well as include them in the design of services. Recognizing these populations as distinct user groups, with specific needs and barriers when it comes to accessing and utilizing climate services, is crucial.

By the end of this session, you will be able to:

- Explain how the concepts of social justice and climate justice apply to climate services.
- Recognize factors that lead to inequity in rural climate service use and benefits, based on gender, age and other aspects of identity.
- Describe the benefits of treating climate information as a public good.
- Identify climate service practices that can address common drivers of inequitable distribution of benefits from rural climate services.

Climate Justice and Climate Services

Gender and social equity are aspects of growing concern about *climate justice*, and social justice more broadly. *Social injustice* is the unequal, inferior treatment of certain populations and communities based on aspects of their identity, which can include but are not limited to gender, race, ethnicity, religion, sexual identity, age, ability, language, and class. These injustices often overlap and are difficult to separate, with individuals carrying multiple, intersecting identities – for example, a poor elderly woman of a minority ethnic group – experiencing disproportionate and compounded unfair treatments. Thus, *social justice* is the active work to bring about equal rights, opportunities, treatment, and access to resources to all groups and communities in all aspects of society.

Social justice is foundational to our recognition of climate and environmental injustice. That is, climate change and environmental degradation disproportionately impact marginalized

communities because they exacerbate existing inequities caused by social injustice. *Climate justice* recognizes that climate change and climate injustice are human rights issues, and actively works towards more equitable distribution of the burdens of climate change and the efforts to mitigate them. Concern about climate justice stems from recognition that the negative consequences of anthropogenic climate change, including sea level rise, desertification, and increasingly common crop failures and extreme weather events, have major impacts on human quality of life. Wealthy nations, where lifestyles are more resource-intensive, are responsible for a larger portion of greenhouse gas emissions which have led to climate change, while poorer nations and vulnerable communities often experience the negative impacts of climate-related crises sooner and more severely. To recognize that the communities less responsible for climate change are suffering first-and-worst is to recognize climate injustice.

Just as economic, social, racial, and other inequalities lead different groups and communities to experience different levels of vulnerability to risks posed by climate change, adaptation solutions that aim to address climate vulnerabilities have the potential to benefit some groups and communities more than others, and further exacerbate the marginalization of some groups and communities. Climate services aim to apply climate information and services to reduce the gaps in ability to respond and adapt to climate impacts and risks. However, not all individuals—depending on their age, gender, socio-economic status, geographical location, physical ability, education, religion, ethnicity, and many other factors and categorizations—may have equal and fair participation in designing and accessing these services. In this session, we focus on gender-based and wealth-based equity and justice challenges in rural climate services.

Taking a Gender Equality and Social Inclusion (GESI) approach can help ensure that climate services are inclusive, fair and beneficial for everyone. This means going beyond just treating everyone equally, and instead considering how a person's gender, as well as other aspects of their identity (intersectionality), impact their unequal access to resources, ability to participate in decision-making, and chance to benefit from climate services within a particular cultural and institutional context. Social inclusion, which is about improving ability, opportunity and dignity of disadvantaged individuals and groups in society, seeks to address the different barriers people face. By using a GESI approach and tailoring solutions to address these intersectional inequities, climate service providers can help make these critical resources more accessible and beneficial for all members of rural communities.

Drivers of Gender Inequality in Rural Climate Services

On average, across Africa rural women experience lower income access to education, property and finance; political participation; mobile phone ownership; and health status than rural men. Sociocultural norms, institutional biases, and differing resource endowment and capacities among individuals reinforce these inequalities within rural populations. The drivers of gender inequality present crucial challenges to agricultural development efforts generally, and to equitable assess, use and benefit from climate services. Climate services have potential to strengthen the wellbeing of rural women and other disadvantaged groups. However, they risk

reinforcing existing inequalities if service providers fail to understand and effectively address their differing needs and constraints, and include them in the development of services.

The discussion that follows highlights some of the gender-related challenges that have been recognized in some contexts in rural sub-Saharan Africa. However, the drivers of gender inequity can be quite context- and culture-specific. Efforts to develop equitable agricultural CIS should therefore be informed by knowledge of how gender and other aspects of identity interact with sociocultural norms and institutional biases in a given local context.

Sociocultural norms influence control of climate-sensitive decisions

Sociocultural norms that differentiate farming and decision-making roles based on gender can lead to differences in participation in farm and household decision making. In a few cases, this leads to differences in the types and time scales of information that individuals can act on. For example, in contexts where men are responsible for draught animals and therefore plowing of the fields, information regarding rainfall onset timing has been found to be more beneficial to men than women (Tall et al., 2014). In Kenya, women traditionally have more responsibility for staple food crops such as beans, sorghum and millets (Bullock and Katothya, 2022). An intra-household survey of 156 married couples in Kenya found that husbands accessed climate-related early warnings and advisory services more frequently, while their wives accessed weather forecasts more frequently (Ngigi and Muange, 2022). In pastoral settings women prefer information about water resources, as they are in charge of household chores and caring for young animals, while men prefer information about livestock grazing pattern as they make decision about herd mobility (Bedelian, 2024).

In some contexts, sociocultural norms and unequal access to resources may account for lower rates of climate information access and use by reducing women's influence over climate-sensitive decisions (Bullock and Katothya, 2022). In Kenya, for example, an estimated 1–5% of land titles belong to women.

Sociocultural norms and historical institutional biases influence access

In some cultures, gender roles and household dynamics can constrain rural women's access to certain communication channels, such as radios, mobile phones, and group meetings. Furthermore, the process of sharing information within households is complex and influenced by various factors beyond just the initial receipt of the information. Thus, even when one spouse (usually the husband) receives climate information, it is not guaranteed to be effectively shared or transferred to the other spouse.

Men and women may prefer to use different channels to access climate information services. For example, in Kenya, Ngigi and Muange (2022) found that husbands tended to favor extension officers, printed materials, television, and local leaders as their communication channels. In contrast, wives showed a preference for radio broadcasts and information shared through social groups.

Agricultural extension institutions, producer associations, and related service providers across Africa have historically favoured men's participation or focused on agricultural commodities that are considered men's responsibility. Farmers' associations and cooperatives often exclude women based on membership criteria of land ownership and capital requirements. In Kenya, for example, gender norms have precluded women from participating in rangeland institutions, with the majority of the grazing and water committees comprised of men (Bullock et al., 2023).

Since Kenya instituted a new constitution in 2010, gender-sensitive policy reform efforts have helped to increase women's participation in political processes and access to government services. However, rural women still often face barriers at the community level. While group participatory communication processes can be effective at raising farmers' capacity to understand, access and act on climate information (Huyer et al., 2023) (Session 4.1), social norms that associate public meeting participation with men, or restrict cross-gender interaction, can prevent women from accessing climate information shared in those forums (Gumucio et al., 2020). For example, women's participation in community meetings (*barazas*) in rural Kenya is often quite high, yet women may sit separately or speak less than men in these settings. Furthermore, childcare, household responsibilities or spouse disapproval can limit women's ability to attend meetings in which climate information and advisories are discussed, particularly when they require travel.

Social norms may reduce education opportunities for girls

Education attainment and literacy rates have historically been lower for women than for men across sub-Saharan Africa. Literacy rates are higher in Kenya, and the gap between men is lower, than for the continent as a whole. However, education gaps during earlier decades still affect the older rural population, particularly women.

Climate information use is associated with level of education, and hence with gender and age. Education enhances literacy and numeracy skills, enabling individuals to better understand and interpret complex climate information, and to participate in climate service-related group discussions. Higher levels of education are generally associated with greater awareness of the existence and usefulness of climate information for agricultural decision making, and with greater access to technologies and institutions for obtaining climate-related information and advisories. Conversely, lower educational attainment and literacy rates among rural women can exclude them from text-based climate information resources like SMS, bulletins, and written training materials. Generally lower levels of digital literacy among female producers, and older producers of both sexes, hinders their ability to access and use digital climate information products and tools. This is a particular challenge for pastoralists settings, where nomadic education opportunities are limited, and school dropout rates are high due to competing migration and labour needs compared to sedentary farmers (Krätli and Dyer, 2009).

Public- vs. Private-Goods Models and Wealth-Based Inequality

The tension between public-good and private-good approaches to climate services is an important current issue in the development of climate services across Africa and globally. It involves complex historical, policy, economic and equitability issues.

Shifting balance between public- and private-goods approaches

A resource is considered a *public good* if it is *non-rival* – meaning that its use by an individual does not prevent use by other individuals – and *non-excludable* – meaning that non-paying individuals cannot be prevented from use. In the absence of externally imposed restrictions, information has these two characteristics of a public good.

Several forces in the late 1980s and 1990s contributed to a global shift: away from treating climate information, particularly historical data, as a public good for development, and towards treating it as a private good for generating revenue. Major international development banks promoted structural adjustment programs that encouraged or required developing countries to privatize or downsize public services to reduce government spending. At roughly the same time, several countries in the Global North, particularly in Western Europe, began efforts to recover a portion of NMS costs by commercializing aspects of their data and services. In 1995, the World Meteorological Organization (WMO) responded to the debate around data access by issuing Resolution 40¹⁷ as a compromise between proponents of data as a public good, and pressure to restrict access in order to support cost recovery and limit private-sector competition. Resolution 40, which now governs how NMS share climate data, makes a distinction between a minimum set of “essential data and products which are necessary for the provision of services in support of the protection of life and property and the well-being of all nations” – which should be freely available for non-commercial purposes – and additional data which NMS can restrict or charge for at their discretion. These forces led NMS to greatly decreased the amount of climate-related data that they made freely available, and more recently to develop fee-based weather and climate services – directly and through public-private partnerships – that aim to supplement their inadequate public funding.

Strengths and limitations of alternative business models

The three main business models for agricultural climate services are:

- *publicly-funded public goods*;
- *user pays*; and
- *third-party pays*.

These models may exist in combination in a given country and context. The “*third-party pays*” model involves a development donor or other non-governmental funder subsidizing public

¹⁷ http://www.wmo.int/pages/about/Resolution40_en.html

and/or private service providers. Such subsidies are generally limited to project cycles, and may come with the expectation that service providers will transition to a user-pays model. Several variations of *user-pays* climate service business models exist in Africa, including annual subscriptions, pay-per-use, and climate information bundled with mobile phone or other services. Furthermore, user-pays and third-party-pays models may involve public-sector, private-sector, or a mix of public and private provider organizations.

Arguments for promoting user-pays service business models include: inadequate public funds for NMS to maintain services and infrastructure, sustainability concerns over dependence on external project funding, greater flexibility and innovativeness within the private sector, and opportunity to promote new businesses in the non-farm rural economy. Because the private sector typically faces fewer obstacles to innovating, it may have a comparative advantage in aspects of service delivery such as developing user-friendly digital tools, bundling new information into existing services for producers, and developing specialized advisories for high-value agricultural commodities. On the other hand, public-sector NMS have the mandate and comparative advantage to provide the high-quality data and information that underpin climate risk management.

The user-pays model faces important economic challenges, and has therefore had very limited success in sub-Saharan Africa. Consider the case where an individual pays to access climate information. The information, once obtained, can be freely shared and used among non-subscribers within community and kin networks. Such informal sharing increases the social value of the information, but it also decreases the number of potential customers who would be willing to pay for the service, and the amount that subscribers are willing to pay. Recall that a resource is a public good if it is non-rival and non-excludable. Information can be treated as a private, marketable good only if it is made excludable. If a service provider attempts to make information excludable by imposing restrictions and penalties for sharing the information to non-paying users, this would negate or greatly reduce the benefits to subscribers and to the broader rural community. Such restrictions and penalties would likely also reduce the number of producers who would be willing to pay for information.

Wealth-based equity concerns

In addition to the economic challenge, depending solely on fee-based services for producers risks reinforcing wealth-based inequities because relatively poor, subsistence-oriented rural households are less able to pay for services than more commercially-oriented farmers and ranchers. Willingness-to-pay studies typically provide separate estimates of the proportion of the sampled population that would be willing to pay for the service, and for those who are willing to pay, the amount (average and range) they would be willing to pay. Available willingness-to-pay studies show that fee-based climate services would exclude a large proportion of farmers (Table 4.2-1).

Farmers who lack the willingness or ability to pay for climate information are disproportionately relatively poor farmers who face land and capital (e.g., credit) constraints, and women farmers

who lack control over household finances (Amegnaglo et al., 2017; Antwi-Agyei et al., 2021a; Diallo and Dossou-Yovo, 2024; Ouédraogo et al., 2018). Note that a particular information package typically has a fixed cost, but the returns to investing in information are dependent on scale and production system. The benefit-cost ratio for a fee-based information service is therefore less favourable or unprofitable for farmers who cultivate small areas, than for relatively wealthy farmers who cultivate larger areas or produce higher value crops. Since women control substantially less land than men, on average, they can expect substantially lower returns from the same investment in a climate-related information service.

Table 4.2-1. Published studies of the proportion of farmers (un)willing to pay for weather and climate information in Africa.

Study	Country	Product	Unwilling to pay (%)	Mean WTP*	Sample size
Amegnaglo et al., 2017	Benin	Seasonal forecasts	19	\$23.42	354
Antwi-Agyei et al., 2021	Ghana	various	57	n/a	193
		Seasonal forecast	79		
		Daily forecast	76		
Kamau et al., 2024	Kenya	"Agro-weather advisory"	49	\$3.09	2,384
Ouédraogo et al., 2018	Ghana	Weather forecast	54	\$28.37	n/a
Ouédraogo et al., 2018	Burkina Faso	Seasonal forecast	47	\$7.51	169
		Daily forecast	47	\$4.27	
		Agro-advisories	67	\$3.50	
Zongo et al., 2015	Burkina Faso	Seasonal forecasts	36	\$1.19	629

*Annual amount per farmer, averaged among entire sample, adjusted to 2022 USD.

Under-funded public-sector meteorological and agricultural extension institutions face difficult challenges as they seek to support the information needs of farmers and other agricultural decision makers. As these institutions and the broader agricultural climate service community seek for solutions to these challenges, it is important to consider equitability, and the needs of resource-poor producers who would be excluded from fee-based services. Adequate investment in appropriate climate-related information, as a public good, while also engaging private sector innovation where it adds value, can be expected to maximize the benefit of climate services for farming populations and the agricultural economy as a whole.

Improving Distribution of Rural Climate Service Benefits

Once disadvantaged groups are identified, and the main constraints they face in accessing, using and benefitting from services are understood, there are several options available to foster more equitable rural climate services (Table 4.2-2). The context-specific forces that drive inequality based on factors such as gender, age, educational opportunity and wealth underscore the importance of understanding the distinct needs and constraints of various user

groups when designing and delivering climate services. A one-size-fits-all approach risks inadequately serving certain user groups, and limits the potential impact of climate information for all producers.

Communication channels and processes

Available evidence suggests that the most widespread challenges and hence the most promising opportunities to improve the distribution of benefits from rural climate services involve communication processes and channels. Understanding differences in how men and women prefer to access information, and the challenges that they encounter, may suggest opportunities to make access more equitable by combining communication channels.

Table 4.2-2. Potential solutions to common equity challenges in rural climate services.

Equality challenge	Potential solutions
Gender and age differences in climate information needs	Separately assess information needs of women, men and youth; of female-headed households; and of pastoralists.
	Facilitate community conversations around enhancing women's decision-making within households and communities.
Obstacles to accessing ICT, broadcast media, group communication channels	Combine communication channels suited to differing needs and resources.
	Schedule meetings, broadcasts to accommodate women's time and mobility constraints.
	Partner with women's and youth groups, and organizations with experience in designing socially inclusive information and advisory services, to deliver information and build capacity. Take advantage of youth as disseminators of information.
	Train extension, other intermediaries to support socially inclusive climate services through trainings and workshops; and to recognize when gender, age or status adversely affects participation.
Education and literacy constraints	Build capacity through participatory processes.
	Present information and training in local languages, audio and video formats.

Group participatory communication processes are particularly effective at raising the capacity of rural women to understand, access and act on climate information (Brisebois et al., 2022; Huyer et al., 2023). Participatory processes provide opportunity to integrate training with climate communication, to strengthen the capacity of women and other groups who have had less access to education or less prior experience with climate information products. For example, in Rwanda, group participatory communication interventions (PICSA and Radio Listener Clubs) eliminated a gender gap in the use of weather and climate information for management; and reduced the gap in overall investment in their farms, coping capacity, and confidence in planning; relative to a control group in which farmers accessed weather and climate information primarily through broadcast media and mobile phones (Gumucio et al., 2020; Ingabire, 2021). Results also showed women's empowerment benefits in the form of

increased participation in household decision making and increased social standing in their communities. Women Radio Listener Club focus group participants referred to “talking with actions” to describe how gaining new knowledge, and using that knowledge to improve their farms’ performance, enhanced their husbands’ confidence in their advice and hence their participation and influence in decision making. In any group communication process, it is important that facilitators know how to recognize when gender, age or social status adversely affects some individuals’ group participation.

Accessible timing and location

Since women’s household and child care roles impose significant time constraints, climate services are most likely to benefit rural women if communication processes fit within their schedule constraints or save them time. Scheduling programming to fit women’s time constraints, and possibly repeating programming to fit the schedules and preferences of men and women, may improve accessibility of climate information via broadcast media. Likewise, group climate service communication and training meetings must fit within women’s time and mobility constraints if rural women are to benefit. For pastoralists, women tend to be most available for climate communication activities in the afternoon, once milking and other chores are done. Pastoralist women are traditionally responsible for milking, which occurs each morning and evening.

Thus, to ensure that services effectively reach both women and men, and other groups (e.g., youth) who may face timing and mobility constraints, it is important to understand availability and workloads of each of these groups. This can be done by conducting a participatory daily, weekly and seasonal schedule activity to map out their different responsibilities and time constraints, and identify the best times for climate-related meetings and broadcast media.

Partners and processes

Local culture and context may determine whether mixed-gender or gender-segregated groups are more effective at strengthening the capacity of women to access, understand and act on climate information. Where institutional biases or sociocultural norms hinder women from participating in group processes, partnering with local women’s groups, or inclusive community or religious gatherings, might improve women’s participation.

Climate services are likely to contribute more to women’s livelihoods and empowerment if service providers collaborate with civil society organizations, such as women’s savings and loans groups, women’s cooperatives and women’s rotational labour sharing groups, that are working to address the underlying socio-cultural institutional drivers of inequality, and if they facilitate community conversations around enhancing women’s decision-making and resource access within households and communities.

Limited evidence suggests that involving both spouses in climate communication activities might increase women’s use of climate services. Two local-language radio programs (one live show and one drama) were piloted in Kitui County, Kenya, to increase access and uptake of

climate services. Feedback group respondents advised that the messages are more effective when couples listen to the programs together (Bullock et al., 2023). As one married female participant explained, *"There will be a change if I listen with my husband, because men tend not to listen to their wives if they did not get the teachings themselves. But if we hear the teachings together, we will be able to work together as a team, because we will have gotten the same knowledge or idea from the teachings."* Respondents recommended early evening programming and more male voices to encourage couples to listen together.

Information content

While there is evidence that women are likely to benefit from climate communication strategies and channels than men, there is more limited evidence that differences in women's and men's agricultural activities, and the sociocultural norms that often disadvantage women and influence the decisions that are under their control, may lead them to need different types and time scales of information, or at different times of the year. Where this is the case, intentional effort is needed to identify and respond to these differing information needs. Climate information needs, access and use should therefore be assessed separately for female-headed households, and for women and men within households. This may be challenging in cultures where women are expected to not speak directly to male field personnel on their own. The format of information can influence who can access and use it. Providing information and educational resources in local languages, and in audio and video formats, can make it more accessible and usable to women and other groups who have had less access to education.

Although sociocultural norms might lead women and men to benefit from different types and time scales of information, participants in gender-disaggregated focus groups in three lower Eastern counties (Kitui, Makueni, and Taita Taveta) unanimously advised that men and women in a given location should receive the same climate-related information and advisories. They argued that, because married couples increasingly make decisions jointly, receiving the same messages reduces the risk of misunderstandings and conflict between spouses, and shared information reduces the risk the information will be forgotten (Bullock and Katothya, 2022).



Exercise: Existing climate information through a GESI lens

Working in small groups from the same region, for one or two existing climate information products or advisories, answer the following questions in the context of a specific rural setting:

- *How does this information product address gender-specific needs and vulnerabilities?*
- *Does the product consider the differing roles, responsibilities, and impacts of climate risk on men and women?*
- *Are there any gender biases or stereotypes evident in the language, imagery, or assumptions?*
- *What channels would rural men and rural women use to access this information? Would any particular groups have difficulty accessing these channels?*
- *How could this product be made to be more inclusive and accessible to rural women and other disadvantaged groups?*

Session 4.3. SPPARCK Seasonal Forecast Workshop

Farmers can benefit more from seasonal climate forecasts if they understand what they mean for their own local climate. In this session, we will learn how to lead a group of farmers in a seasonal forecast training, presentation and planning workshop. The process, known as Seasonal Participatory Planning Seasonal Participatory Planning for Agricultural Risk with Climate Knowledge (SPPARCK), uses historical climate graphs, and the probability-of-exceedance format for seasonal forecasts, which is available through the KMD Flexible Forecast Maproom. This session provides a summary of the workshop process. Appendix 2 provides detailed step-by-step instructions for facilitating a SPPARCK workshop.

By the end of this session, you will be able to:

- Train individuals, with no prior background, how to interpret seasonal climate time series and probability-of-exceedance graphs.
- Lead farmers in a basic participatory seasonal forecast communication and planning workshop.

Rationale and Overview

The workshop is designed to equip producers to interpret seasonal forecasts in the context of the variability of their local climate, and incorporate this information into their seasonal planning decisions. It was first piloted in Kenya in 2004, and later in Kenya, Senegal and Tanzania. The presentation below draws from Hansen et al. (2022).

The SPPARCK approach is based on a few assumptions about participating producers. First, producers understand seasonal climate variability and resulting risk, and factor this information into their agricultural and livelihood management decisions. Their understanding of climate risk is based on their memory of past seasonal climate conditions and their impacts on their own crops, herds and livelihoods; and not necessarily on statistical or graphical descriptions of variability or risk. Second, although producers understand climate risk, they are susceptible to cognitive biases and decision errors that research shows affect most people when they make decisions based on probabilistic information. Third, with simple training, producers can understand information presented visually in graphs. Fourth, producers have a basic level of numeracy (i.e., understanding of numbers, counting, proportions). The workshop does not require literacy, but the process would need to be adapted when participants cannot read.

The workshop uses several approaches to strengthen farmers' capacity to understand probabilistic seasonal climate forecasts and incorporate it into their decisions. First, relating climate information to farmers' experience helps them connect their analytical and experiential cognitive processing modes. As discussed in Session 4.1, people are more likely to use new, probabilistic climate information, and less likely to make significant errors in interpreting and acting on this information, if they use both their analytical and experiential cognitive processing systems. Second, the workshop presents climate in terms of natural frequencies associated with historical variability, before it introduces the probability of future seasonal climate conditions. Research shows that some of the widespread errors that people make interpreting and acting on probabilistic information are reduced or eliminated if the information is expressed in equivalent natural frequencies, even though historical frequencies are used to estimate future probabilities (Gigerenzer and Hoffrage, 1995). Fourth, like other participatory climate communication processes, the workshop incorporates group discussion to take advantage of farmer-to-farmer social learning. Within a rural community, a few farmers typically understand new information or adopt new innovations more quickly than others. These lead farmers, who quickly understand the new climate information products and their implication for farm management decisions, can help their peers learn.

Workshop Process

The six steps in the seasonal forecast workshop are summarized in Table 4.3-1, and detailed in the rest of this session. The workshop process follows a logical progression that starts with farmers' memory of climate variability, and leads them through a step-by-step process to interpret the forecast in the context of their local climate, and apply it to their routine seasonal planning decisions. It seeks to introduce complex new information and concepts in small incremental steps (Figure 4.3-1), including participatory graphing activities for producer groups who have never been exposed to graphs. Step-by-step guidelines for facilitating the workshop are available in the Appendix.



Figure 4.3-1. Sequence used to train producers to interpret and use Flexible Forecast graph.

Table 4.3-1. Summary of steps in farmer seasonal forecast training and planning workshop. Adapted from Hansen et al. (2022).

Step	Purpose	Process	Options
1. Purpose, concepts	Shape participants' expectations.	Present workshop purpose Define key terms and concepts	Discuss indigenous climate indicators to build trust.
2. From memory to variability	Relate time series data and graphs to participants' experience.	Elicit recent growing season conditions. Introduce time series graph, validate against collective memory.	Participatory activity drawing time series graph, to scale, for elicited years. Calculate probability of exceeding thresholds from time series graph.
3. From variability to probability	Understand relationship between variability and probability, and interpret POE graph.	Sort time series into frequency of exceedance graph. Re-define y-axis from relative frequency to probability, and discuss relationship between past frequency and future probability. Practice reading probability of experiencing above or below a threshold.	Participatory activity sorting recent time series into frequency of exceedance, to scale.
4. Forecasts shift probabilities	Understand forecast as a shifted probability distribution.	Show POE curve shifted to the right and/or to the left of the climatological distribution, and discuss its implication for climate and for farming. Practice reading shifts in probability of exceeding a threshold.	Highlight El Niño years in time series graph, and show POE graph for El Niño years alongside all years. Identify a familiar location with a wetter or drier climate, and discuss how that climate would affect farm performance and management.
5. Current forecast	Present forecast for upcoming growing season.	Present current forecast and other information relevant to planning. Review forecast interpretation. Respond to any questions.	Enlist NMS staff to discuss the forecast and local climate, but only if trained in Flexible Forecast communication.
6. Farm planning	Facilitate discussion of farm management plans for upcoming season	Present framing questions Discuss management options in breakout groups. Present and discuss group plans to plenary. Address producer questions and need for additional support.	

Step 1: Introduce the workshop purpose and key concepts

Step 1 introduces the purpose and roadmap of the workshop, and explains key concepts including: weather, climate, variability, frequency, uncertainty, probability, and forecast.

Several concepts are crucial to understanding and using probabilistic climate information appropriately, it is a good idea to discuss the concepts with producers at the beginning, and perhaps leave a short definition or description available as a reminder (for participants who can read) during training and planning meetings.

First, it is important to explain the time scale of seasonal forecasts. In many places, producers and the general public think about long-term climate change when they encounter the concept of “climate.” In other places, producers may have weather forecasts in mind when seasonal forecasting is introduced. If your producers do not already have a good understanding of climate variability and seasonal climate forecasts, then discuss these concepts: *weather* (atmospheric conditions at a particular time and place), *climate* (statistics such as average, seasonal cycles, variability, trends over longer time periods), *climate variability* (how seasons differ from year to year), and *climate change* (changes in things like average temperature and average rainfall over at least several decades driven in part by changes in the atmosphere due to human activity).

Second, define and explain these concepts: *variability* (how climate conditions differed in past years), *frequency* (expresses variability with numbers), *uncertainty* (Because the climate has been variable in the past, I am uncertain about what the weather will be like in next growing season.), *probability* (expresses uncertainty with numbers), and *forecast* (or *prediction*). A key message is that a forecast is new information that changes the probabilities about the future. A forecast reduces uncertainty, but doesn’t eliminate it completely.

Since the workshop will use these concepts in ways that might be new to the community, either because their language does not have an equivalent word, or the closest word has a different meaning within the rural community, it is important to agree on what words best represent each concept, and on the meaning in the context of climate information. When translating into the closest word or phrase in the local language, are farmers or pastoralists likely to have a different meaning in mind for that word? Does each word fully convey the concept, or do you need to define how we (climate service providers, communicators or facilitators) are using the words? In climate services, we often use words that have a particular technical meaning that is different from how the general public might use that word. To avoid misunderstanding, it is important to explain and agree with participants what we mean when we use key terms and concepts. It is important to discuss key concepts, especially if the local language does not have words for some of the key concepts.

Two additional topics may help prepare participants for the remainder of the workshop, if time permits.

Traditional climate knowledge. Recognizing and discussing the community's traditional climate indicators can help demonstrate respect for farmers' knowledge, build trust, and foster two-way discussion. In most cultures, farmers and pastoralists, or other members of the community such as traditional forecasters, have identified methods to predict what the future season might be like or what the weather will be. Since most farming communities make some use of traditional climate knowledge and indicators, it can be useful to discuss how those indicators influence their farming decisions, and whether they are 100% reliable or have some uncertainty.

Forecast and decision analogies. You could discuss examples of ways that participants use uncertain information outside of farming, and how new information that shifts the probabilities is a form of forecast. Use examples that are relevant to the producers that you work with. One illustration that might work in some contexts is betting which team will win a sporting event, such as football. Past records of wins and losses against a particular team (or similar teams) give an idea of the probability that your favourite team will win the next game. Suppose you learn that the star forward on your team (or the opposing team) is injured and can't play. This new information provides a forecast; it changes the probability that the team will win the next game.

Step 2: Understand past variability

Step 2 is designed to help producers relate time series graphs to their collective experience. The process starts with eliciting participants' collective memory of growing season rainfall and resulting agricultural performance for the five most recent years. Five years is suggested because the period is recent enough for at least some producers to remember, and because it is easy to convert number of years out of five into percent.

If participants are not already familiar with graphs, involving them in a participatory activity to constructing a time series graph, to scale, for the set of years they discussed fosters understanding and confidence. Once they are comfortable with the format, a computer-generated graph with the full set of available historical data is presented and discussed.

The discussion of the time series graph should highlight three key issues. First, the graph should represent their experience with seasonal rainfall for the specified growing season. Does the graph seem to be consistent with the way they classified each of the past five years? Does it show years that they remember as unusually wet or unusually dry? Second, the time series graph is a way to summarize information about past climate variability. Does the graph show that seasonal rainfall is more variable or less variable than they expected? Does it seem to show any pattern (e.g., increasing or decreasing trend), or just random variability? Third, the time series graph can be used to find what percent of years (or how many out of ten) had more than or less than a particular threshold amount. If at least some of the participants are familiar with division and percentage, it is useful to lead them to calculate the percent of years in which seasonal rainfall exceeded a meaningful threshold amount. This exercise will help them interpret the probability-of-exceedance graph in Step 3, and recognize its usefulness.

At this point, participants can also consider how well their current farming system is adapted to their local climate. For example: Are the farmers growing the crops and varieties that are best suited to average growing season conditions? Do they plant and harvest at the best times? How often can they expect crop harvests or pastures to fail due to climate variability? Are diversification, insurance and other strategies appropriate to mitigate climate risk? What would they like to change to make their farms and livelihoods more secure and prosperous under their climate conditions. This discussion could be facilitated by examining time series graphs of additional seasonal variables, such as onset and duration of the rainy season, risk of long dry spells during critical periods, mean temperatures, growing degree-days or chill units. Considering how well their farming system is adapted to historical climate variability might suggest some changes. It also helps prepare them to start identifying climate-sensitive management decisions they might adjust based on a seasonal forecast.

Step 3: Introduce the probability of exceedance graph

Step 3 introduces the probability-of-exceedance (POE) graph and helps participants to interpret it. However, it is first presented in frequency terms, as a way to describe historical variability.

Similar to Step 2, involving producers in a participatory graphing activity can help producers understand the POE graph, and how it is related to the time series graph. This involves participants in sorting recent growing season rainfall totals onto a blank POE graph, with frequency rather than probability on the vertical axis. The vertical axis is then changed from number of years to percentage of years (or number of years out of ten) with at least a given amount of seasonal rainfall. Once they are comfortable with the format, a computer-generated graph with the full set of available historical data is presented and discussed.

At this point, the facilitator discusses how relative frequency of past variations relates to probabilities in the future. Even though relative frequency and probability are equivalent mathematically, the use of past relative frequency to estimate probability for the next growing season might be a new concept for participating producers.

Participants will learn to find the probability of experiencing rainfall above, and then below, some threshold that they agree would be relevant to farm decisions. If they calculated the percent of years when seasonal rainfall exceeded a particular threshold in Step 2, they should recognize how much easier it is to find these probabilities from the POE graph. It is important to emphasize that the POE graph contains the same information as the time series graph, just arranged in a way that makes it easier to find probabilities.

This step can be extended to return to the discussion of how well participants' farming systems are adapted to the variability of their local climate, from Step 2. If time series graphs of additional seasonal variables (e.g., rainfall onset and duration, dry spell risk, temperatures, growing degree-days, chill units), the same historical data can be presented as probability-of-exceedance graphs.

Step 4: Understand forecast as a shift of the historical probability distribution

Step 4 presents a forecast as new information that shifts the historical probability distribution, and equips participants to interpret a forecast in POE format. Two activities are used to reinforce this idea.

First, where producers are familiar with El Niña and/or La Niña, the shifted distribution can be obtained by showing a POE graph for El Niño alongside the climatological distribution, and the corresponding time series graph with El Niño years highlighted. A simplified explanation of what meteorologists mean when they refer to El Niño (i.e., warmer than normal eastern equatorial Pacific Ocean temperatures), and how it can influence climate conditions in other parts of the world, can help build confidence.

The second activity involves identifying familiar location with a wetter (or dryer) climate, and discussing how that climate differs from the climate at the farmers' location. If participants interpret the probability of exceedance graph correctly, they should expect the POE curve for the wetter location will be shifted to the right of their location. If they use a dryer location, it will be shifted to the left. Optionally, the time series and POE graphs both locations (participating farmers' location, and the wetter or dryer location). Discussing what it would be like to have their farm, but with the climate of the selected wetter (or dryer) location, will help them relate a hypothetical forecast to their farming experience.

To help participants interpret a shift in the POE towards the right (i.e., probability shift wards wetter conditions) or left (i.e., probability shift towards dryer conditions), they repeat the activity of finding the probability of experiencing rainfall above or below the same threshold. This can be done using either the POE curve for El Niña (or La Niña) years for their location, or for the historical POE curve for a specified location with a wetter (or dryer) climate.

Step 5: Present the seasonal forecast

Steps 1–4 equip producers to understand and trust the seasonal forecast. The way Steps 5 and 6 are implemented depends on whether the workshop occurs just before the start of the rainfed growing season, or as a training activity during a fallow period long before the growing season:

- If the workshop occurs just before the season, the focus in steps 5 and 6 shift from training to planning for the upcoming season based on the current forecast.
- If the workshop occurs long before the start of the growing season, steps 5 and 6 use a forecast from a previous year or a hypothetical forecast to prepare participants to understand the forecast and use it for planning for the next growing season when it becomes available. In this case, producers would participate in a short workshop that covers Steps 5-6 once the forecast for the next season becomes available.

When the current or prior-year forecast is presented, participants should discuss its interpretation. Explanation of the seasonal forecast should include the brief explanation about

the context and implications of the forecast that KMD includes in its seasonal forecast bullets. Participants should understand:

- what institution (i.e., KMD) produced the forecast;
- how seasonal forecasts are produced;
- what variable(s) and time period the forecast covers; and
- how to interpret the forecast as a shift in probabilities.

If the forecast includes additional seasonal variables (e.g., season onset and cessation dates, probabilities of dry spells, growing degree-days), these forecasts can be presented in the same format and discussed.

To reinforce interpretation, participants will identify the probabilities of experiencing more or less than a threshold seasonal rainfall based on the historical and on the forecast POE curves, using the same threshold value that was used in Steps 2-4.

Step 6: Plan how to adjust farm management based on the forecast

The forecast presentation leads into Step 6, farm planning, when producers discuss and decide what seasonal management decisions, if any, they will change based on the seasonal forecast. If the workshop occurs as a training activity long before the season, then they discuss what seasonal management decisions, if any, they would change if the forecast for the next season were to look like the forecast presented in Step 5.

Group discussion allows participants to learn from other producers, and get feedback on their ideas. This can be done either in the large group, or in breakout groups that then summarize their plans to the larger group.

A given seasonal forecast may or may not lead producers to change their management plans. Whether they choose to adjust their plans for the upcoming season, and the kinds of adjustments that they make, may depend on how much the forecast shifts probabilities that are important for decisions, and whether options are available that would be better suited than existing plans to the forecast conditions. They may agree as a group to change some of their plans, while some decisions might be different for different producers. While Development Agents and any other professionals may provide information about management options and answer questions, the process aims to support farmers' decision making.

Practical Considerations

Timing

The full forecast training, communication and planning workshop is needed the first time producers are exposed to the downscaled forecast in the Flexible Forecast format. The entire process would typically take about 8 to 12 hours, spread over two days.

Farmers and extension workers tend to be quite busy shortly before the start of the growing season. Furthermore, there may be a short time between when KMD releases a seasonal

forecast, and when farmers must purchase seed and other inputs and prepare their fields for planting. Because of these timing constraints, it might be desirable to conduct the training (steps 1-4) during a slow part of the agricultural calendar, and hold a shorter workshop to present the actual forecast and adjust plans for the upcoming season (steps 5-6). For pastoral households, appropriate timing will allow them to plan when to move, how to move, scout for safe place to move and mobilise labour and resources required for moving. As such, such trainings need to happen during lean season. If the process is separated into a training workshop and a forecast presentation and planning workshop, then a forecast from a previous year should be presented, and discussed. Participants can identify what planning decisions they would consider adjusting, depending on the actual forecast when it becomes available.

Once producers have been trained are familiar with the format of the forecast, and understand how it relates to historical variability, they will only require a short workshop to:

- briefly review what they have learned in steps 1-4;
- present the current seasonal forecast (step 5); and
- plan how to adjust farm management based on the forecast (step 6).

Without the training (steps 1-4), a seasonal forecast presentation and planning workshop would typically take about 2-3 hours. Figure 4.3-2 summarizes these options.

- First year, option 1: combined workshop

TRAINING, PRESENTATION, PLANNING

- 2 days (8-12 hours)
- Steps 1-6
- XXXXX

- First year, option 2: split workshops

TRAINING

- 1 or 2 days (6-10 hours)
- Steps 1-4
- Present & discuss a past forecast

PRESENTATION, PLANNING

- 1/2 day (2-3 hours)
- Review concepts from steps 1-4
- Steps 5-6

- Subsequent years:

PRESENTATION, PLANNING

- 1/2 day (2-3 hours)
- Review concepts from steps 1-4
- Steps 5-6



Figure 4.3-2. Options for scheduling seasonal forecast training, presentation and planning workshops.

Group size and composition

The size of a workshop should generally be limited to about 25-30 producers. If the group is too large, it will be difficult to involve all participants in discussion and participatory activities, and to assess whether all participants understand the concepts. If producers are already organized in groups, those existing groups should be used as much as possible.

In some cultures, and contexts, women farmers might be reluctant to participate fully in a mixed group. Consider local culture, your experience with mixed vs. single sex groups, and any relevant guidelines when deciding whether to hold separate workshops for men and women, and whether female facilitators are needed to ensure that women participate freely and equitably.

Adapting to different producer backgrounds

The workshop process can be adapted to producers with differing education and literacy levels. First, if literacy rates are low, then more discussion and repetition may be required. Pictures could be used instead of text to identify graph components (e.g., axis labels) and to characterize farmers' memory of recent years. Second, if participants have been exposed to graphs in school or other training, then the participatory activities deriving time series and POE graphs could probably be eliminated and overall time reduced. While past pilot training workshops took 12–14 hours over two days, it may be feasible to reduce them to a single day if the majority of producers are literate and already comfortable with graphs. Third, if participants are unfamiliar with percentages, then probabilities could be expressed as number of years out of ten.

For pastoralists, adopting the timing of the trainings to their mobility calendar is essential, the trainings need to happen when herders are close to the main camp, mostly in settled area. For women, a full day training might not be feasible due to other competing childcare and caring for young animal's needs.



Exercise: Practice seasonal forecast workshop

- *Work in groups, 10-15 per group.*
- *Resources required:*
 - ♦ **Appendix 1. Facilitating a SPPARCK Seasonal Forecast Workshop**
 - ♦ **A4-2 Participatory workshop practice schedule.pdf**
 - ♦ **Printed graphs from A4-2 workshop graphs to print.pptx**
- *This is a role-playing activity. Take turns leading discussion, and playing the role of farmers.*
- *For each step, we will review, practice, and discuss.*
- *You have about 6 hours to practice and discuss a workshop that typically takes 2 days. The goal is to understand the process, not complete every step.*
- *Spend enough time on the more complicated steps, especially steps 2, 3 and 4, to be confident that you can lead farmers through them.*

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GLOSSARY

absolute humidity	A measure of the amount of water vapor in a given parcel of air that is typically measured in mass/volume or volume/volume units
adaptation	Adjustment in natural or human systems in response to actual or expected climatic stimuli or their effects, which moderates harm or exploits beneficial opportunities, typically over long periods
adverse selection	The tendency for insurance to be purchased preferentially by producers who experience more frequent losses
agricultural calendar	A visual planning aid that summarizes annual cycles of climate and agricultural activities for a particular location
amplitude	The difference between the maximum and minimum, the seasonal contrast
analytical processing	System the human mind uses to process information that is in the form of a statistical description
anemometer	Instrument that measures wind speed and direction
anomaly	The difference between the average or baseline
area yield insurance	Index insurance based on yields estimated over a specified region, using statistical sampling from many farmers' fields.
atmospheric pressure	A measure of the force or weight of the overlying air per unit area on the surface
barometer	Instrument that measures atmospheric pressure
basis risk	The risk that insurance payouts will not match losses due to the imperfect relationship between factual losses and the index that triggers payouts
breakeven price	Minimum farmgate price needed to break even for a given yield
breakeven yield	Minimum yield needed to break even for a given farmgate price
certainty equivalent	A guaranteed return that someone would accept, rather than taking a chance on a higher, but uncertain, return in the future

chance node	Decision tree symbol representing uncertainty due to multiple probabilistic states of nature
climate	The statistics of weather at a given location, over a specified period of time, typically including mean, seasonality, variability and trend
climate change	Changes in the characteristics of climate over long periods of time. It is important that these changes occur not only in the mean conditions but also in the variability.
climate data	Arrays of measurements of weather and climate variables from which information that is more useful in everyday life is distilled or that are ingested in applications such as crop or hydrological models
climate information	Structured data describing past, current, or future climate
climate-sensitive decision	A decision is climate sensitive if a decision maker would select different options under different observed or expected weather or climate conditions
co-production	A process that involves climate information generators and users engaging throughout the production of climate services
coefficient of variation	A statistical measure of the relative dispersion of data points in a data series around the mean
compound risk	Instances in which multiple types of simultaneous hazards interact
constraint	A shortage of some resource that prevents a decision maker from implementing a desired option
contract window	The specific range of dates when insurance covers a particular risk
coping	Actions that individuals or communities take to withstand a shock and limit its immediate adverse impacts
crop simulation model	A computer program that uses mathematical functions to mimic the growth and development of a crop in response to weather, soil conditions, and management
decision node	Decision tree symbol representing a decision among multiple options
decision support tool	A tool or information system that supports organizational decision-making activities

decision tree	A decision support tool that uses a tree-like model of decisions and their possible consequences
dynamical methods	The use of models based on physical equations that govern interactions between various components of the climatic system, called General Circulation Models, and similar to the models used in Numerical Weather Prediction
efficient set	The set of management options that rational decision makers with varying levels of risk aversion might select
end node	Decision tree symbol representing the consequence of a decision option, typically in monetary terms
enterprise	The production and marketing of a single crop or livestock commodity that produces a marketable product
enterprise budget	Analysis for estimating the profitability of a farm enterprise, and for comparing the profitability of alternative ways of managing farm enterprises
exit	A pre-identified threshold of an insurance index that triggers the maximum payout amount
expected return	The anticipated profit or loss that is anticipated from an enterprise or portfolio, estimated as the average across the distribution of stochastic states of nature
expected value	The arithmetic mean of a large number of independently selected outcomes of a random variable, calculated as the sum of all possible values multiplied by their respective probabilities of occurrence
experiential processing	Cognitive system the human minds use to make decisions based on information acquired through repeated experience
exposure	The frequency and severity of environmental hazards, shocks or stresses that a community experiences
fixed cost	Expenses (e.g., land rent, taxes) that are not dependent on the management of an enterprise or portfolio, or the amount of goods produced

global warming	Also known as climate change, a gradual increase in the overall temperature of the earth's atmosphere generally attributed to the greenhouse effect caused by increased levels of carbon dioxide, chlorofluorocarbons, and other pollutants
gross margin	Refers to the net return, or profit, on an enterprise in a given year, ignoring fixed costs, expressed on an area or animal unit basis
gross receipts	The total amounts received from an enterprise during a year
hazard	A physical phenomenon that has the potential to trigger adverse impacts on human wellbeing – directly or through the natural resource base. Equivalent to <i>shock</i> and <i>extreme event</i> .
humidity	Measures how much water vapor is in the air at a given time
indemnity insurance	Insurance that pays out based on a verified loss
index-based insurance	Insurance that pays out based on the value of data that are used as a proxy for a particular loss, rather than actual losses
index-based livestock insurance	Insurance for livestock based on livestock mortality data estimated over a specific region, or on vegetation remote sensing data as a proxy for livestock mortality
insurance payout	The amount of money that insurance pays a client when contractual conditions (i.e., a verified loss or an index exceeding a specified threshold) occur
insurance premium	Contractual amount of money that a client pays periodically for insurance
lead time	The amount of time that is needed between making a decision and implementing the decision
Maproom	Interactive online climate information products
median	The number with the middle value of the set when arranged in ascending order
merged data	Meteorological data sets based on a blend of station observations and gridded proxy data from, e.g., satellite remote sensing or reanalysis
moral hazard	The incentive for producers to neglect good risk management in order to receive insurance payouts

normal distribution	A function that represents the distribution of many random variables as a symmetrical bell-shaped graph
oceanic data	Data based on observations of oceanic properties (temperature and velocity are of particular climate/weather relevance)
participatory process	A facilitated communication or planning process in which all participants play an active role
partitioning	Allocation of new dry matter, produced by photosynthesis, among different plant parts
phenology	The occurrence and timing of development phases of a plant or animal
photosynthesis	The process by which plants convert atmospheric carbon dioxide and energy from sunlight into biomass
poverty trap	A condition in which an individual, household or community is unable to escape poverty without external intervention, in rural settings characterized by subsistence food production, poor adoption of improved agricultural production practices, and chronic poverty and food insecurity
probability density function (PDF)	A function whose value at any given sample in the sample space can be interpreted as providing a relative likelihood that the value of the random variable would equal that sample
probability of exceedance graph	A graph that shows the probability (on the vertical axis) that a random variable, such as seasonal climate conditions (on the horizontal axis), will fall above any threshold
probability of exceedance/non-exceedance	The probability that a certain value will be exceeded or not exceeded
reanalysis data	Data based on a mix of observational inputs from the above forms of data and dynamical models of how the atmosphere is expected to behave
relative humidity	A measure of the amount of water vapor in the air at a given time relative to the saturation level (the maximum amount of water vapor a parcel of air can retain), typically expressed as percentage of saturation

resilience	The capacity of an individual, community or society to resist moving to a less desirable state (e.g., poverty), or to recover if it is already in an undesirable state (relative to a development goal), in the face of stochastic shocks or long-term stresses
respiration	The conversion of plant biomass into energy
risk	Impacts of stochastic variability on productivity, profitability or some aspect of wellbeing
risk analysis	A systematic approach to analyzing decision options under uncertainty
risk efficiency analysis	Analysis, based on a few general assumptions, used to identify decision options that could and would not be considered for a group of decision makers with varying levels of risk aversion
risk aversion	Willingness of a decision maker to sacrifice some expected return in order to reduce the variability or riskiness of returns
risk premium	A measure of the subjective cost of uncertainty to an individual, for a particular decision option, expressed as the difference between expected return and certainty equivalent
seasonality	Times of the year when agricultural activities occur and key reoccurring management decisions are made
senescence	Loss of plant biomass associated with aging
soil water balance	Calculation of amount of water in the soil, accounting for all quantities of water added, removed or stored in a given volume of soil during a given period of time
standard deviation	A measure of how dispersed the data is in relation to the mean, or average
standard precipitation index (SPI)	An index to characterize meteorological drought on a range of timescales, expressed as the number of standard deviations that observed cumulative precipitation deviates from the climatological average
standardized anomaly	An anomaly divided by the standard deviation
state of nature	Conditions that are random, uncertain and beyond a decision maker's control, and that influence the consequence of a decision

station data	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
temperature	Measure of how hot or cold a substance is
tercile	A set of data arranged in order with values that partition the data into three groups, each containing one-third of the total data
thermometer	Instrument for measuring temperature
time horizon	The amount of time into the future a decision maker considers when evaluating the consequences of a decision option
time series graph	Time series graphs represent variability by plotting a value (e.g., seasonal average climate conditions, along the vertical axis) as a function of time (along the horizontal axis)
trend	A pattern within a random variable that changes systematically through time
trigger	A pre-identified threshold value of an insurance index that triggers the beginning of a payout
tropical livestock unit (TLU)	A unit that converts livestock numbers of different species to a common weight. Common TLU conversion factors are: cattle = 0.70, sheep and goats = 0.10, pigs = 0.20 and chicken = 0.01.
uncertainty	Imperfect information about future states or consequences that result from stochastic variability
variable cost	A production cost that varies with management
vertical measurements	Measurements to assess atmospheric properties at different levels in the atmosphere
vulnerability	Characteristics of human communities or social systems that cause them to be susceptible to adverse impacts, such as increased food insecurity, poverty or mortality, when exposed to an external shock or stress
weather	The state of the atmosphere at a given time and place with regard to variables such as temperature, precipitation, humidity, air pressure, wind, cloudiness and sunshine

weather index insurance	Insurance based on a meteorological index such as rainfall or temperature data
weather station	A facility, either on land or sea, with instruments and equipment for measuring atmospheric conditions
wet-bulb thermometer/hygrometer	Instrument used to infer ambient humidity

APPENDIX. FACILITATING A SPPARCK SEASONAL FORECAST WORKSHOP

This Appendix provides guidance about how to facilitate the farmer participatory seasonal forecast training and planning workshop that was introduced in Session 4.3. It serves two purposes:

- Instructions for a learning activity to gain experience facilitating the workshop; and
- Resource for implementing the workshop with producers.

The historical time series and the probability-of-exceedance graph examples in this guide are based on 1981-2018 June-September rainfall data from a location near Kitui (37.75E-38°E, 1.25S-1.00°N). The data were downloaded from the KMD Historical Daily Precipitation Analysis Maproom. Although Maproom graphs could be used for the workshop, Excel was used to improve the format of these graphs. Step 5 uses a hypothetical seasonal rainfall forecast graph representing the same location. You will need to prepare the corresponding graphs for your location as you prepare to facilitate a farmer workshop.

As a learning activity, you will practice a workshop that combines all 6 steps. However, you will use a hypothetical forecast to learn how to lead the process. The purpose is to learn how to lead the process and not to plan for the current year.

Overview

The workshop is designed to equip producers to interpret seasonal forecasts in the context of the variability of their local climate, and incorporate this information into their seasonal planning decisions. It follows a logical progression that starts with farmers' memory of climate variability, and leads them through a step-by-step process to interpret the forecast in the context of their local climate, and apply it to their routine seasonal planning decisions. The six steps in the seasonal forecast workshop are summarized in Table A1-1 and detailed in the rest of this Appendix. See Session 4.3 and (Hansen et al., 2022) for more information about the rationale for the Flexible Forecast and workshop process.

The full forecast training, communication and planning workshop is needed the first time producers are exposed to the downscaled forecast in the Flexible Forecast format. As discussed in the presentation and Reference Guide, it can either be done at one time, or split between training (steps 1-4) during a slow part of the agricultural calendar, and a shorter planning workshop (steps 5-6) shortly before the start of the growing season.

The entire training and planning process would typically take about 8 to 12 hours, spread over two days. However, for this activity we have only 4-6 hours to practice the process, including discussion time.

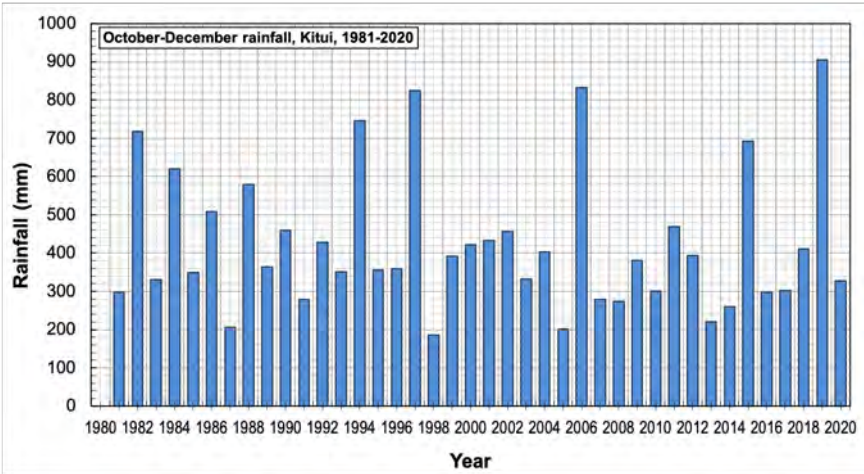
Table A1-1. Summary of the six steps in the seasonal forecast workshop.

Step	Purpose	Process
1. Purpose, concepts	Shape participants' expectations.	• Present workshop purpose • Define key terms and concepts
2. From memory to variability	Relate time series data and graphs to participants' experience.	• Elicit memory of recent years • Participatory time series graph activity • Interpret time series graph
3. From variability to probability	Understand relationship between variability and probability, and use probability graph to interpret forecast categories.	• Participatory probability graph activity • Interpret probability graph
4. Forecasts shift probabilities	Understand forecast as a shifted probability distribution.	• Show how El Niño shifts the probability distribution • Use a familiar location to discuss what a wetter or drier climate might look like
5. Current forecast	Present forecast for upcoming growing season.	• Present current forecast and other information relevant to planning. • Review forecast interpretation.
6. Farm planning	Facilitate discussion of farm management plans for upcoming season	• Present framing questions. • Discuss management options in breakout groups. • Present and discuss group plans to plenary. • Address producer questions and needs for additional support.

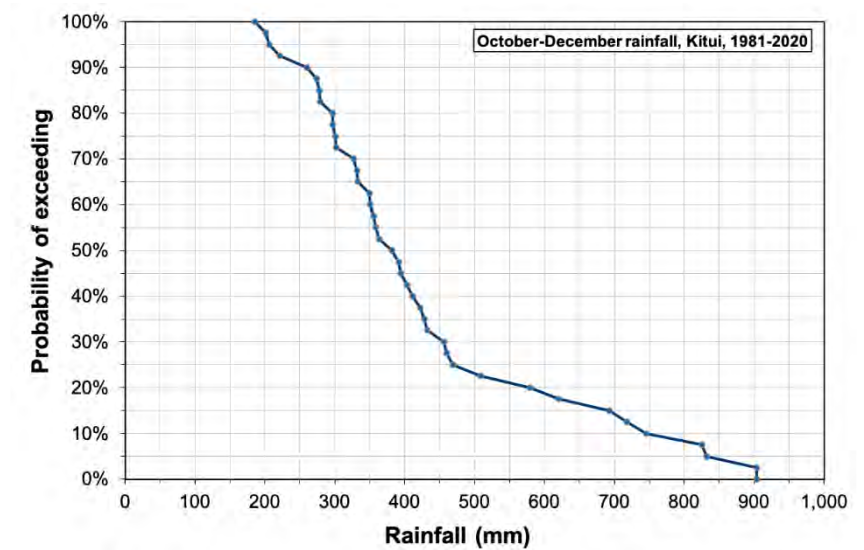
Materials needed:

- Flip chart
- Markers
- Meter stick
- Tape
- Printouts (one large copy for the group, and one A4-size copy per participant):

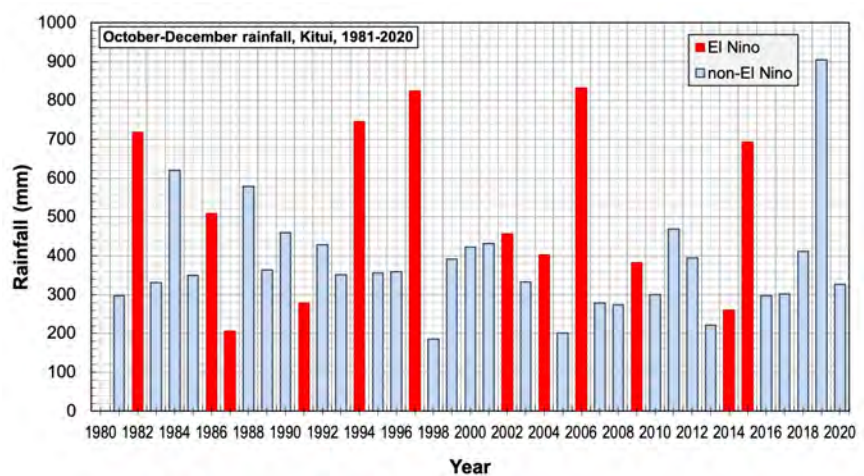
seasonal rainfall historical time series graph:



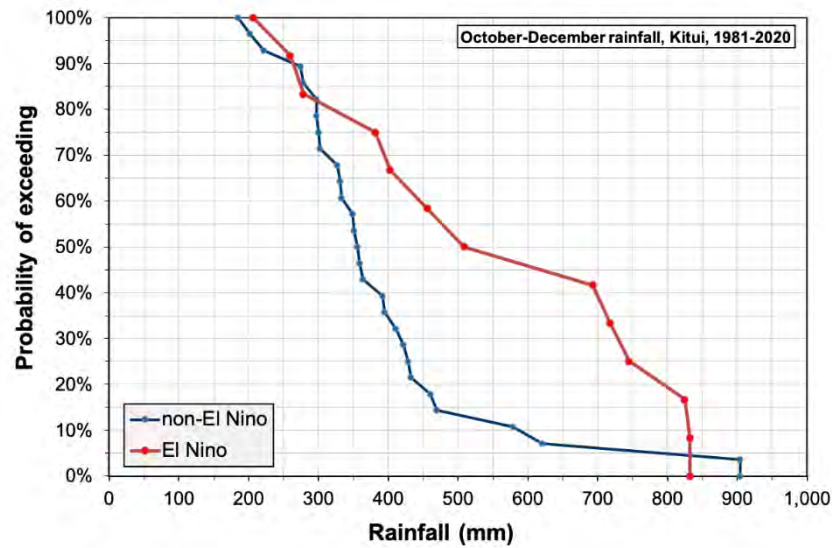
○ seasonal rainfall probability of exceedance graph:



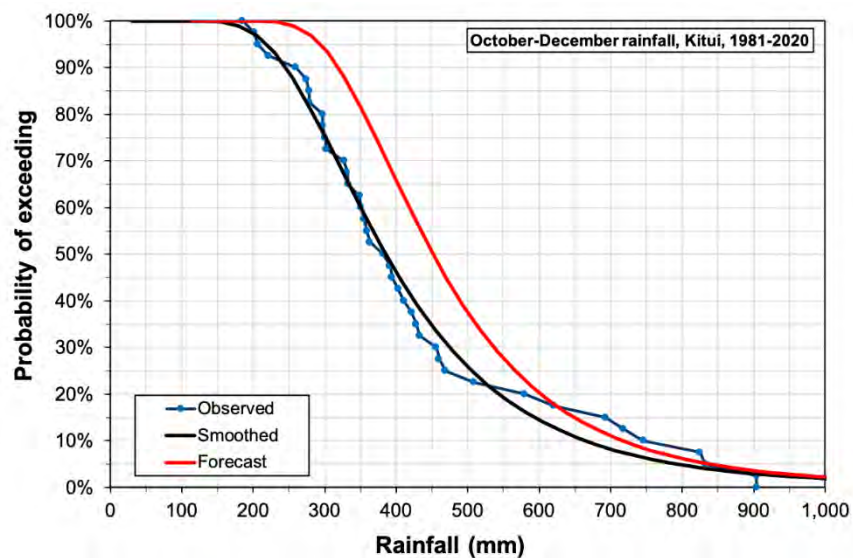
○ seasonal rainfall historical time series graph with El Niño highlighted:



- seasonal rainfall probability of exceedance graph with El Niño highlighted:



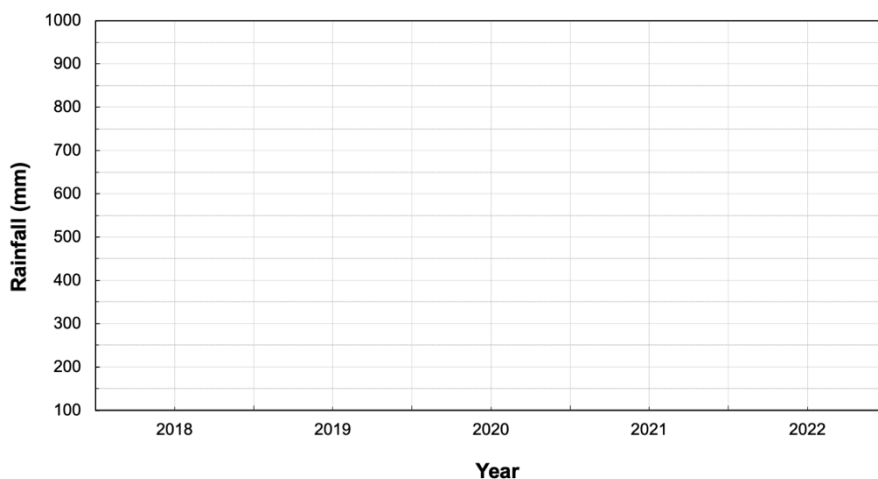
- seasonal rainfall forecast graph:



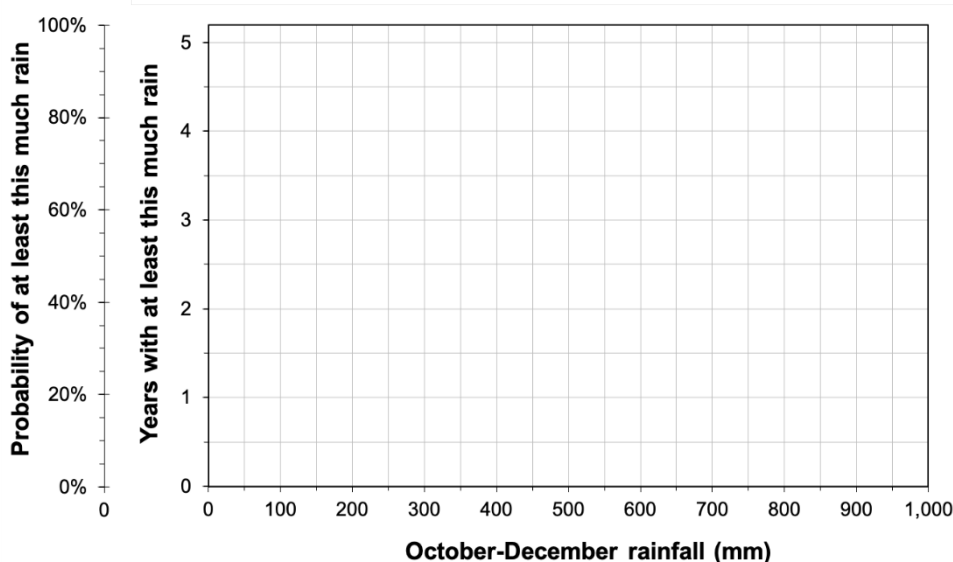
- On a flipchart or poster-sized paper, blank table with three columns (Year, Crops and Rainfall) and five rows. Leave extra space in the *Rainfall* column because you will later add measured October-December rainfall amounts.

Year	Crops	Rainfall
2022		
2021		
2020		
2019		
2018		

- On a flipchart or poster-sized paper, blank graph with Year as the x axis, and October-December rainfall as the y axis:



- On a flipchart or poster-sized paper, blank graph with October-December rainfall as the x axis. The y axis will have two labels as shown below:
 - “Years with at least this much rain”
 - “Probability of at least this much rain”



Step 1: Workshop purpose and key concepts

This step involves explaining the purpose of the workshop, and making sure participants understand and agree about the meaning of key concepts such as climate and how it differs from weather, variability, frequency, uncertainty, probability and forecast.

Workshop purpose

Explain that the purpose of this workshop is to talk with producers about climate variability, about forecasts for the next rainy season, and about how this type of information might be useful for their agricultural management decisions.

Key concepts

Several concepts are crucial to understanding and using probabilistic climate information appropriately, it is a good idea to discuss the concepts with producers at the beginning, and perhaps leave a short definition or description available as a reminder (for participants who can read) during training and planning meetings.

When translating into the closest word or phrase in the local language, are producers likely to have a different meaning in mind for that word? Does the selected word or phrase fully convey the concept, or do you need to define how we (climate service providers, communicators or facilitators) are using the words? To avoid misunderstanding, it is important to explain and agree with participating producers what we mean when we use key terms and concepts.

- First, explain the time scale of seasonal forecasts. Do your producers think about long-term climate change when they encounter the concept of “climate?” Do your producers have weather forecasts in mind when seasonal forecasting is introduced. If your producers do not already have a good understanding of climate variability and seasonal climate forecasts, then discuss these concepts.
- Second, define and explain these concepts:
 - *Variability* refers to the fact that climate conditions have been different in different years in the past. For example, growing season rainfall in 2022 was different from rainfall in 2021, which was different from rainfall in 2020.
 - *Frequency* expresses variability with numbers. For example, in two out of the past ten years I was not able to produce enough crops to feed my family until the next harvest.
 - *Uncertainty* deals with what will happen in the future. Because the climate has been variable in the past, I am uncertain about what the weather will be like in next growing season.
 - *Probability* expresses uncertainty with numbers. For example, there are two chances in five that I will not produce enough crops to feed my family until the next harvest.
 - *Forecast*. A forecast is new information that changes the probabilities about the future. A forecast reduces uncertainty about the future, but doesn't eliminate it completely.

Explain that the workshop will show producers how to use probability and graphs to describe past climate variability, and to understand what a seasonal climate forecast means for their local climate.

- **Optional: Forecast and decision analogies.** You could discuss examples of ways that participants use uncertain information outside of farming, and how new information that shifts the probabilities is a form of forecast. Use examples that are relevant to the producers that you work with. One illustration that might work in some places is guessing (or betting) which team will win a sporting event, such as football. Past records of wins and losses against a particular team (or similar teams) give an idea of the probability that your favorite team will win the next game. Suppose you learn that the star player on your team (or the opposing team) is injured

and can't play. This new information provides a forecast; it changes the probability that the team will win the next game.

- **Optional: Indigenous climate indicators.** If a community has lived in the same location for a long time, it has likely developed some knowledge of how to anticipate weather conditions by observing the sky or biological phenomena. Showing respect for farmers' indigenous climate knowledge can be a useful way to build trust and foster communication. This discussion should emphasize several points:
 - Both producers and meteorologists make forecasts by observing the environment around them. You are not trying to replace traditional climate knowledge. Instead, you are introducing new information that producers can consider alongside their traditional knowledge.
 - Forecasts from producers and meteorologists provide useful information about the future, even though it has some uncertainty. Forecasts about future climate conditions do not have to be certain to be useful.
 - Meteorologists use information about the environment in distant locations, for example what is happening with temperatures in distant oceans. This helps meteorologists make predictions farther in the future.

Step 2: From memory to variability

Producers generally have a good understanding of their local climate based on their collective experience. This step starts with discussing climate conditions in recent years, and lead producers to trust and correctly interpret time series graphs of their local climate.

Memory of recent years

- Display a table with three columns (Year, Crops and Rainfall) and five rows, listing five latest years for which rainfall data are available, starting with the most recent.
- For the upcoming agricultural season, ask participants to classify each of the past 5 years as *good*, *medium* or *poor* based on agricultural performance. Repeat in terms of rainfall: *wet*, *medium* or *dry*. Record their consensus responses on the table. Note and discuss any obvious differences between crops and rain.

Year	Crops	Rainfall
2022		
2021		
2020		
2019		
2018		

- On the table with farmers' memory of rainfall conditions, write the amount of rainfall measured for each of the past five years.

Participatory time series graph activity

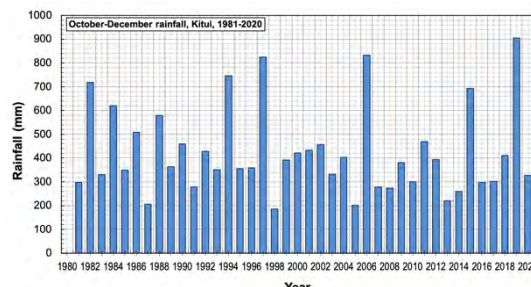
This participatory activity may not be needed if participants already have experience reading simple graphs.

- Involve participants in plotting the rainfall amounts on a time series graph. Show a blank graph on a flip chart page, with Year as the x axis and rainfall as the Y axis. Ask volunteers to take turns marking the amount of rainfall measured in each year. They will measure from the bottom, and place a horizontal mark above the corresponding year, and connect the marks with vertical lines to make a rectangle. Write the amount of rainfall above each mark.
- Discuss how the rainfall amounts in the graph relate to the way they classified those years, in terms of rainfall and in terms of crop yields.



Interpret a time series graph

- Display a large printout or projection of the seasonal total rainfall time series graph, and distribute small (A4) printouts to participants. By this point, participants should be comfortable with this format of graph. Remind them of what the vertical axis (total rainfall for a particular season or set of months) and the horizontal axis represent (year).
- Discussing the following questions will help participants interpret the time series graph:
 - How many years are in the graph?* Ask a volunteer to count.
 - If participants did the participatory graphing activity: *Do the last five years in the graph look like the graph that they just made?* They should recognize that the computer-generated graph has the same information as the graph that they made, but with more years of data.
 - What year had the most rainfall (for the June-September season)? How much rain was measured that year?*
 - What year had the least rainfall? How much rain was measured that year?*
 - What years do you remember because they were either unusually wet or unusually dry? Discuss your experience during those years.*



- Discuss whether the graphs show more variability or less variability than participants expected. You may discuss whether the time series graphs show a long-term increasing or decreasing trend in rainfall, particularly if producers have already expressed a belief that rainfall has been changing in a particular direction.
- **Optional:** If most participants are familiar with division and percentage, lead them through an activity to use the time series graph to find the probability that seasonal rainfall will exceed a given threshold. Either suggest a threshold, or ask participants to identify some threshold rainfall amount, above which they would consider a season to be wetter than normal. Ask them to count how many years had greater than this rainfall amount. If any of the participants know how to divide, ask them to calculate the probability that rainfall will be above the threshold. If not, do the calculation for them.

For example, suppose you were using the graph below for this activity, and you selected a threshold of 650 mm. Out of the 38 years of data in the graph, there were 8 years, or 21%, or about two out of ten, that had rainfall greater than 650 mm.

- **Suggestion:** Holding a straight-edge horizontally across the graph, with the top edge of the straight-edge lined up with the threshold amount on the vertical axis, makes it easier to count the number of points above or below a given threshold. You can demonstrate this process on the large printout.
- **Suggestion:** If the participants are not familiar with percentage or fractions, you can round the probability to the nearest 10%, and explain the result in terms of the number of years out of ten in which rainfall exceeds the given threshold.
- **Optional:** If time permits and participants are interested, lead them through the same process to find the probability that rainfall will be less than 450 mm **or** another threshold below which they would consider a season to be dryer than normal.

Step 3: From variability to probability

This step introduces participants to a probability of exceedance graph, and trains them to interpret it correctly. Participants will learn that probability is a way to quantify the uncertainty about the future, and that probability is calculated from relative frequency (meaning the number of times that something occurred in the past, divided by the number of observations that are available). They will learn that the probability of exceedance graph contains the same information as a time series graph, but arranged in a format that makes it easier to see the probability that seasonal climate conditions will fall above or below any threshold that might be relevant to their decisions.

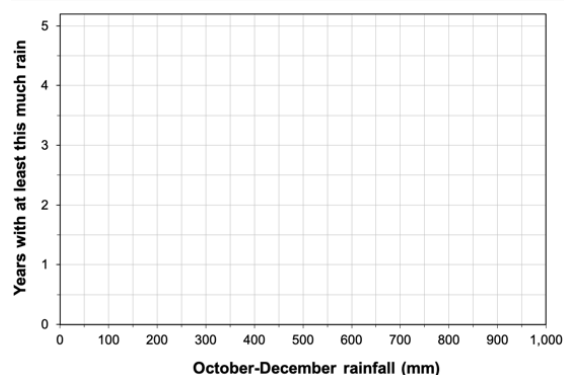
Participatory probability graph activity

- Start with a blank graph with quantity (e.g., seasonal rainfall) on the x-axis and frequency ("Years with at least this much rain," 0 to 5) on the y-axis. When you first display it, hide the second y

axis ("Probability of at least this much rain"). If there is interest and sufficient time, ask volunteers to sort the rainfall amounts over the past 5 years (September-December season) from lowest to highest, and mark the point on the new graph.

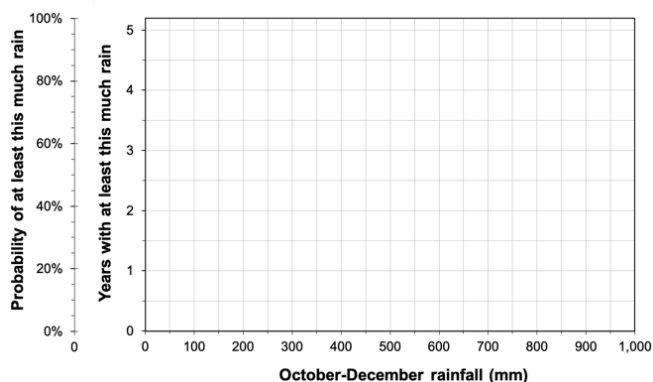
- For the first point: *What was the driest year on the graph? How many mm of rainfall were measured? Out of the five years, how many had at least that much rain?*

(The correct answer is all 5 years.) Line up the ruler horizontally at 5 years, then measure to the right that many cm, and make a dot. Write above the dot what year it was. The second point is similar: *What was the second driest year? How much rain? Out of 5 years, how many had at-least that much rain?* (The correct answer is 4 years.) Make a dot at the correct point. Repeat for the third driest, the fourth driest, and finally the wettest. The last person to make a dot can also connect all the dots.



To turn this graph into a probability distribution, we need to do two things.

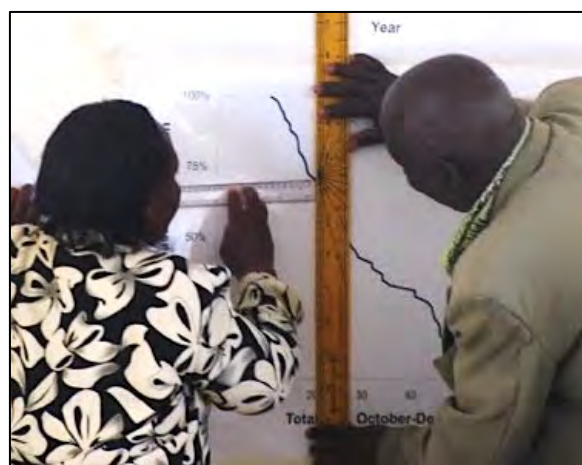
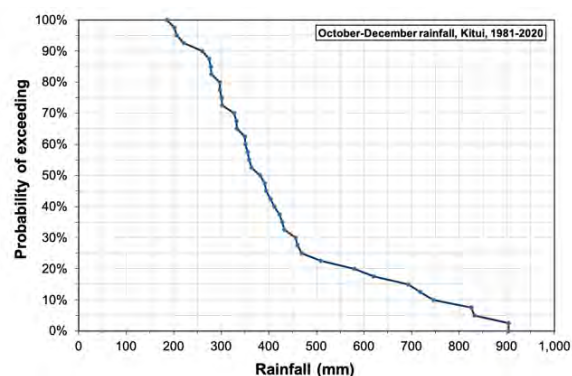
- First, we turn number of years (frequency) into percent of years (relative frequency). Probability can also be expressed as percent. *Something with a 100% probability will definitely happen. Something with a 50% probability will happen 50% of the time – if you repeat it enough times.* Note: we chose 5 because it is easy to calculate the relative frequency (in percent): $5/5 = 100\%$, $4/5 = 80\%$, $3/5 = 60\%$, $2/5 = 40\%$, $1/5 = 20\%$. Write these percentages next to the numbers on the vertical axis.
- Next, we go from frequency to probability. Show the hidden label or write a new label for the vertical axis, next to the old one: "Probability of at least this much rain." (You could also explain this after you put up the probability graph printout based on all 30 years of data.)
- Explain that frequency (in the past) is related to probability (in the future).



Note: Research shows that presenting information as relative frequencies rather than equivalent probabilities has a positive effect on many quantitative reasoning or estimation tasks. This is why we first express the graph as number of years, then percent of years, and finally percent probability.

Interpret a probability graph

- Explain that looking at more years in the past makes the probability graph more accurate. Then show a complete probability of exceedance graph, based on all available years of data. This graph shows the probability associated with any given amount of rain, or the amount of rain associated with a given probability.
- Lead participants through an activity to interpret the probability of exceedance graph, similar to the exercise that you did in Module 2. Whatever threshold you used with the time series graph in Step 2, lead participants through the process of finding the probability of experiencing more than this amount using the probability of exceedance graph. Discuss which is easier to use.
- Remind participants that the time series and probability graphs have the same information, just arranged differently. Allow time for discussion until most of the participants appear to understand the probability of exceedance graph. Although this is probably the most complicated step, experience shows that producers can understand probability graphs with training and repetition.



Step 4: A forecast shifts the probability distribution

Once producers understand the probability of exceedance graph, and how it is related to historical data for their location, you can discuss how a seasonal forecast changes the forecast. Two activities can help:

- Show how El Niño (or La Niña) conditions shift the probability distribution.
- Use a familiar location with wetter or drier climate to illustrate what a forecast climate might mean.

El Niño shifts the probability distribution

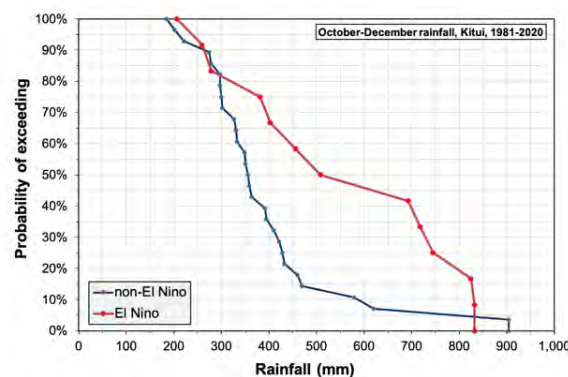
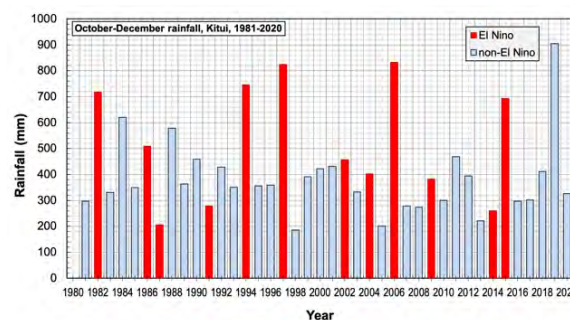
This activity can be effective if most producers are already familiar with El Niño and La Niña. It requires preparing a time series graph that uses a different symbol or colour to highlight the El Niño (or La Niña) years; and a probability of exceedance graph with just the El Niño (or La Niña) years, plotted alongside the full climatological distribution. El Niño (and La Niña) an important example of how the oceans influence the climate in many parts of the world, including Kenya.

- Describe the El Niño phenomenon. *When meteorologists talk about “El Niño,” this refers to unusually warm temperatures in the eastern Pacific Ocean, near the equator. This is on the other side of the world from Kenya. For a long time, Fishermen in Peru and Ecuador noticed unusually warm waters every few years. Because it was usually strongest at the end of the year, near Christmas, they called it “El Niño,” which is Spanish for Little Boy, and refers to baby Jesus because of Christmas. The reason why it is possible to make climate predictions several months in advance is because the oceans affect the atmosphere above them, but the oceans change slowly.*

Suggestion: Using a globe can help producers visualize the Pacific Ocean in relationship to Kenya.

If producers have heard of El Niño but have an inaccurate understanding, it is important to avoid correcting them in a way that embarrasses them.

- Present the time series graph with El Niño years highlighted. Discuss whether El Niño years have tended to be wetter or drier than years that were not El Niño. Ask what they think the probability of exceedance graph would look like if it only included El Niño years.
- Present the probability of exceedance graph for El Niño years, plotted with the climatological distribution. Discuss how to interpret this type of forecast in terms of shifted probabilities. Discuss how knowing that the next season will be an El Niño would influence their expectations.



Use a familiar location to discuss what a wetter or drier climate might look like

This activity requires selecting a location that the producers would be familiar with, and that has a wetter or drier climate. Plot seasonal data in time series and probability of exceedance formats for both locations (your location, and the wetter or dryer location), using different symbol shapes and colours.

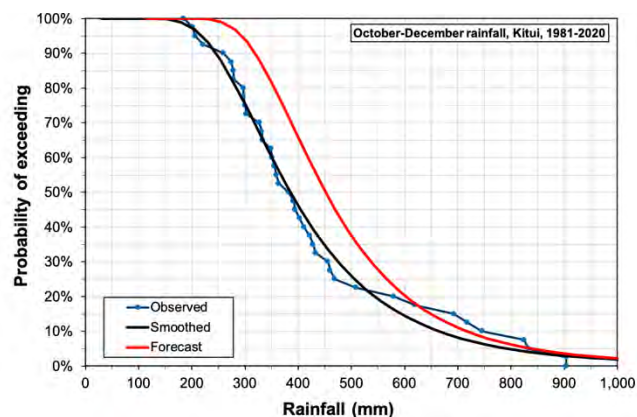
- Explain: Imagine that we used rainfall data from a wetter location to develop a probability distribution. How would it compare with your location? (If they interpret the probability of exceedance graph correctly, they should expect the curve will be shifted to the right of their location. If you use a dryer location, it will be shifted to the left.)

Be careful that this doesn't lead to confusion between a forecast that shifts the probability distribution, and a forecast referring to a different geographic location.

Step 5: Present the current seasonal forecast

Note: In this activity, we are using the 2018 forecast as an example. This means that all of the discussion in steps 5 and 6 should focus on interpreting what a forecast means and identifying what producers might do differently, and not planning for the next agricultural season.

- Present a seasonal forecast for your location from the KMD Seasonal Forecast Maproom. Someone from KMD could present and discuss the forecast, if they are available and if they have been trained to interpret and communicate the Flexible Forecast format.
- When you first introduce producers to the new format, lead producers through the process of finding the probability of experiencing more than this amount using the probability of exceedance graph, for whatever threshold you used with the time series graph in Step 2 and probability of exceedance graph in Step 3. Discuss what the probability is based on the historical distribution and based on the forecast. Discuss why they are different.
- Make sure that everyone understands:
 - KMD produces the seasonal forecast;
 - what variable(s) and time period the forecast covers; and
 - how to interpret the forecast as a shift in probabilities.



Note: When you go through this process with producers, additional seasonal forecast variables might be available besides total rainfall. Any forecast variables that may be relevant to farmers' decisions should be presented.

Suggestion: If threshold values of seasonal climate variables have been identified for particular crops, cultivars or other management options, the probabilities of experiencing more or less than the threshold value can be derived for the historical distribution and for the forecast. Examples of forecast parameters that could be developed in the future include:

- length of the rainfed growing season, relative to the time from sowing to the end of grain fill for particular cultivars;
- Water Requirement Satisfaction Index (WRSI) required for sufficient harvest yield to cover the costs of production; or
- chill units needed to trigger flowering, also known as vernalization, in some cool-season cereals or fruits.

This would help reinforce the relevance of the forecast to farm management decisions.

Step 6: Plan farm management based on the forecast

In this step, you will facilitate participants to decide what seasonal management decisions, if any, they will change in response to the forecast. Group discussion allows participants to learn from other producers, and get feedback on their ideas. While agricultural extension personnel and researchers can provide information about management options and answer questions, the process aims to support farmers' decision making.

Note: When this step is done as part of the training, using a forecast from a past year, be sure to understand that participants are discussing management options as a way to learn how to interpret the new forecast format, and to identify the types of decisions that they think they should consider changing if and when the actual forecast for the upcoming season is presented.

- Guide participants to discuss the question, *"What, if anything, will I do differently this season because of the forecast?"* Explain that whether they want to adjust their plans for the upcoming season, and the kinds of adjustments that they make, may depend on: (1) how much the forecast shifts probabilities that are important for decisions, (2) whether management options are available that would be better suited than existing plans to the forecast conditions.

Note: Discussion among producers can help them identify ideas and clarify their own plans. This can be done either in the large group, or in breakout groups that then summarize their plans to the larger group. Participants may or may not want to adjust some of these plans in response to the seasonal forecast that they have been given. They may agree as a group to change some of their plans, while some decisions might be different for different producers.

- A few discussion questions can help guide participants' thinking and discussion:
 - *What does the forecast say about rainfall for the upcoming season?* It would probably be: (a) increased probability of wet conditions, (b) increased probability of dry conditions, or (c) very little change from the historical probability distribution.
 - *For the forecast variable(s), are there any thresholds that would affect the performance of your farm, crops or livestock; or influence what management options you would choose? If so, how does the forecast affect the probability of experiencing rainfall above/below the threshold?*
 - *How do you expect the forecast to affect your farm (or crops or livestock) management decisions?*
 - *Think about a recent year in which the growing season was wetter than usual, or a year in which the season was dryer than usual. Is there anything you would have done differently on your farm if you had known what rainfall would have been like?*
 - *What if anything, will you do differently this season because of the forecast?*
 - *Do you need any further information in order to decide how to best manage your farm based on the seasonal forecast?*

- *Do you need any further assistance in order to implement your plans for the upcoming season?*
- If participants plan in small groups, ask a representative from each to present their list of management decisions they would change based on the forecast.
- Record the types of decisions that participants say they plan to change in response to the seasonal forecast.



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