African Forest Forum

A platform for stakeholders in African forestry

Basic Science of Climate Change

A COMPENDIUM FOR PROFESSIONAL TRAINING IN AFRICAN FORESTRY

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Front cover photos: *Borassus aethiopum*-based agroforestry system in central Benin (left), Grazing area in central Benin (middle), private plantation of *Moringa oleifera* in southern Benin (right).
Credit: Dèdéou A. Tchokponhoué

Back cover photo: Zio riverbed at Alokoegbé-kpota in southern Togo.
Credit: Dèdéou A. Tchokponhoué

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Abbreviations and Acronyms

ACMAD	African centre for meteorological application and data
AFF	African Forest Forum
CFC	Chlorofluorocarbons
CH_4	Methane
CO	Carbon monoxide
CO_2	Carbon dioxide
EIA	Environmental Impact Assessment
FAO	Food and Agriculture Organization of the United Nations
FSC	Forest Stewardship Council
GHGs	Greenhouse gases
H_2	Hydrogen
H_2O	Water vapor
HCFC	Hydrochlorofluorocarbons
HFCs	Hydrofluorocarbons
ICPAC	IGAD Climate Prediction and Application Centre
IPCC	Intergovernmental Panel on Climate Change
ISO	International Organization for Standardization
ITCZ	Inter-Tropical Convergence Zone
IUCN	International Union for Conservation of Nature
LULCC	Land-use and land-cover change
N_2O	Nitrous oxide
NASA	National Aeronautics and Space Administration
NGOs	Non-Governmental Organizations
NH_4^+	Ammonium
NOAA	National Oceanic and Atmospheric Administration
NOx	Nitrogen oxides
NWFP	Non-Wood Forest Products
O_3	Ozone
PAFC	Pan African Forest Certification
PEFC	Programme for Endorsement of Forest Certification Scheme
PFC	Perfluorocarbons
PSCs	Polar Stratospheric Clouds
RRA	Rapid Rural Appraisal
SFM	Sustainable Forest Management
SOx	Sulphur oxides
UNECA	United Nations Economic Commission for Africa
VOC	Volatile Organic Compounds
WMO	World Meteorological Organization
WWF	World Wide Fund for Nature

Acknowledgements

This compendium has been developed through an organic process that initially led to the development of "Training modules on forest-based climate change adaptation, mitigation, carbon trading, and payment for other environmental services". These were developed for professional and technical training, and for short courses in sub-Saharan African countries. The compendium provides the text required for effective delivery of the training envisaged in the training modules; in other words, it is structured based on the training modules. In this context many people and institutions, including those from government, civil society, academia, research, business, private sector, and other communities, have contributed in various ways in the process that culminated in the development of the compendium. We wish to collectively thank all these individuals and institutions for their invaluable contributions, given that it is difficult in such a short text to mention them individually.

We also appreciate the kind financial support received from the Government of Switzerland through the Swiss Agency for Development and Cooperation (SDC) to implement an AFF project on "African forests, people and climate change" that generated much of the information that formed the basis for writing this compendium. AFF is also indebted to the Swedish International Development Cooperation Agency (Sida) for its support of another AFF project on "Strengthening sustainable forest management in Africa" that also provided inputs into the compendium, in addition to helping facilitate various contributors to this compendium. The issues addressed by the two projects demonstrate the interest of the people of Switzerland and Sweden in African forestry and climate change.

We are also grateful to the lead authors, the contributors mentioned in this compendium and the pedagogical expert, as well as reviewers of various drafts of the compendium.

We hope that the compendium will contribute to a more organized and systematic way of delivering training in this area, and eventually towards better management of African forests and trees outside forests.

Preface

African forests and trees support the key sectors of the economies of many African countries, including crop and livestock agriculture, energy, wildlife and tourism, water resources and livelihoods. They are central to maintaining the quality of the environment throughout the continent, while providing international public goods and services. Forests and trees provide the bulk of the energy used in Africa. Forests and trees are therefore at the centre of socio-economic development and environmental protection of the continent.

Forests and trees outside forests in Africa are in many ways impacted by climate change, and they in turn influence climate. Hence, African forests and trees are increasingly becoming very strategic in addressing climate change. The great diversity of forest types and conditions in Africa is at the same time the strength and the weakness of the continent in devising optimal forest-based responses to climate change. In this regard, given the role of forests and trees to socio-economic development and environmental protection, actions employed to address climate change in Africa must simultaneously enhance livelihoods of forest dependent populations and improve the quality of the environment. It is therefore necessary for Africa to understand how climate change affect the inter-relationships between food, agriculture, energy use and sources, natural resources (including forests and woodlands) and people in Africa, and in the context of the macro-economic policies and political systems that define the environment in which they all operate. Much as this is extremely complex, the understanding of how climate change affect these inter-relationships is paramount in influencing the process, pace, magnitude and direction of development necessary for enhancing people's welfare and the environment in which they live.

At the forestry sector level, climate affects forests but forests also affect climate. For example, carbon sequestration increases in growing forests, a process that positively influences the level of greenhouse gases in the atmosphere, which, in turn, may reduce global warming. In other words, the forests, by regulating the carbon cycle, play vital roles in climatic change and variability. For example, the Intergovernmental Panel on Climate Change (IPCC) special report of 2018 on the impacts of global warming of 1.5 °C above pre-industrial levels underscores the significance of afforestation and reforestation, land restoration and soil carbon sequestration in carbon dioxide removal. Specifically, in pathways limiting global warming to 1.5 °C, agriculture, forestry and land-use (AFOLU) are projected with medium confidence to remove 0-5, 1-11 and 1-5 $GtCO_2$ yr^{-1} in 2030, 2050 and 2100, respectively. There are also co-benefits associated with AFOLU-related carbon dioxide removal measures such as improved biodiversity, soil quality and local food security. Climate, on the other hand, affects the function and structure of forests. It is important to understand adequately the dynamics of this interaction to be able to design and implement appropriate mitigation and adaptation strategies for the forest sector.

In the period between 2009 and 2011, the African Forest Forum sought to understand these relationships by putting together the scientific information it could gather in the form of a book that addressed climate change in the context of African forests, trees, and wildlife resources. This work, which was financed by the Swedish International Development Cooperation Agency

(Sida), unearthed considerable gaps on Africa's understanding of climate change in forestry, how to handle the challenges and opportunities presented by it and the capacity to do so.

The most glaring constraint for Africa to respond to climate change was identified as the lack of capacity to do so. AFF recognizes that establishment and operationalization of human capacities are essential for an effective approach to various issues related to climate change, as well as to improve the quality of knowledge transfer. For example, civil society organisations, extension agents and local communities are stakeholders in implementing adaptation and mitigation activities implicit in many climate change strategies. In addition, civil society organisations and extension agents are more likely to widely disseminate relevant research results to local communities, who are and will be affected by the adverse effects of climate change. It is therefore crucial that all levels of society are aware of mechanisms to reduce poverty through their contribution to solving environmental problems. Training and updating knowledge of civil society organisations, extension service agents and local communities is one of the logical approaches to this. Also professional and technical staff in forestry and related areas would require knowledge and skills in these relatively new areas of work.

It was on this basis that AFF organized a workshop on capacity building and skills development in forest-based climate change adaptation and mitigation in Nairobi, Kenya, in November 2012 that drew participants from selected academic, research and civil society institutions, as well as from the private sector. The workshop identified the training needs on climate change for forestry related educational and research institutions at professional and technical levels, as well as the training needs for civil society groups and extension agents that interact with local communities and also private sector on these issues. The training needs identified through the workshop focused on four main areas, namely: Science of Climate Change, Forests and Climate Change Adaptation, Forests and Climate Change Mitigation, and Carbon Markets and Trade. This formed the basis for the workshop participants to develop training modules for professional and technical training, and for short courses for extension agents and civil society groups. The development of the training modules involved 115 scientists from across Africa. The training modules provide guidance on how training could be organized but do not include the text for training; a need that was presented to AFF by the training institutions and relevant agents.

Between 2015 and 2018, AFF brought together 50 African scientists to develop the required text, in the form of compendiums, and in a pedagogical manner. This work was largely financed by the Swiss Agency for Development and Cooperation (SDC) and with some contribution from the Swedish International Development Cooperation Agency (Sida). In this period eight compendiums were developed, namely:

1. Basic science of climate change: a compendium for professional training in African forestry
2. Basic science of climate change: a compendium for technical training in African forestry
3. Basic science of climate change: a compendium for short courses in African forestry
4. Carbon markets and trade: a compendium for technical training in African forestry
5. Carbon markets and trade: a compendium for professional training in African forestry

6. Carbon markets and trade: a compendium for short courses in African forestry
7. International dialogues, processes and mechanisms on climate change: compendium for professional and technical training in African forestry
8. Climate modelling and scenario development: a compendium for professional training in African forestry

Another notable contribution during the period 2011-2018 was the use of the training module on "Carbon markets and trade" in building the capacity of 574 trainers from 16 African countries on rapid forest carbon assessment (RaCSA), development of a Project Idea Note (PIN) and a Project Design Document (PDD), exposure to trade and markets for forest carbon, and carbon financing, among others. The countries that benefited from the training are: Ethiopia (35), Zambia (21), Niger (34), Tanzania (29), Sudan (34), Zimbabwe (30), Kenya (54), Burkina Faso (35), Togo (33), Nigeria (52), Madagascar (42), Swaziland (30), Guinea Conakry (40), Côte d'Ivoire (31), Sierra Leone (35) and Liberia (39). In addition, the same module has been used to equip African forest-based small-medium enterprises (SMEs) with skills and knowledge on how to develop and engage on forest carbon business. In this regard, 63 trainers of trainers were trained on RaCSA from the following African countries: South Africa, Lesotho, Swaziland, Malawi, Angola, Zambia, Zimbabwe, Mozambique, Tanzania, Uganda, Kenya, Ethiopia, Sudan, Ghana, Liberia, Niger, Nigeria, Gambia, Madagascar, Democratic Republic of Congo, Cameroon, Côte d'Ivoire, Burkina Faso, Gabon, Republic of Congo, Tchad, Guinea Conakry, Senegal, Mali, Mauritania, Togo and Benin .

An evaluation undertaken by AFF has confirmed that many trainees on RaCSA are already making good use of the knowledge and skills gained in various ways, including in developing bankable forest carbon projects. Also many stakeholders have already made use of the training modules and the compendiums to improve the curricula at their institutions and the way climate change education and training is delivered.

The development of the compendiums is therefore an evolutionary process that has seen the gradual building of the capacity of many African scientists in developing teaching and training materials for their institutions and the public at large. In a way this has cultivated interest within the African forestry fraternity to gradually build the capacity to develop such texts and eventually books in areas of interest to the continent, as a way of supplementing information otherwise available from various sources, with the ultimate objective of improving the understanding of such issues as well as to better prepare present and future generations in addressing the same.

We therefore encourage the wide use of these compendiums, not only for educational and training purposes but also to increase the understanding of climate change aspects in African forestry by the general public.

Macarthy Oyebo
Chair, Governing Council of AFF

Godwin Kowero
Executive Secretary-AFF

Executive Summary

Overview

A clear understanding of the basics of the science of climate change lays a foundation on the terms, definitions, and concepts used and their application in forestry science. This module will introduce learners to the key and basic concepts of the science of climate change. It is divided into five chapters: Physics and chemistry of environment; General ecology; Sustainable forest management; Processes, drivers and impacts of climate change; and Climate change data management.

Aim

To build the learners' understanding of the concepts of basic science of climate change and their application in forestry and other related sectors.

Objectives

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

1) describe the elements of global change;
2) describe components of climate systems and concepts of climate change;
3) analyze the drivers of climate change;
4) explain the impact of climate change in forestry and in other related sectors;
5) relate concepts of vulnerability and response to climate change;
6) relate concepts of vulnerability and response to climate change;
7) develop climate models that predict vulnerability and impact of climate change; and,
8) evaluate the implications of international agreements, discussions, conventions, and negotiations on climate change.

Chapter 1: Physics and Chemistry of the Environment

1.0 Chapter overview

Interactions between the elements of the atmosphere and Earth are at the root of climate change. The accumulation beyond a certain threshold of certain elements or the changes of states of these elements can have extreme consequences on the environment. This chapter introduces the basics of atmospheric physics and chemistry, the water cycle, the Earth crust and the interactions between the Earth and the atmosphere.

General Objective

At the end of this chapter, learners will be able to:

a) state the major and minor constituents of the atmosphere and its various layers and functions;

b) define ozone, the types of ozone;

c) describe the importance of ozone for living organisms and the mechanisms of it destruction;

d) define the terms pollution and depollution of an environment and to understand different types of pollution;

e) define the aerosols, the types of aerosols and their manifestation;

f) describe the properties and different states of water, the mechanisms of cloud and strong winds formation; and,

g) elaborate on the difference between climate change and climate variability.

Scope

At the end of this chapter, learners should be able to:

- describe the interactions between atmosphere, water and land;
- explain greenhouse effects and mechanisms for the destruction of the ozone layer;
- define global change and climate change;
- explain the elements of global change and their implications for climate change;
- differentiate the various components of the climate system; and,
- describe trends in climate change using indicators.

Activity 1 (Brainstorming; duration: 15 minutes)

Divide the class into groups.

- The first group will identify the minor and major constituents of the atmosphere and its different layers.
- The second group will give a definition of ozone, its location, types of ozone, its importance for living organisms and the mechanisms of its destruction.
- The third group will define the terms pollution and depollution of an environment and the different types of pollution.
- The fourth one will explain the mechanisms of formation of the clouds, the winds and their origins.
- The fifth group will give the properties of water, its different states, and the great reservoirs of water on Earth.
- The sixth group will define the climate, give the difference between climate change and climatic variability and finally give the consequences of climate change (acid rain, aerosols, energy discharges) on the living organisms of the Earth.

Session delivery plan

This chapter is structured into four sessions of four hours each. The detailed description of these sections and the required materials are described below.

Sessions	Time required	Approach	Educational materials
Physical chemistry of the atmosphere	4 hours	Iterative exchanges, discussions, question and answer sessions, theoretical courses and case studies	Computers, video projector
Notion of pollution	4 hours	Field visit, theoretical courses, directed work, iterative exchanges	Computers, video projector
Weather Phenomena	4 hours	Meteorological station visits, question and answer sessions, theoretical courses, discussions and group work, personal research and presentations	Computers, video projector, field outfit
Physical chemistry of water	4 hours	Theoretical courses, iterative exchanges followed by question and answer sessions	Computers, video projector, sticky note

1.1 Physical chemistry of the atmosphere

Objectives

At the end of this module, learners will be able to:

a) explain basic physico-chemical principles that govern atmospheric interactions;

b) describe the different components of the atmosphere; and,

c) explain the dynamics and importance of ozone.

Exercise

Students must:

- describe the chemical composition and the different layers of the atmosphere;
- define what the Ozone layer is and its role on living organisms;
- briefly comment on the interaction of light with the different layers of the atmosphere; and,
- carry out a synthesis of the various meteorological phenomena that can be distinguished.

1.1.1 Chemical composition of the atmosphere

The air is a mixture of gas in a remarkably uniform proportion over the whole thickness of the atmosphere. It contains 78% nitrogen, 21% oxygen and 1% rare gases, in particular argon. In addition, there are gases of variable concentration: water vapour, carbon dioxide, and sulphur dioxide. Though light, the air is glued to the Globe by gravity. It is therefore on the ground that its density and pressure are maximum: 1.3 g per liter and 760 mm of mercury (= 1,013 billion in mb, 1 mb worths 100 pascals). The atmospheric pressure decreases as one rises up: 264 mb to 10 km, 55 mb to 20 km and so on until reaching zero around 600 km above ground.

The atmosphere of the Earth consists essentially of a mixture of nitrogen (N_2) and oxygen (O_2); these two molecules occupy nearly 99% of the total volume in a dry atmosphere. They are distributed homogeneously across the homosphere, both vertically and horizontally. Ozone is among the minority constituents alongside with water vapor (H_2O), carbon dioxide (CO_2), methane (CH_4), hydrogen (H_2), nitrous oxide (N_2O) and carbon monoxide (CO). Typical concentrations for these various atmospheric constituents are shown in Table 1.

Carbon monoxide has a high chemical reactivity, in particular with respect to the hydroxyl radical (OH, reactive molecule, a true tropospheric detergent). This results in a relatively short lifetime estimated at two months; therefore, this compound exhibits significant latitudinal and seasonal variation. During the year, its mixing rate can double at the mid-latitudes of the northern hemisphere. By comparison, the seasonal variations of CO_2 and CH_4 are of the order of a few percentages. The concentrations of the various compounds are reported as mixing rates and volume percentages (average), respectively, in the third and fourth columns.

Table 1. Concentrations of various atmospheric constituents. The magnitude of seasonal changes in concentrations of minor constituents is highly variable.

Atmospheric constituents		Volume mixing ratio (dry air) (ppv)	%Vol (dry air)
Major	Nitrogen (N_2)	0.7808	78.08
	Oxygen (O_2)	0.2095	20.95
Minor	Carbon dioxide (CO_2)	$380\ 10^{-6}$	0.038
	Stratospheric Ozone (O_3)	$1 – 10.10^{-6}$	~0.0005
	Methane (CH_4)	$1.80\ 10^{-6}$	0.00018
	Water vapour (H_2O)	Highly variable	Highly variable
	Hydrogen (H_2)	$550\ 10^{-9}$	0.000055
	Nitrous Oxide (N_2O)	$312\ 10^{-9}$	0.0000312
	Carbon monoxide (CO)	$40 – 225\ 10^{-12}$	~0.000013

The abundance of an atmospheric constituent is generally expressed in terms of mixing ratio (vmr); this corresponds to the fraction of volume occupied by the molecules of the constituant considered with respect to the unit volume of dry air:

(equation 1)

It is expressed in parts per million-volume (ppmv: 10^{-6}), parts per billion-volume (ppbv: 10^{-9}) or part per trillion-volume (pptv: 10^{-12}).The average mixing rates of the minor constituents given in Table 1 show a wide range of concentrations, ranging from 40 pptv (or 0.04 ppmv) for CO and 380 ppmv for CO_2. The terrestrial atmosphere also contains a large number of trace constituents. Their low concentrations should not lead us to neglect the effects they may have on our environment. In addition to the carbon (C_2H_6, C_2H_2, H_2CO, etc.), nitrogen (NO, NO_2, HNO_3, etc.) and sulfur (SO_2, etc.) compounds, there are the halogenated compounds, such as fluorine, chlorine, bromine or iodine.

The latter are strongly linked to the problem of the destruction of stratospheric ozone. Over the last few decades, the range of halogenated compounds present in the troposphere has been greatly altered due to the intensive use of synthetic products which led to their massive release into the atmosphere, more or less delayed depending on the application. Because of their high stability, these products are characterized by relatively long atmospheric lifetimes and will therefore influence the environment for many years after being released to the atmosphere. Among these compounds are chlorofluorocarbons (CFC: CCl_2F_2 or CFC-12, CCl_3F or CFC-11, CCl_2FCClF_2 or CFC-113, etc.), hydrochlorofluoro-carbons (HCFC: $CHClF_2$ or HCFC-22, CH_3CCl_2F or HCFC-141b), halons ($CBrClF_2$ or H-1211, $CBrF_3$ or H-1301), some chlorinated derivatives of alkanes (CH_3CCl_3, CCl_4), hydro-fluorocarbons (HFC: CH_2FCF_3 or HFC-134a) and perfluorocarbons (PFC: CF_4 or PFC-14, C_2F_6 or PFC-116).

1.2 Atmospheric layers

Earth's atmosphere

The word atmosphere comes from the Greek "*atmos*" - moist vapor - and "*sphere*" that is the representation of the Earth. The atmosphere is a gaseous envelope fundamental to the existence of life on Earth. The latter also plays a major role in the water cycle since evaporation is the prerequisite for precipitation. The air inside the atmosphere is defined in terms of temperature, pressure, wet load and movements or direction (horizontal and vertical).

The Earth's atmosphere is a thin layer of gases that surrounds the Earth. It is composed of 78% nitrogen, 21% oxygen, 0.9% argon, 0.03% carbon dioxide, and of other gases as trace. The atmosphere protects life on Earth by absorbing ultraviolet solar radiation, warming the surface through heat retention (greenhouse effect), and reducing temperature extremes between day and night (the diurnal temperature variation). The Earth's atmosphere is about 480 km thick, but most of the atmosphere (about 80%) is within 16 km of the surface of the Earth. There is no exact place where the atmosphere ends; it just gets thinner and thinner, until it merges with outer space.

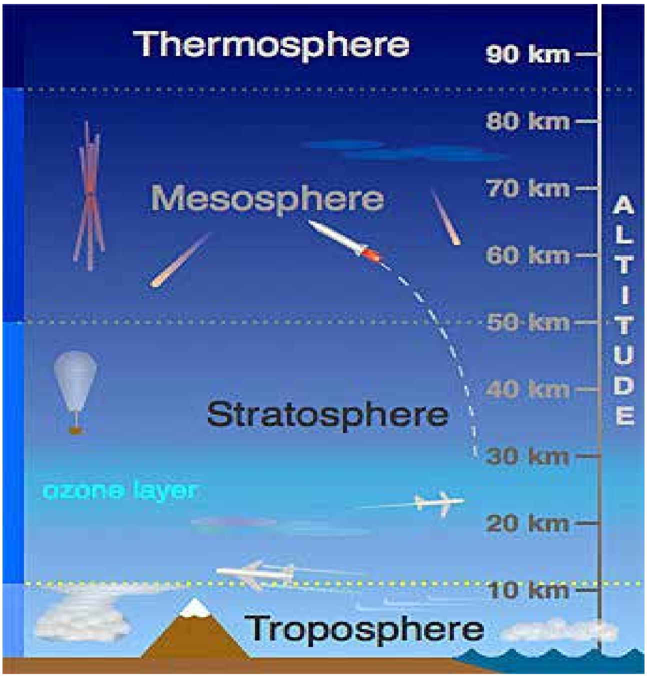

Figure 1. The layers of the atmosphere.
Source: Russell (2015)

Moving upward from ground level, the layers of the atmosphere are named the troposphere, stratosphere, mesosphere, thermosphere and exosphere. The exosphere gradually fades away into the realm of interplanetary space.

The **troposphere** is the lowest layer of our atmosphere. Starting at ground level, it extends upward to about 10 km above sea level. We humans live in the troposphere, and nearly all weather occurs in this lowest layer. Most clouds appear here, mainly because 99% of the water vapour in the atmosphere is found in the troposphere. Air pressure drops, and temperatures get colder, as you climb higher in the troposphere.

The next layer up is called the **stratosphere** and extends from the top of the troposphere to about 50 km above the ground. The ozone layer is found within the stratosphere. Ozone molecules in this layer absorb high-energy ultraviolet (UV) light from the Sun, converting the UV energy into heat. Unlike the troposphere, the stratosphere actually gets warmer the higher you go. This means that air in the stratosphere lacks the turbulence. Commercial passenger jets fly in the lower stratosphere, partly because this less-turbulent layer provides a smoother ride. The jet stream flows near the border between the troposphere and the stratosphere.

Above the stratosphere is the **mesosphere**. It extends upward to a height of about 85 km above our planet. Most meteors burn up in the mesosphere. Unlike the stratosphere, temperatures once again grow colder as you rise up through the mesosphere. The coldest temperatures in Earth's atmosphere, about -90°C, are found near the top of this layer. The air in the mesosphere is far too thin to breathe; air pressure at the bottom of the layer is well below 1% of the pressure at sea level, and continues dropping as you go higher.

The layer of very rare air above the mesosphere is called the **thermosphere**. High-energy X-rays and UV radiation from the Sun are absorbed in the thermosphere, raising its temperature to hundreds or at times thousands of degrees. However, the air in this layer is so thin that it would feel freezing cold to us! In many ways, the thermosphere is more like outer space than a part of the atmosphere. Many satellites actually orbit Earth within the thermosphere. Variations in the amount of energy coming from the Sun exert a powerful influence on both the height of the top of this layer and the temperature within it. Because of this, the top of the thermosphere can be found anywhere between 500 and 1,000 km above the ground. Temperatures in the upper thermosphere can range from about 500°C to 2,000°C or higher. The aurora, the Northern and Southern Lights, occur in the thermosphere.

Although some experts consider the thermosphere to be the uppermost layer of our atmosphere, others consider the **exosphere** to be the actual "final frontier" of Earth's gaseous envelope. As you might imagine, the "air" in the exosphere is very, very, very thin, making this layer even more space-like than the thermosphere. In fact, air in the exosphere is constantly - though very gradually - "leaking" out of Earth's atmosphere into outer space. There is no clear-cut upper boundary where the exosphere finally fades away into space. Different definitions place the top of the exosphere somewhere between 100,000 km and 190,000 km above the surface of Earth. The latter value is about halfway to the Moon.

The **ionosphere** is not a distinct layer like the others mentioned above. Instead, the ionosphere is a series of regions in parts of the mesosphere and thermosphere where high-energy radiation from the Sun has knocked electrons loose from their parent atoms and molecules. The electrically charged atoms and molecules that are formed in this way are called ions, giving the ionosphere its name and endowing this region with some special properties.

1.3 Ozone layer

Definition, vertical distribution and composition

Ozone is an allotropic gaseous form of oxygen (O), heavier than air. Ozone is a molecule composed of three oxygen atoms (O_3). Although this molecule is present in the Earth's atmosphere in reduced quantity, from the surface to abot 50 km altitude, it plays an essential role by filtering significantly the ultraviolet solar radiation harmful to the cells of living beings and which reduces the photosynthesis of plants. Ozone also intervenes in the stabilization of the stratosphere by limiting vertical exchanges in this region of the atmosphere. Ozone is also found in the troposphere but its presence in this part of the atmosphere is undesirable because it is a low-level pollutant presenting a potential hazard to human health and vegetation (Blin et al., 2007; Sivasakthivel and Siva, 2011).

Box 1. Importance of the ozone layer for living organisms

At high altitudes, the ozone layer absorbs most of the ultraviolet solar radiation, which is harmful to living organisms and ozone therefore plays a protective role for living beings. In the absence of the ozone layer in the upper atmosphere, life would have been possible only in the oceans, at a sufficient depth of the water surface (UV penetrating only on the surface). This was the case during the Archean eon, when the Earth's atmosphere was devoid of dioxygen (and hence of ozone).

Types of ozone

There are generally two types of ozone: good or useful ozone and bad or harmful ozone. "*Good ozone*", indicates stratospheric ozone while "bad ozone" refers to ozone on the surface of the Earth, also called tropospheric ozone. Stratospheric ozone or "good ozone" is found at relatively high concentrations in the terrestrial stratosphere, mainly at altitudes between 15 and 20 km. This ozone strongly absorbs ultraviolet rays and protects living organisms against UV radiation. Ozone is destroyed by aerosols in particular from human activity, including CFCs, resulting in a hole in the ozone layer.

Tropospheric ozone or "*bad ozone*" is generated by pollution near the surface of the Earth. Tropospheric ozone is formed by a chemical reaction involving nitrogen dioxide with oxygen from the air. However, the formation of nitrogen dioxide (NO_2) involves nitrogen monoxide (NO) directly emitted by cars, combined with volatile organic compounds (VOCs) originating mainly from industries. It is therefore called secondary pollutant because it is produced when two primary pollutants react to the sun and stagnant air. These two primary pollutants are oxides of nitrogen (NO_x) and volatile organic compounds (VOCs). Tropospheric ozone contributes to the greenhouse effect and acid rain (alteration of plants and forests). In humans or animals it causes irritation of the ocular and respiratory mucous membranes, and asthma attacks in sensitive subjects.

Role of ozone on living organisms

Ozone protects living organisms by absorbing some of the ultraviolet rays in the upper atmosphere. But at low altitude, this excess gas can have undesirable effects on health and nature. The stratosphere is naturally rich in ozone which filters ultraviolet rays, and thus allows life on our planet. Based on some observations, this protective layer has tended to diminish over the last few decades, under the destructive action of synthetic chemical compounds such as chlorofluorocarbons (CFCs).

Dynamic of the ozone layer

Over the last few decades, a variety of domestic, industrial and agricultural practices have played a role in the depletion of the ozone layer, leading to the emission of nitrogen, chlorine and bromine compounds to the atmosphere. Thanks to the numerous monitoring instruments, both on the ground and on satellite platforms, the recent evolution of ozone is precisely recorded, making it possible to characterize the extent to which the decrease of the ozone layer has affected its function over time and location (Mahieu, 2007; Sivasakthivel and Siva, 2011).

1.4 Long term evolution of total ozone

Since the start of observations in 1971 there have been different periods of stratospheric load with ozone depleting substances. During the first years there were almost no man-made ozone depleting molecules. From c. 1980 onwards the concentration gradually increased, to peak in 1997. Now concentrations have stabilized and show a decrease due the ban of CFC's (chloro-fluorocarbons) and halons containing Bromine in the Montreal protocol, signed in 1987. Therefore, it is common to use the data before 1980 as a kind of reference before anthropogenic influence. To see whether there is a difference in the ozone changes, trends are calculated for two periods (before and after 1997).

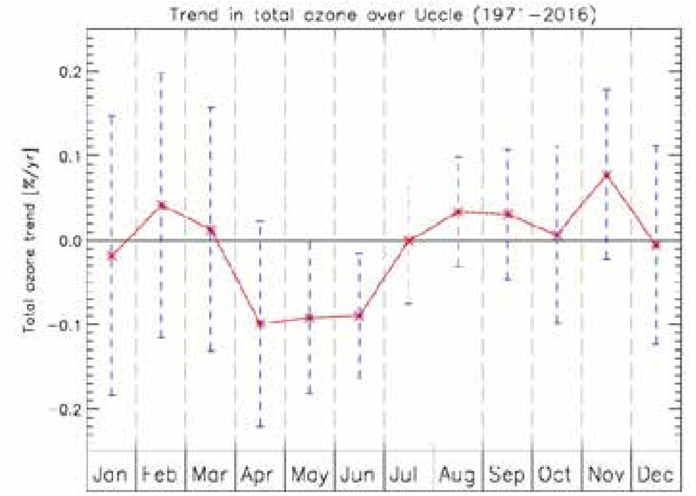

Figure 2: Seasonal ozone trends at Uccle in percent per year derived from the ozone observations with Dobson nr. 40 (1971-1989), Brewer nr. 16 (1990-2001), and Brewer nr. 178 (2002-2016) between 1971 and 2016. The vertical bars represent the 95% confidence level of the calculated trends.

Above the long term evolution of ozone is illustrated by a graph (Figure 2) of the running yearly mean values of total ozone and one of the monthly trends.

The trends are -0.25 % per year and +0.19 % per year for the periods 1980-1997 and 1997-2016, respectively. Although this can be interpreted as a first sign of the recovery of the ozone layer, it should however be noted that the last period is too short for final conclusions about such recovery (note the large year to year variability during the last decade).

1.4.1 Trends as function of season

To calculate the total ozone trends as a function of season, the total ozone column time series has been split up into monthly mean values in Dobson Units (DU). Then a least square linear regression is applied to these time series. During a time of 45 years, there is only a significant negative total ozone column trend present in the data during May and June as shown in the figure 3 below.

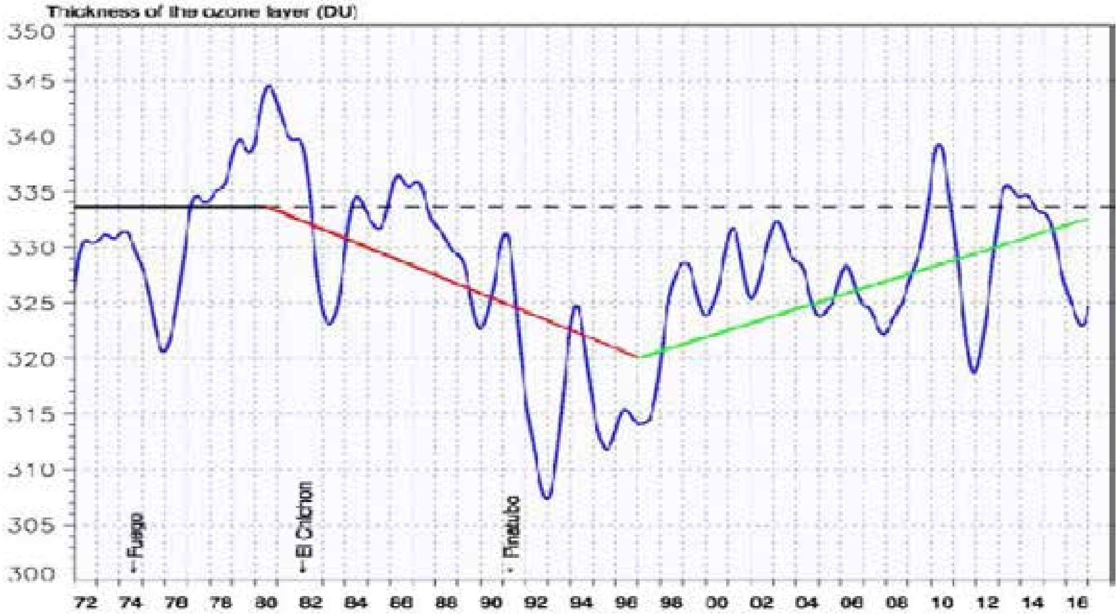

Figure 3: Evolution of the ozone column at Uccle as observed with Dobson 40 (1972-1989); Brewer 16 (1990-2001), and Brewer 178 (2002-2016). Major volcanic erutions affecting the ozone layer are indicated on the time axis.

Box 2. Why is there a hole in the ozone layer?

Multiple substances released into the atmosphere promote the dissociation of ozone (O_3) into dioxygen (O_2). These include chlorofluorocarbons, or CFCs and halons, present in air conditioning, refrigeration systems, aerosols and in some industrial processes. Ozone is destroyed by chlorine and bromine derived from their decomposition, provided there are very low temperatures and light. This is why the hole in the ozone layer takes place after the polar winter (in the stratosphere above Antarctica, about -80°C), when the light reappears at these latitudes, viz. during the southern spring (September to December) over Antarctica, and from March to June above the North Pole, but to a much lesser extent.

Problems caused by the destruction of the ozone layer

Over the last fifty years, various catalytic cycles destroying ozone have been identified; they can be represented as follows:

$$\begin{array}{ll} & O_3 + X \rightarrow XO + O_2 \\ & XO + O \rightarrow X + O_2 \quad \text{(equation 2)} \\ \hline \text{Balance:} & O_3 + O \rightarrow 2O_2 \end{array}$$

These cycles consequently result in the conversion of odd oxygen to molecular oxygen whereas the catalyst, denoted X, is restored at the end of these reactions; it can therefore influence the concentration of ozone while being present in smaller quantities.

Ultimately, the amount of ozone present in the stratosphere is governed by a large number of reactions occurring in the Chapman cycle (production/destruction) and in different catalytic cycles (destruction, HO_x, NO_x, ClO_x and BrO_x). The situation is further complicated by the multiple couplings between these different cycles; couplings which lead to the formation of mixed constituents such as $ClONO_2$, HOCl, etc. These compounds, if they have no direct effect on the destruction of ozone, constitute reservoirs of active molecules. The prediction of the amount of stratospheric ozone thus requires taking into account all the reactions and couplings identified to date, as well as the transport phenomena which intervene in a not inconsiderable way in its redistribution. This complex exercise is carried out using 3-D models incorporating chemistry and transport of air masses (3-D CTM for Chemical Transport Model).

By integrating the most recent knowledge (reaction constants, reagent distributions and abundances, etc.), the relative contributions of the various mechanisms involved in the photochemical control of ozone have been reassessed. Figure 4 shows the ozone destruction rates for each of the catalytic cycles (O_x, HO_x, NO_x, ClO_x) as a function of altitude, with the exception of that based on BrO_x, which plays a significant role below 25 km only. It is noted that these destruction rates vary greatly with altitude. Thus, over 50 km, the HOx account for more than 70% in the destruction of stratospheric ozone, O_x for nearly 20% and ClO_x for 10%; towards 40 km, the NO_x intervene for 40%, ClO_x for 25%, HO_x and O_x for less than 15% in the disappearance of the ozone.

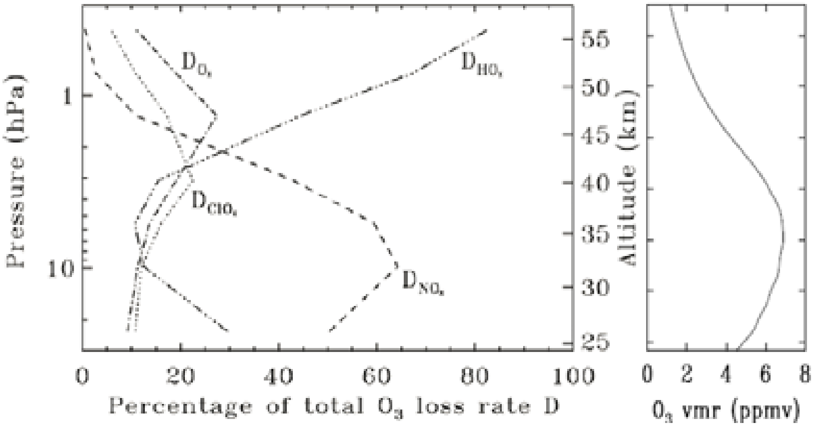

Figure 4. Calculation of ozone destruction rates for January 1994 at 25°S. A typical distribution profile of ozone is shown on the right.

Source: WMO (1999).

The cycle involving NO_x becomes preponderant towards 30 km while that of HO_x is again predominant within 20 km of altitude. If the influence of the ClO_x cycle can be measured, particularly compared to that of NO_x, which is decisive around 30-35 km, an altitude where the ozone concentrations are maximum, several sets of independent observations show a significant decrease in O_3 of 7.4 ± 1.0%/decade occurring around 40 km. The models show that the vertical and southern locations and the extent of this decline are consistent with the accumulation of anthro-pogenic Cl in the upper stratosphere.

Homogeneous gas phase photochemistry leads to progressive, slow and relatively uniform destruction of ozone (Mahieu, 2007). The discovery by Farman of the “ozone hole” above the Halley Bay station in Antarctica made it necessary to identify additional mechanisms to explain the massive destruction of O_3, located both geographically and vertically .

Box 3. Is there a link between ozone and climate change?

Paradoxically, ongoing climate change contributes, to a lesser extent, to the reduction of the ozone hole. If the greenhouse gases heat the lower atmosphere, they cool the stratosphere at a very high altitude, which can have a slight positive effect by slowing down the chemical reactions that destroy ozone. Another slight effect is that by increasing atmospheric circulation, climate change can accelerate the overall improvement of the ozone layer, especially at medium latitudes and at the North Pole.

1.5 Atmospheric physics and solar radiation

Thermal transfer

A thermal transfer, more commonly referred to as heat, is a transfer of disordered microscopic energy. This corresponds to a transfer of thermal energy between particles, as the random shocks occur on the microscopic scale. The most common example of a situation involving heat transfer is the system consisting of two bodies in contact and having different temperatures. The warmest body yields energy in the form of heat to the coldest body. There is heat transfer between the two bodies. There may be thermal transfers to a system whose temperature remains constant, e.g. in the case of a change in physical state (e.g. melting ice at 0°C under atmospheric pressure). The study of these transfers is carried out within the framework of the thermodynamic discipline on the basis of the first two principles.

Unlike thermodynamics, thermokinetics provides information on the mode of transfer in non-equilibrium situations as well as on heat flux values. The controversy about the nature of “heat” lasted until the middle of the nineteenth century. Around 1805, the French physicist and mathematician Joseph Fourier (1768-1830), taking up previous works, decided to completely ignore the nature of heat, to concentrate only on the study of its transmission. Fourier assumed that the heat is transmitted from the hot zones to the cold zones perpendicular to the isothermal surfaces and proportional to the existing temperature deviations. It thus leads to the first quantitative study of a mode of heat transfer, conduction, that we will study in detail first. The resolution of the partial differential equation obtained leads Fourier to develop the notions of Fourier series and integrals.

We study here a set of thermodynamic systems that are not in thermal equilibrium, meaning when the temperature of a particular system is not everywhere equal to the temperature of the other system (s) with which Σ is in contact, or in relation to electromagnetic radiation. The description we make of the heat transfer will be phenomenological, i.e. of experimental origin, although a simplified microscopic analysis will make it possible to justify some of these laws.

We design by ‘’heat transfer” the non-macroscopic part of the energy exchanges either:

$dU - \delta W$, or $dU = \delta W + \delta Q$ or $\Delta U = W + Q$. (equation 3)

The term “heat transfer” has recently been introduced to replace the term “heat”, a source of possible confusion between the notions of heat transfer (extensive, transformation-related) and temperature (intensive, state-bound). The confusion was explicitly raised for the first time around 1760 by the British physicist Joseph Black (1728-1799); he then named the temperature as *intensity of heat* and the heat transfer as “*quantity of heat*”.

Adiabatic phenomenon

The adjective “adiabatic” describes any process, any phenomenon, any evolution associating two physical, chemical or biological systems that do not exchange heat. This definition applies in particular to the couple formed by a system and the environment external to this system. The current study of fluids, and of air in particular, is based on the division into more or less moving particles of fluid; we can wonder what is the usual behavior of the system which constitutes a piece of air in relation to the atmosphere which surrounds it and which most often forms the whole of its external environment.

The various transformations to which such a piece may be subjected to, considering the aero-logical scale, include adiabatic transformations: in fact, it may be considered that the piece, in the course of its vertical movements, will not exchange heat with the external environment, because the dissemination of heat is poorly effected through the air. Now, it turns out that when a parcel is subjected to an adiabatic expansion - the atmospheric pressure decreasing - it undergoes at the same time a cooling. Conversely, if this piece is subjected to an adiabatic compression - with increasing pressure - it undergoes a warming. As a result, a piece of air taken in an upward movement cools, since the pressure decreases when altitude rises; the opposite conclusion applies to a parcel taken in a subsidence. It is then demonstrated in meteorology that as long as there has not been saturation, the variations of the temperature and the pressure of a piece of moist air are carried out in the same direction and are practically bound by a universal law whose sole parameter is the temperature taken by the piece at a given pressure, conventionally fixed at 1,000 hPa (the temperature of the piece at this particular pressure constitutes by definition its potential temperature).

With the hypothesis of adiabatism, extremely valuable information on the meteorological situation and the sensitive time in a given atmospheric section can then be deduced from the examination of the vertical profile of temperature as a function of pressure, plotted for example, on an emagram. This examination sheds light on two primary factors, firstly the thickness, stability or instability of the layers examined, and secondly the formation of condensation, giving rise to clouds and possibly precipitation. The movement of a piece is then depicted on the emagram by a “displacement” of the representative point of its state along the curve which represents, for the corresponding value of the potential temperature, the above mentioned relationship between pressure and temperature (such a curve is called an adiabatic isoline or simply, by substantivation, an adiabatic).

1.5.1 Interaction of light with the atmosphere layers

Before the radiation used for remote sensing reaches the Earth’s surface, it must pass through a certain thickness of atmosphere. The particles and gases in the atmosphere can deflect or block the incident radiation. These effects are caused by the mechanisms of diffusion and absorption.

The diffusion occurs during the interaction between the incident radiation and the particles or large molecules of gas present in the atmosphere. The particles deviate the radiation from its initial trajectory. The level of diffusion depends on several factors such as the wavelength, the density of particles and molecules, and the thickness of the atmosphere that the radiation must pass. There are three types of diffusion:

- the diffusion of Rayleigh;
- the diffusion of Mie; and,
- the non-selective diffusion.

The diffusion of Rayleigh occurs when the particle size is less than the wavelength of the radiation. These can be either dust particles or nitrogen or oxygen molecules. The diffusion of Rayleigh disperses and deviates more importanttly short wavelengths than long wavelengths. This form of diffusion is predominant in the upper layers of the atmosphere. This phenomenon explains why we perceive a blue sky during the day. Since the Sun's light passes through the atmosphere, the short wavelengths (corresponding to the blue) of the visible spectrum are dispersed and deviated more than the long wavelengths. At sunset and at sunrise, radiation must travel a greater distance through the atmosphere than in the middle of the day. The diffusion of short wavelengths is more important. This phenomenon allows a greater proportion of long wavelengths to penetrate the atmosphere.

The Mie diffusion occurs when the particles are almost as large as the wavelength of the radiation. This type of diffusion is often produced by dust, pollen, smoke and water. This type of diffusion affects the longest wavelengths and occurs mostly in the lower layers of the atmosphere where the coarse particles are more abundant. This process dominates when the sky is clouded.

The third type of diffusion is the **non-selective diffusion**. This type of diffusion occurs when particles (drops of water and large dust particles) are much larger than the wavelength of the radiation. We call this kind of diffusion "non-selective" because all wavelengths are scattered. Water drops in the atmosphere disperse blue, green, and red almost equally, producing white radiation (blue + green + red light = white light). That is why the fog and the clouds seem white.

Another phenomenon comes into play when electromagnetic radiation interacts with the atmosphere: it is absorption. Absorption occurs when large molecules of the atmosphere (ozone, carbon dioxide and water vapor) absorb energy of various wavelengths (http://www.rncan.gc.ca/sciences-terre/geomatique/imagerie-satellitaire-photos-aeriennes/imagerie-satellitaire-produits/ressources-educatives/14636).

1.5.2 Atmospheric circulation and dynamics of atmospheric fluids

Atmospheric circulation

Atmospheric circulation is the large-scale movement of air by which heat is distributed on the surface of the Earth. It is any atmospheric flow used to refer to the general circulation of the Earth and regional movements of air around areas of high and low pressure. On average, this circulation corresponds to large-scale wind systems arranged in several east–west belts that encircle the Earth. In the subtropical high-pressure belts near latitudes 30° N and 30° S (the horse latitudes), air descends and causes the trade winds to blow westward and equatorward at the Earth's surface. These merge and rise in the intertropical convergence zone near the Equator and blow eastward and poleward at altitudes of 2 to 17 km. Part of the flow descends in the subtropical high-pressure belts, and the remainder merges at high altitudes with the midlatitude westerly winds farther poleward.

The genral circulation is defined to be the complete statistical description of large-scale atmospheric motions. A complete understanding of the general circulation requires an undsersdanting of the role of small-scale motions, radiation, conservation and interaction with the ocean and land surface. Figure 5 below shows the general atmospheric circulation models.

The proposed general circulation model consists of six convection cells: two equatorial cells in the direct sense called Hadley cells, two cells with reverse circulation of the previous ones known as Ferrel cells and two polar cells again with direct circulation. The atmospheric general circulation thus defined ensures 70% to 80% of the transfer of energy between regions with positive radiative balance and those with negative radiative balance. It plays an important role in the water cycle, transporting enormous quantities of water vapor. The displacement of air masses conditions the climate of the various regions of the planet.

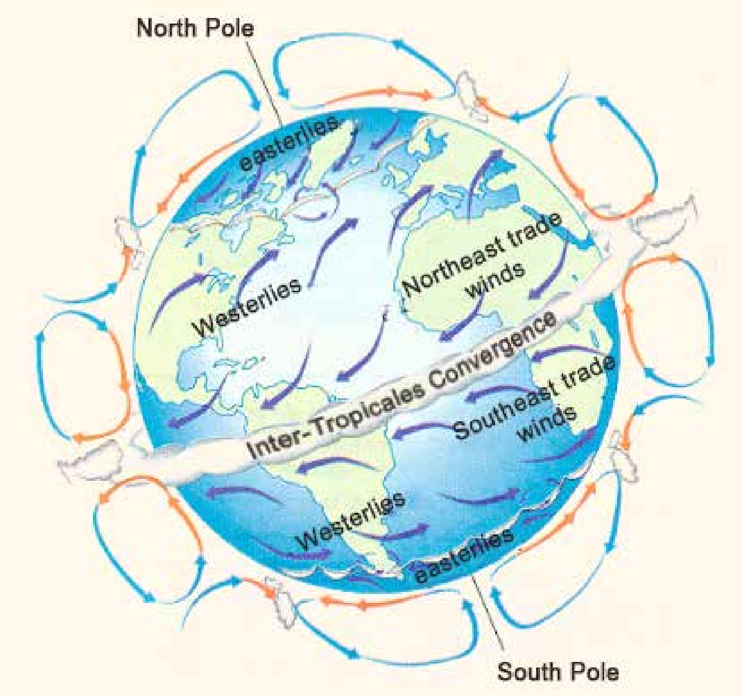

Figure 5. Atmospheric General Circulation Models.
Source: http://eduscol.education.fr/obter/appliped/circula/theme/atmos32.htm

Summary

This session provides learner with a thorough knowledge of the components of the atmosphere as well as physicochemical interactions. In addition, the issue of ozone is widely addressed through its characteristics and importance to climate change. Emphasis is placed on the dynamics of the ozone layer and the factors that affect its integrity.

1.6 Notion of pollution

Objectives

At the end of this training, learners will be able to:

a) Describe the different types of pollution;
b) identify the different pollutants; and
c) know the techniques of depollution.

Activity 1 (Brainstorming) (20 minutes)

- Define pollution.
- State the various sources of pollution.
- Describe the different types of pollutants.
- Propose depollution methods.

1.6.1 Definition and concepts

The term pollution can be defined as "an unfavorable modification of the natural environment which results in whole or in part from human action, through direct or indirect effects altering the criteria of distribution of energy flows, radiation levels, the physico-chemical constitution of the natural environment, and the abundance of living species".

1.6.2 Types of pollution

The types of pollution can be divided into three main categories:

- physical pollution: radiation due to radionuclides, thermal pollution, noise and infrasound;
- chemical pollution: natural, mineral or organic products and synthetic substances previously absent in nature; and,
- microbiological pollution: untimely introduction of animal or plant varities.

Pollution is not only a phenomenon to be attributed to human activities. Nature also produces its own pollutants, altering, albeit to a lesser extent, the quality of the air. Natural pollutants can be:

- mineral particles (marine spray, rock corrosion, soil erosion);
- living particles (bacteria, viruses, microscopic fungi);
- particles (pollens); and
- gases (radon, carbon dioxide, ozone).

1.6.3 Decontamination of the atmosphere

Depollution refers to the elimination of pollution and contamination from ambient environments such as soils, groundwater, sediments or surface waters. The challenges of depollution are often financial but also of general interest (protection of public health and the environment, or for example in the case of a disused industrial or commercial site, reuse).

Depollution generally has to fulfill a set of legislative standards and may also be based on health or ecological risk assessments where no legislative standard exists or when they are in an advisory capacity.

Summary

The session addresses issues of pollution in all its forms and its impact on the ecosystem. There is also evidence of natural pollution. In addition, the notions of depollution are also presented.

1.7 Physical and chemical water properties

Objectives

At the end of this training, learners will be able to:

a) Explain the importance of water through its physico-chemical parameters;
b) identify and characterize all the states of water; and
c) Analyse different water reservoirs and the exchanges between them.

Activity 1 (Brainstorming) (20 minutes)

- What are the characteristics of water?
- Describe the different states of water List the major water tanks in your community?

1.7.1 Surface water

Surface water is composed, in opposition to groundwater, of all common or stagnant, fresh, brackish or salty water bodies that are in direct contact with the atmosphere). Therefore, surface water is water that is on or near the surface of the soil. These are mainly rivers, oceans, seas, lakes and runoff (Bordet, 2007). Its temperature varies according to the climate and seasons. Its suspended matters are variable according to the rainfall and the nature and relief of the land in its vicinity. Its composition in mineral salts varies according to the terrain, rainfall and discharges; it retains little nitrates (Bordet, 2007). A surface water is usually rich in oxygen and low in CO_2.

Sooner or later, eventually after contributing to the physiological life of the flora or fauna, the surface water evaporates or joins the slow course of groundwater. Wetlands contain a relatively constant amount of surface water, which in turn contributes to the biodiversity interest of the area in the form of open water, soil moisture or water imbibing the base of the plant formations that reproduce there.

1.7.2 Water properties

A formidable solvent

Water is the most important natural solvent on the surface of the Earth. Water is able to dissolve almost any substrate, to the point where it can be asserted that pure water does not exist since the bottle which could contain it, without being dissolved a bit by it, is yet to be invented.

Rainwater, which is essentially derived from the evaporation of seawater (and therefore freshwater), is loaded with minerals into the atmosphere. Its total dissolved salt content is close to 7 g/m^3. When the rains flow or seep into the subsoil, their waters take on all the minerals or organic matter they encounter, including polluting or toxic substances. Thus, on average, river water has a dissolved salt load of about 120 g/m^3.

It is these waters that are responsible for the salinity of seawater, which is about 35,000 g/m^3, nearly 300 times more than fresh water. All these minerals and dissolved organic substances are essential nutrients or trace elements for photosynthetic organisms (algae, plants, phytoplankton, cyanobacteria, etc.) for their primary production.

High specific heat

Water is the natural element (except ammonia NH_4^+) whose specific heat is the highest on Earth. Specific heat being the amount of energy that must be supplied to a given mass of water to raise its temperature by 1°C. This means that water is difficult to heat, as difficult as is it to be cooled. It can be said that, apart from the most superficial strata, the world ocean is essentially a cold hydrosystem. On the other hand, important continental bodies of water play an important role in the establishment of local climates.

High latent heat of fusion and vaporization

The latent heats of fusion and vaporization represent the amounts of heat that must be supplied either to melt ice or to produce water vapour. The necessary energy is taken from the substrate, that is to say that if the majority of the atmospheric water vapor comes from the ocean, it is constantly cooled by this vaporization mechanism.

These two characteristics explain in large part why hydrosystems, mainly oceanic but also continental, behave like formidable thermal buffers and why the temperature at the surface of the Earth varies in reduced proportions.

Significant variations in density

Water has a maximum density at a temperature close to +4°C. This means that the waters of the ocean floor are at a temperature of +4°C. This is true everywhere, except in the glacial oceans since their waters do not reach this temperature. It is also the temperature of the waters at the bottom of the lakes located in cold temperate regions.

When superficial waters are cooled to the temperature of +4°C, they become heavier than the water which supports them and will therefore flow towards the bottoms. This phenomenon is very important, especially for inland waters, since it ensures the mixing of water, a mixture that occurs once or twice a year (monomictic lakes or dimic lakes).

Ice, because it floats, plays a fundamental role in preventing the penetration of cold into the deep masses of waters subjected to extreme cold.

Water and its colours

Water appears colourless because it is transparent in the visible spectrum. Large bodies of water absorb infrared radiation over a few meters. This is the essential reason why only the most superficial layers of the water are heated. The same applies to atmospheric water vapour, which largely limits the penetration of infrared radiation. This is one of the reasons why temperature differences between winter and summer are more limited in regions under oceanic influence than in continental regions (far from the ocean).

The waters remain transparent to great depths for greens and blues radiations. This is one of the reasons why lakes or oceans, especially if their waters are clear, are green (shallower) or blue (deeper). The waters are transparent to photosynthesis-radiation only on a thickness that varies, on average, from 10 to 50 meters (euphotic zone).

A particularly stable molecule

The high dielectric constant of water explains why the substances that it dissolves easily are frequently found in the form of ions. The molecule of water is particularly stable for the reason that hydrogen atoms and oxygen atom bind together with one electron. In fact, the hydrogen atoms possess two electrons and that of oxygen has eight electrons on its peripheral layer. It is this saturation of the outer layer of the molecule which gives it its great stability.

Even if the outer electron layer remains saturated, electrons tend to migrate to oxygen (O^{2-}) leaving hydrogen (H^+). This potential electronic "availability" makes the molecule of water very refined for multiple substances which it can thus dissolve.

Moreover, the electronic imbalance has the effect of making possible links between the hydrogen atom of one molecule and the oxygen atom of another molecule (hydrogen bond). In fact, a molecule of water surrounds itself with four other molecules constituting a tetrahedron whose oxygen atoms occupy the summits.

This hydrogen bond, weak with respect to the covalent bond, is sufficiently so as at low temperatures the "crystalline" tetrahedron arrangement is permanent in the ice and is partially maintained in the liquid water. From 25°C to 30°C, hydrogen bonds lose much of their effectiveness until they no longer exist in hot or boiling water and naturally in steam. It is the existence of this hydrogen bond that explains why it is necessary to provide much energy to vaporize water; to do this, it is necessary first to break these so-called weak links.

The pH support

It happens that an oxygen atom of another molecule captures a hydrogen atom of a molecule of water. Two molecules of water will therefore give rise to an OH^- ion and another H_3O^+ (hydronium). In pure water, there are the same numbers of OH^- and H_3O^+ ions. But if a dissolved substance gives an excess of OH^- ions, the solution becomes basic; that other substance provides an excess of H_3O^+ ions, the solution becomes acidic.

The pH reflects the concentration of H_3O^+ ions in a solution: 0 to 7 acid; 7 neutral; 7 to 14 basic or alkaline.

1.7.3 Water states

Water can exist in the following states:

- **solid:** it is the ice state; the water molecules are perfectly organized so as to form something hard and solid;
- **liquid**: it is the water of the rivers, the ocean, the tap; the molecules of water are a little bit in every direction, but close to each other;
- **gaseous**: these are the clouds, the steam of the pressure cooker; the molecules of water are disordered and very spaced from each other.

The water can change state at any time, just that certain conditions must be fulfilled. Depending on the temperature, water can take different forms. For example, for water to change from liquid to solid state, the temperature must fall below 0°C (zero degrees Celsius). This phenomenon is reversible, i.e. if the temperature becomes higher than 0°C, the water becomes liquid again. But the transition from one state to another is not immediate: at 0°C there will be a little liquid water and a little solid water, until all the liquid water becomes solid.

The passages from one state to another bear names:

- **condensation**: it is the transition from the gaseous to the liquid state; there is also solid condensation, which is the passage from the gas to solid state, without going through the liquid phase;
- **evaporation**: it is the transition from the liquid state to the gaseous state;
- **fusion**: it is the transition from solid to liquid state;
- **sublimation**: it is the passage directly from the solid state to the gaseous state; this occurs under certain pressure conditions; and,
- **solidification**: it is the passage from the liquid to solid state.

1.7.4 Global water resources

Almost all the water on the planet is permanently salted or frozen. The water that is accessible and necessary for human life, i.e. soft and liquid, represents only 0.0103% of the total reserves of the blue planet.

Water tanks on Earth

Rainfall water has variable trends: over one year and across the globe - 11% infiltrate, 24% trickle down, and 65% evaporate. Water is present in four large reservoirs:

- the hydrosphere with:
- on the one hand the seas and the oceans; and,
- on the other hand, the continental waters, either superficial or subterranean;
- the atmosphere; and,
- the biosphere.

The only quantities of water that can now be estimated are those contained in the four major reservoirs of the hydrosphere, namely seas and oceans, continental waters (surface and underground), atmosphere and the biosphere. The most difficult volumes to evaluate are those of the groundwater of the Earth's crust, whose estimates vary, depending on different authors, according to the thickness of crust they consider.

Water also exists in the Earth's mantle: it is assimilated to that of the basalts of MORB (oceanic ridges) or 3,000 ppm. The water is therefore distributed between fresh water and salt water. Salt water is by far the majority: it represents 97% of the volume of water on the blue planet. Water is defined as fresh if its dissolved mineral content is less than 1 mg/l. Glaciers and groundwater account for 99.9% of fresh water.

Overall, the total amount of water in the hydrosphere remains constant. The volume of ocean waters has changed very little over a billion years. Any loss of water by one or the other of the reservoirs is compensated by a gain of water by another reservoir.

Table 2. Global water reservoirs in km³

Tanks	Water stocks (km³)
Oceans	1 350 000 000
Continental waters	35 976 700
Ice	27 500 000
Ground water	8 200 000
Inland seas	105 000
Freshwater Lakes	100 000
Soil humidity	70 000
Rivers	1 700
Atmosphere (air humidity)	13 000
Biosphere (living cells)	1 100

Flow between water tanks

Evaporation is a gradual transition from the liquid state to the gaseous state. This phenomenon is therefore a progressive vaporization which has the effect of absorbing calories and therefore reducing the temperature of the environment. When there is a free volume above a liquid, a fraction of the molecules composing the liquid is in gaseous form. At equilibrium, the amount of gaseous material defines the saturated vapour pressure in the case of a pure liquid (solvent), which depends on temperature. This pressure may be partial or total. When the partial pressure of the vapour in the gas is less than the saturated vapour pressure and the latter is itself less than the total ambient pressure, some of the molecules pass from the liquid phase to the gaseous phase: that is evaporation, which requires supplying the corresponding latent heat, which cools the liquid.

Evapotranspiration (ET) is the amount of water transferred to the atmosphere through evaporation at the soil level and through the transpiration of plants. It is the transfer to the atmosphere of water from the ground, intercepted water (Aussenac and Boulangeat, 1980) by the canopy and bodies of water. Transpiration is defined by the transfer of water in the plant and the loss of water vapour in the stomata of its leaves. A change in vegetation may result in changes in evapotranspiration (mean or maximum) (Zhang et al., 2001; Yang et al., 2015; Ying et al., 2018) and significant changes in the water cycle and soil or ceiling congestion (Bosch and Hewlett, 1982; Lixin et al., 2018), but in dense vegetation (forest, megaphorbiae), some water will return to the ecosystem as dew. It modifies or explains certain microclimates and has effects on climate at biogeographic scale (Shukla and Mintz, 1982; Zeng et al., 2018). It is a “magnitude” that also concerns the practice of hydrology (Morton, 1983; Lei et al., 2017).

The concept of evapotranspiration and its measurements appeared in the 1950s (Thornwaite and Mather, 1957). It is important to explain and quantify water transfers in ecosystems, to calculate the water requirements of forests, agricultural crops and more generally for the management of water in natural or semi-natural vegetation areas, or to estimate the importance of urban heat bubbles.

Precipitation refers to all meteors that fall into an atmosphere and may be solids or liquids depending on the composition and temperature of the atmosphere. This meteorological term is always in the plural and refers to hydrometeors (ice crystals or water droplets) on Earth, which, having been subjected to condensation and aggregation processes within clouds, have become too heavy to remain suspended in the atmosphere and fall to the ground or evaporate in virga before reaching it. By extension, the term can also be used for similar phenomena on other planets or moons having an atmosphere.

Runoff refers in hydrology to the phenomenon of flow of water on the surface of the soil. It opposes the phenomenon of infiltration. This phenomenon occurs when the intensity of precipitation exceeds infiltration and retention capacity of the soil surface. Diffuse or water-leakage runoff is a surface wash (sheet wash) or in divagre nets which, by means of rainfall erosion ("splash effect", splashing of drops of water) and lateral erosion, exports fine particles and highlights the pebbles. Runoff is conditioned by the importance of water erosion, which depends on several factors: rain erosivity, infiltrability, soil erosion and erosion, slope of the ground, land cover (vegetation cover, cultivation practices).

Infiltration refers in hydrology and Earth sciences, to the process by which water penetrates the soil or other substrates from the surface of the soil or substrate. If the precipitation rate exceeds the infiltration rate (and evaporation and evapotranspiration), a runoff phenomenon usually occurs, unless there is a physical barrier which will form a water reservoir (natural or artificial), which can, if its bottom is not impermeable, play a buffer role by feeding more permanently the phenomenon of infiltration (and therefore the supply of the water table and the sources that it produces if necessary). The infiltration is related to the hydraulic conductivity at saturation of the soil near the surface.

1.7.5 Acid rain, aerosols, energy discharges

Acid rain

Known since the mid-nineteenth century, acid pollution is the result of a set of mechanisms that cause the transfer of acidic or acidifying substances at the air-soil-vegetation interface. It is generated by pollutants (mainly sulphur, nitrogen and ammonia), which originate mainly from anthropogenic emissions such as the burning of fossil fuels. In the absence of pollution, rainwater is slightly acidic with a pH close to 5.6 on average. This acidity is the result of the dissolution of CO_2 from the air as well as the presence of sulphuric acid and nitric acid. Several chemical reactions are at the origin of the formation of sulphuric acid in the atmosphere:

- in the atmosphere, sulphur dioxide (SO_2), for example from volcanic emissions, gives rise to sulphurous acid (H_2SO_3) in contact with water vapour. The unstable sulphurous acid converts to sulphuric acid (H_2SO_4). Currently, a large amount of sulphur dioxide originates from human activities;

- SO_2 in the presence of the OH radical converts to sulphuric anhydride SO_3 which also gives sulphuric acid in contact with water; the combination of sulphur dioxide with nitrogen dioxide in the presence of water gives: $SO_2 + NO_2 + H_2O \rightarrow H_2SO_4 + NO$; and,
- above oceans, the photochemical oxidation of dimethyl sulphide is converted into sulphur dioxide and sulphates.

If sulphuric acid contributes more than two-thirds to the acidification of precipitation, nitric acid HNO_3 formed by the oxidation of nitrogen oxides from industrial combustion also plays a role.

Aerosols

An aerosol is a suspension of fine solid particles or liquid droplets, in air or another gas. Aerosols can be natural or anthropogenic. The term aerosols covers a wide spectrum of small particles, like sea salt particles, mineral dust, pollen, drops of sulphuric acid and many others. Aerosols have a great impact on several atmospheric phenomena, Earth's climate and on the biosphere. During their atmospheric residence, different size solid and liquid particles influence the radiation and energy budget of the Earth's surface, the hydrological cycle, atmospheric circulation and the abundance of trace gases. Aerosol particles can be characterized by their concentration, size distribution, structure and chemical composition, which are highly variable both temporally and spatially.

Examples of natural aerosols are fog, dust, forest exudates and geyser steam. Examples of anthropogenic aerosols are haze, particulate air pollutants and smoke. The liquid or solid particles have a diameter, mostly smaller than 1 µm or so; larger particles with a significant settling speed make the mixture a suspension, but the distinction is not clear-cut. In general conversation, aerosol usually refers to an aerosol spray that delivers a consumer product from a can or similar container. Other technological applications of aerosols include dispersal of pesticides, medical treatment of respiratory illnesses, and convincing technology. Diseases can also spread by means of small droplets in the breath, also called aerosols (or sometimes bioaerosols).

Emissions of greenhouse gases are not the only human activities that change the climate. We must add the emission of dust and aerosols (which are small solid or liquid particles suspended in the atmosphere) from industrial activity (release of sulphur-containing molecules), from traffic, forest fires or soil erosion. Among the sulphur compounds present as trace elements in the free atmosphere, sulphur dioxide (SO_2) and sulphur dimethyl (DMS) play an essential role in the dynamics of the radiative balance of the Earth because they undergo the complex physicochemical transformations whose final products are submicron aerosols.

One of the manifestations of aerosols made up of small particles is to cool the terrestrial system either by reflecting directly the solar radiation entering the atmosphere (albedo effect) or by increasing the number of condensation nuclei in the clouds so they reflect more the solar radiation. These direct and indirect effects can be a factor of cooling of the Earth's surface which acts in opposition to the greenhouse effect. By helping to reduce the Earth surface temperature, aerosols also limit photosynthesis, respiration and methanogenesis. These sulphur molecules also contribute to acidify the rains and, when injected into the stratosphere, catalyze the destruction of ozone over the poles.

Aerosols are in principle precipitated by the rain after a few weeks and do not accumulate in the atmosphere.

Sources of aerosols particles

Aerosols originate from a wide variety of natural and anthropogenic sources. Various aerosol particles are generated through a combination of physical, chemical and biological processes. Based on the formation processes, different source types can be distinguished. Primary particles emitted directly to the atmosphere as liquids or solids, through a wide range of processes (Bulk-to-Particle Conversion, BPC). Some particles formed by nucleation and condensation of precursor gases (Gas-To-Particle Conversation, GPC), and others from the reactions of dissolved substance in cloud droplets. During Bulk-to-Particle Conversion, many different aerosol particles are generated from solid or liquid base materials. Oceans and dry continental regions are the two main natural sources of atmospheric aerosol. A large amount of water droplets and sea salts are released to the atmosphere through sea spray and air bubbles at the surface of the seas.

As a water droplet evaporates, the salt is left suspended into the atmosphere forming a maritime aerosol particle (e.g. sodium-chloride (NaCl), magnesium sulphate (MgSO4)). Another major source of primary particles is the windblown mineral dust from dry continental areas, like deserts and semi arid regions. Further natural sources are volcanic ash, clay particles from soil erosion and biological materials (plant debris, pollen etc.). Additionally, different particles are formed by anthropogenic activities, like biomass burning, combustion of fossil fuel or industrial activities.

Aerosol particles originated during Gas-To-Particle Conversion (e.g., sulphates, secondary organics) are not directly emitted, but are formed in the atmosphere from gaseous precursors. Two basic processes can cause the formation of these secondary particles: an existing particle may grow through material condensing from gas phase, or new particle may forms through homogeneous nucleation.

Some other particles can form or transform by cloud droplets. When a cloud condensation nucleus as an aerosol particle dissolves in the water, and then reacts with other substances, it can build new aerosol substance and form a new aerosol particle when the water evaporates.

Sink processes

Aerosols can be removed from the atmosphere by different ways in the function of their size and disposition. Two main types of removing processes of aerosol particles are wet and dry deposition (see e.g. Sportisse, 2007; Petroff et al., 2008). In an annual global mean, about 80–90% of aerosol particles are removed from the atmosphere by in-cloud and below-cloud scavenging (wet deposition). Remaining parts of particles are removed by different ways of dry deposition, viz.:

Wet deposition processes (the main sink of atmospheric aerosol particles): Rain-out and washout: a part of cloud droplets form precipitation which reaches Earth's surface removing aerosols from cloud and from the column of air below the cloud.

Cloud deposition: deposition form of aerosols in high elevation ecosystems due to inter-ception of cloud droplets by vegetation.

Dry deposition processes (less important on a global scale):

- Turbulent diffusion: for larger particles (with a diameter larger than 1 µm) eddy diffusivity becomes important.
- Gravitational settling (sedimentation): larger particles are influenced more by gravity and fall back to the surface. This process becomes increasingly important for particle sizes above 1 µm.
- Impaction: if a particle cannot follow the flow streamline around an obstacle (e.g. a larger particle), small particle can hit this obstacle.
- Interception: if an object is not directly in the path of particle moving in the gas stream (as in case of impaction), but particle approaches the edge of the obstacles, it may be collected by the obstacle.
- Brownian diffusion: randomly moving smaller particles bump each other (thermal coagulation) or to larger obstacles. This process dominates for particle sizes below 0.2 µm. Brownian diffusion coefficients increase as particle diameter decreases. Additionally, in a very thin (about 1 mm) layer over the surface, the Brownian diffusion becomes more important for larger particles too.

Summary

The session covered water in all its various forms, characteristics and different states. The various reservoirs of the water are presented as well as questions relating to precipitation, runoff and infiltration. Current environmental problems were also addressed through acid rain and aerosols.

1.8 Weather phenomena

Objectives

At the end of this training, the learners will be able to:

a) Interpret meteorological data and events;

b) Describe the phenomena at the base of cloud formation; and,

c) Explain the importance of weather phenomena in climate processes.

Activity 1 (Brainstorming) (20 minutes)

- What is meteorology?
- List the main meteorological phenomena.
- Explain the formation of clouds above oceans and areas of altitude (such as mountains).

1.8.1 Cloud formation

A cloud is formed by a set of droplets of water or ice crystals suspended in the air. The appearance of the cloud depends on the light it receives and the particles that make it up. A cloud forms by condensation of water vapour when the moist air cools down. Cooling is caused either by contact with a colder surface, or - more often - depending on the process.

1.8.2 Convection

The heating of the ground transmits to the air, which dilated and therefore lighter, starts to rise and cools by relaxation. Convection clouds appear as easily as there is cold air at altitude (unstable air mass). The bases of such clouds are horizontal, their summits evolve according to the temperature. They are frequent on land during thre summer and on the sea during winter.

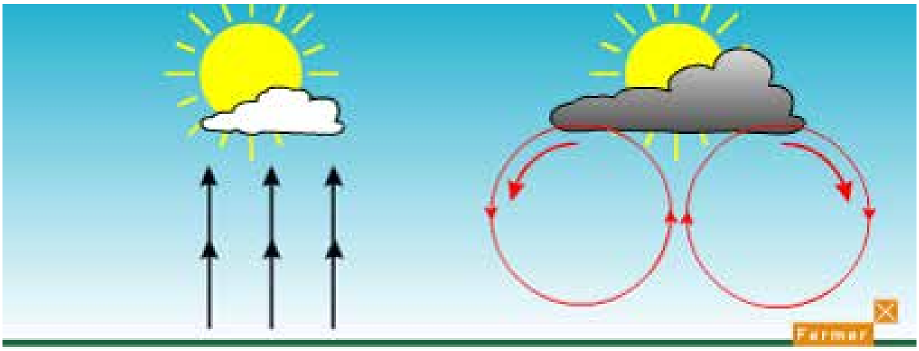

Figure 6. Convection phenomenon

http://eduscol.education.fr/obter/appliped/circula/theme/atmos32.htm

1.8.3 Orographic uplift

The ground relief forces the mass of air to rise on its face to the wind. As the mass of air rises, its temperature falls and can reach the saturation threshold. A cloud forms on the winward slope and dissipates on the leeward slope.

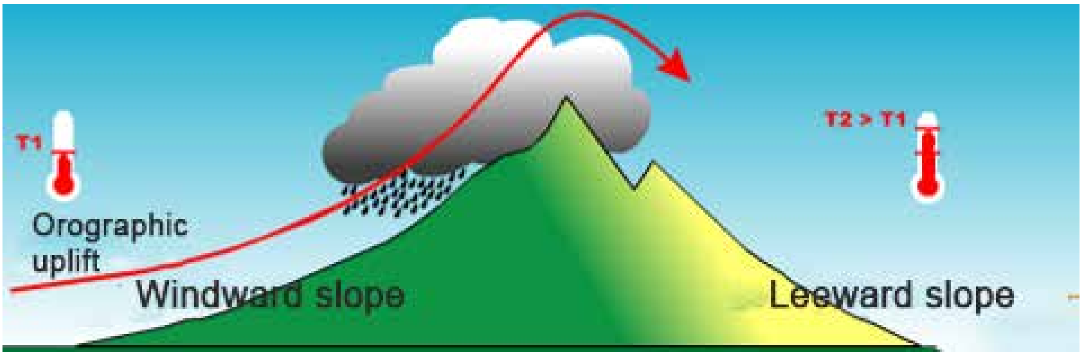

Figure 7. Orographic uplift phenomenon.

http://eduscol.education.fr/obter/appliped/circula/theme/atmos32.htm

1.8.4 Front elevation

In a perturbation in motion, the hot air is raised at the front by the mass of cold anterior air (hot front). The cold posterior air rejects hot air at high altitude (cold front). Clouds form along the foreheads.

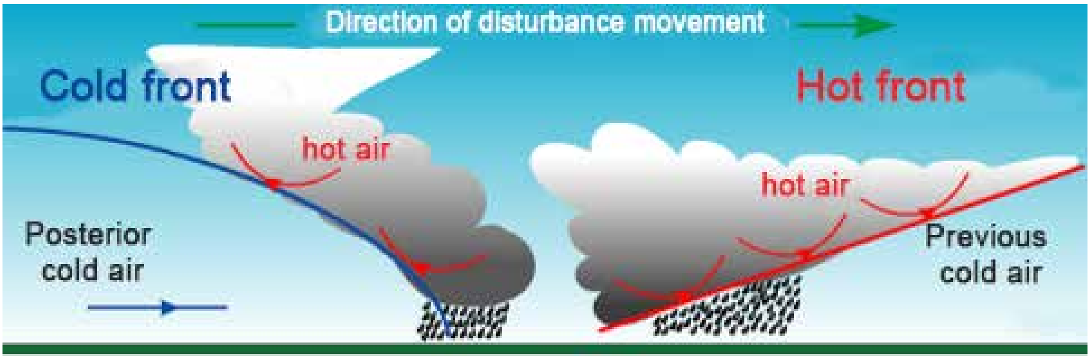

Figure 87. Front elevation phenomenon

http://eduscol.education.fr/obter/appliped/circula/theme/atmos32.htm, accessed on 7 August 2016.

1.8.5 Strong winds

The wind is created by differences in temperature and pressure. The pressure on the ground is high (H) if heavy and cold air goes down and low if hot and light air rises. The warm air (lighter) naturally rises in the upper layers of the atmosphere to create a zone of low pressure “L”. However, the hot air attracts to another mass of air: the zone of high pressure. It is from this difference in pressure between the two masses of air that the wind originates, simply because the air contained in the “H” naturally tends to rush into the “L” that adjoins it. The air that moves is the wind.

The great cause of this phenomenon is the sun. It heats the seas and the continents but not at the same rate. Once heated, they heat up the air masses that overhang them. The air then moves, as it increases in volume when heated. It becomes lighter and rises. An example on the Earth scale of this displacement of air masses is that the hot air rises from the equator and the colder air masses coming from the poles come to replace it (these are the trade winds).

Here are examples of winds in everyday life:
- opening a door creates a temperature difference, hence an air current; and
- dropping a feather above a heating radiator will cause it to rise.

The wind is a stream of air that can be represented as the big wheel of a fun fair: the warm and light air rises, the cold and heavy air descends. The movement of the air, like that of the great wheel, is circular. It is a perpetual motion: the air rises and falls, it warms and cools. Near the ground, the wind has a slight tendency to be diverted towards the low pressures. Thus, wind is a displacement of air represented by a direction (that from which the wind comes) and a velocity. The speed is commonly expressed in km/h, but the International System uses as unit the m/s and the sailors and pilots the nodes (1 node = 1,852 km/h). Wind measurement is always an average over a specified period of time.

In meteorology, we use:
- the average wind over 10 minutes measured at 10 meters in height; and,
- the gust (or instantaneous wind), an average of about 0.5 seconds.

The origins of violent winds include storms and thunderstorms.

Storms

At sea, a storm is an atmospheric depression which generates an average wind greater than 90 km/h. On land, a storm is when the depression generates gusts greater than 90 km/h. In France, for example, the diameter of storms is less than 1,000 km. Storms from the Atlantic move quickly, up to 100 km/h. At one point, their duration does not exceed a few hours.

Thunderstorms

They cause strong and short winds (a few minutes) over a restricted area (a few square kilometers). The cumulonimbus, clouds characteristic of the storm, animated by powerful vertical movements, create gusts of unpredictable direction.

In mountains, the passage of the wind on the summits can create violent gusts under the wind, downwards. Waterspouts and tornadoes are swirling phenomena linked to cumulonimbus, clouds of storms. The waterspout (a few tens of meters in diameter) is smaller than the tornado (a few hundred meters). Their lifetime does not exceed one hour, but several phenomena can follow one another.

In marine weather, the meteorological services broadcast strong wind warnings at 50 km/h (force 7 Beaufort) in areas near the coast (up to 35 km offshore). Beyond this coastal strip, strong wind warnings are broadcast from 62 km/h (force 8 Beaufort, gale warning).

In tropical regions, strong winds are generated by cyclonic phenomena.

1.8.6 Some concepts in Meteorology

Climate change corresponds to a lasting change (from the decade to million years) of the statistical parameters (mean parameters, variability) of the global climate of the Earth or its various regional climates. These changes may be due to processes intrinsic to the Earth, external forces or human activities.

In the recent context of ecological policy, the term “climate change” refers only to changes in the current climate that have emerged throughout the 20th century and expected in the 21st century. In the work of the IPCC, the term “climate change” refers to any change over time, whether due to natural variability or human activities. In opposite, in the United Nations Framework Convention on Climate Change, the term refers only to changes due to human activities. The Framework Convention uses the term “climate variability” to refer to climate change of natural origin.

- **Climate:** climate in a narrow sense is usually defined as the average weather, or more rigorously, as the statistical description in terms of the mean and variability of relevant quantities over a period of time ranging from months to thousands or millions of years. The classical period is 30 years, as defined by the World Meteorological Organization (WMO). These quantities are most often surface variables like temperature, precipitation and wind. Climate in a wider sense is the state, including a statistical description, of the climate system.
- **Climate change** refers to a statistically significant variation in either the mean state of the climate or in its variability, persisting for an extended period (typically decades or longer). Climate change may be due to natural internal processes or external forces, or to persistent anthropogenic changes in the composition of the atmosphere or in land use.
- **Climatic variability**: climate variability refers to variations in the mean state and other statistics (such as standard deviations, the occurrence of extremes, etc.) of the climate on all temporal and spatial scales beyond that of individual weather events. Variability may be due to natural internal processes within the climate system (internal variability), or to variations in natural or anthropogenic external forcing (external variability).
- **Meteorology**: the weather in a given area at a given time.
- **Weather**: the state of the atmosphere at a particular place and time as regards heat, cloudiness, dryness, sunshine, wind, rain, etc.

Summary

All important atmospheric phenomena have been addressed in this session. This raises the question of the winds, the formation of clouds, extreme phenomena such as storms and thunderstorms. There is also a focus on climate variability and differences with climate change.

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Chapter 2: General Ecology

2.0 Chapter overview

The terrestrial globe is composed of several ecosystems of which the stability or evolution depends on several factors, both endogenous and exogenous. Within ecosystems, interactions between organisms and their environment can lead to environmental change. Similarly, the influence of external factors (e.g. atmospheric elements) can lead to irreversible changes in the ecosystem or in the interactions between components of the ecosystem. This chapter presents the concepts of ecology, biogeography and biodiversity.

Objectives

At the end of this chapter, the learners will be able to:

a) define ecology, its purpose and methods of study;

b) define the ecosystem, its composition, its structure, the organization of its components and its functioning.

c) identify factors and indicators of disturbance of ecosystems, methods of disturbance assessment;

d) describe the types of forest ecosystems, the state and evolution of ecosystems, the state and evolution of species;

e) define biodiversity, different levels of diversity, indicators for measuring biodiversity, methods for assessing biodiversity and the causes of biodiversity degradation;

f) define ecosystem services as well as different types; and,

g) define water stress, indicators of stress and responses, adaptation mechanisms to water deficit.

Expected final outcomes

At the end of this training, learners will be able to:

- distinguish the large terrestrial ecosystems and their evolution;
- explain the interactions between organisms and their environment;
- describe the role of forests in climate change; and,
- identify threats to species and ecosystems.

Content

This chapter is structured in two sessions of an average duration of 4 hours each. Details on these sessions and the required materials are described below.

Sessions	Time required	Approaches	Educational materials
Concepts of ecology and ecosystem functioning	4 hours	Iterative exchanges, ecosystem demonstration sessions, question and answer sessions, theoretical courses and field visits	Computers, video projector, field outfit
Concepts of biodiversity	4 hours	Theoretical courses, tutorials, iterative exchanges and market visits to understand the importance of biodiversity	Computers, video projector

2.1 Concepts of ecology and ecosystem functioning

Objectives

At the end of this training, learners will able to:

a) Describe the fundamentals of ecology;

b) Explain the characteristics of the ecosystem;

c) Define the principles of ecosystem functioning; and,

d) Demonstrate the balance of an ecosystem.

Activity 1 (Group work) (20 minutes)

Divide the class into four groups:

- the first group will define the ecosystem, give its components, structure and functioning;
- the second group will cite the types of forest ecosystems, their evolution, factors and indicators of their disturbance and methods of their evaluation;
- the third group will define ecosystem services, and provide different types of ecosystem services; and,
- the fourth group will define the biodiversity, give the causes of its degradation and the methods of its assessment.

2.1.1 Definition of ecology

There are several definitions of ecology. The most widespread is "study of the interactions between living organisms and their environment, and living organisms between them under natural conditions". One can also say that ecology is the study of interactions that determine the distribution and abundance of organisms, or the study of ecosystems. Ecology thus appears as the science of habitat, studying the conditions of living organisms and all kinds of interactions that exist between them and their environment. It involves understanding the mechanisms that allow different species to survive and coexist by sharing or competing for available resources (space, time, energy, matter).

2.1.2 History of ecology

To better understand ecology, we can look at the historical evolution of this discipline (Frontier and Pichod-Viale, 1993).

- Firstly, it was concerned with individual species when trying to define the responses of a species to environmental factors (soil and climate, for example). Today this subject is called **autecology**. It was originally intended to explain the distribution of species at various scales (planetary range, distribution due to soil, climate, altitude, distribution at the scale of a station). Autecology has rapidly stumbled over an obstacle: the distribution of a species is not only due to abiotic factors but also to other species with which it cohabits. Species can indeed interact (predator-prey relationships, competition, symbiosis). For example, the growth of certain tree species is facilitated by mycorrhizae (symbiotic fungi).

- Following the limitations of autecology, we have been interested in an ecology of the interactions between species that we call **synecology**.

- Finally, it has been observed that living organisms modify the surrounding environment, which creates new (indirect) interactions between species. For example, a forest stand creates a microclimate, a forest environment that allows certain plants to settle (typical forest flora) and certain animals to live (birds, for example). This last observation leads to a complex system of interactions between species and between species and their environment. This gives the notion of **ecosystem**.

2.1.3 Object and methods of ecology

Ecological studies focus conventionally on three levels: the individual, the population and the community.

An **individual** is a specimen of a given species.

A **population** is a group of individuals of the same species occupying a particular territory at a given period.

Figure 9. Population of *Terminalia macroptera.* (Credit: A. Thiombiano)

A **community** or **biocoenosis** is a set of populations in a same environment, animal (zoocenosis) and plant (phytocenosis) populations living in the same environmental conditions and in the vicinity of each other.

Figure 10. View of phytocenosis in a savannah formation. (credit A. Thiombiano)

Each of these three levels is the subject of a division of ecology:

- the individual concerns **autoecology**: it is the science that studies the relationships between a single species and its environment; It defines the tolerance limits and preferences of the species with respect to various ecological factors and examines the action of the environment on morphology, physiology and ethology;

- population concerns **population ecology** or **population dynamics**: it is the science that studies the qualitative and quantitative characteristics of populations; it analyzes the variations in abundance of various species in order to investigate the causes and, if possible, to foresee them;
- biocenosis is about **synecology**: it is the science that analyzes the relationships between individuals belonging to various species of the same group and of these with their environments.

Ecology is a transversal science that draws its methods of investigation and its contents from several disciplines such as biology, physics, statistics, climatology, hydrology, oceanography, chemistry, geology, pedology, physiology, genetics, ethology, etc. This makes ecology, a multidisciplinary science.

2.1.4 Composition, structure and functioning of ecosystems

Definition of concepts: ecosystem, biodiversity, biome, biocenosis

The **ecosystem** is a functional system formed by a biocenosis integrated into its abiotic environment, which consists of **edaphotope** (all edaphic parameters: physical and chemical properties of the soil) and **climatope** (all climatic parameters: light, rainfall, tempertaure).

It is a biological system formed by two inseparable elements, **biocenosis** and **biotope**. **Biocenosis** is the set of organisms that live together (zoocenosis, phytocenosis, microbiocenosis, mycocenosis).The **biotope (ecotope)** is the fragment of the biosphere that provides biocenosis with the required abiotic environment. It is also defined as the set of abiotic ecological factors (substrate, soil **“edaphotope”**, climate **“climatope”**) that characterizes the environment where a specific biocenosis lives.

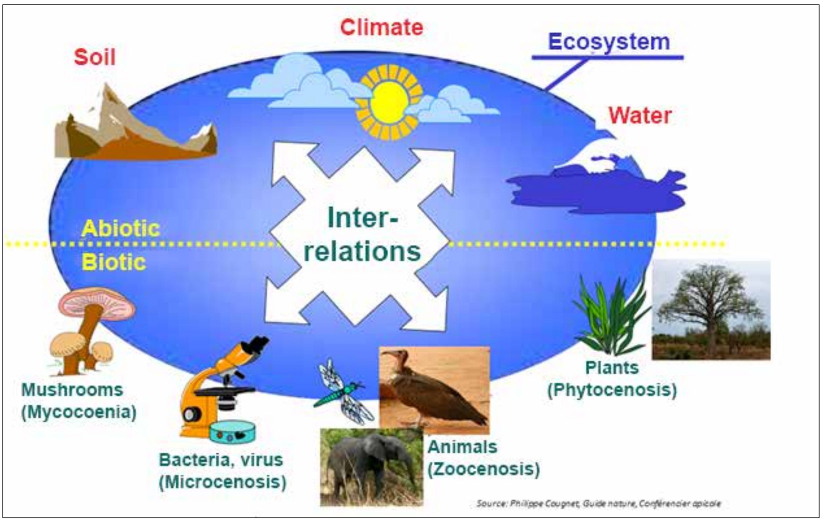
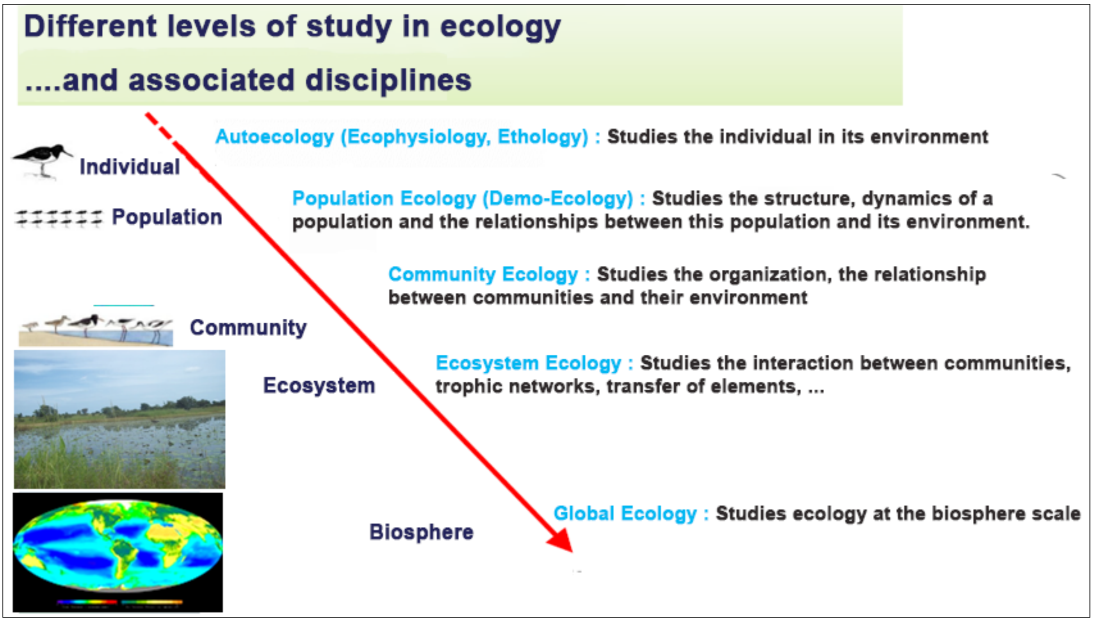


Figure 11. Symbiotic diagram of the ecosystem. Source: Philippe Cougnet.

Organization of an ecosystem components

The components of an ecosystem form a hierarchical whole.



Different levels of study in ecology

....and associated disciplines

Individual — Autoecology (Ecophysiology, Ethology) : Studies the individual in its environment

Population — Population Ecology (Demo-Ecology) : Studies the structure, dynamics of a population and the relationships between this population and its environment.

Community — Community Ecology : Studies the organization, the relationship between communities and their environment

Ecosystem — Ecosystem Ecology : Studies the interaction between communities, trophic networks, transfer of elements, ...

Biosphere — Global Ecology : Studies ecology at the biosphere scale

Figure 12. Level of organization of ecosystems.

Source: Frontier et al., 1993

2.1.5 Types of ecosystems

If one considers the biocenosis, three types of ecosystems can be distinguished:

- synusia: corresponds to the micro-ecosystem: temporary and independent biocenosis;
- the community: corresponds to the meso-ecosystem: it is a sustainable and autonomous biocenosis; and,
- the biome is the community of living organisms specific to a macro-ecosystem.

The notion of ecosystem is multi-scale, meaning that it can be applied to portions of variable dimensions of the biosphere; a lake, a meadow, or a dead tree. Depending on the scale of the ecosystem we have:

- a micro-ecosystem: e.g. a tree;
- a meso-ecosystem: e.g. a forest;
- a macro-ecosystem: e.g. a region.

The **biome** corresponds to vast assemblages with a certain homogeneity in plant and animal associations, such as tundra, steppes, boreal forests, Mediterranean forests, deserts, etc. The distribution of these biomes is under the close control of the macroclimate (temperature, humidity) so that they have a distribution in bands more or less parallel to the equator. There are 6 main types of terrestrial ecosystems (terrestrial biomes) including:

1) **tropical rainforests** - South America, Central Africa, Southeast Asia;
2) **deserts** - on either side of the equator on all continents;
3) **prairies** - North America, South America, Eurasia;
4) **temperate forests** - Northern Hemisphere;
5) **boreal forests** - Subarctic Zone of the Northern Hemisphere in America and Eurasia; and,
6) **the tundra** - Arctic and Antarctic poles.

Aquatic ecosystems (aquatic biomes)

The aquatic biomes occupy largest part of biosphere. The aquatic biome can be broken into:

Freshwater is defined as having a low salt concentration - usually less than 1%. Plants and animals in freshwater regions are adjusted to the low salt content and would not be able to survive in areas of high salt concentration (i.e. oceans). There are different types of freshwater regions: ponds and lakes, streams and rivers, and wetlands. The following sections describe the characteristics of these three freshwater zones. Two categories of freshwater biomes:

- **standing** (lentic) bodies of water : lakes, ponds,and wetlands
- **moving** (lotic)bodies of water; rivers and streams

Marine regions cover about three-fourths of the Earth's surface and include oceans, coral reefs and estuaries. Marine algae supply much of the world's oxygen supply and take in a huge amount of atmospheric carbon dioxide. The evaporation of the seawater provides rainwater for the land.

Mangrove forests are shrubs or small trees that grow in coastal saline or brackish water. The term is also used for tropical coastal vegetation consisting of such species. Mangroves occur worldwide in the tropics and subtropics, mainly between latitudes 25° N and 25° S. The total mangrove forest area of the world in 2000 was 137,800 square kilometres, spanning 118 countries and territories.

Freshwater swamp forests, or **flooded forests**, are forests which are inundated with fresh water, either permanently or seasonally. They normally occur along the lower reaches of rivers and around freshwater lakes and are found in a range of climate zones, from boreal through temperate and subtropical to tropical.

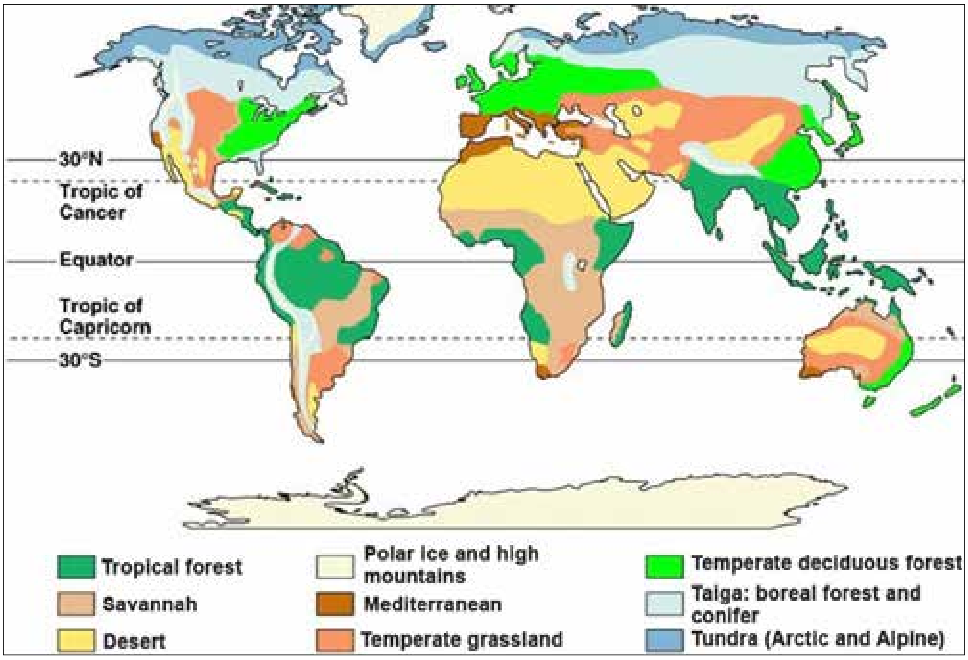


Figure 13. Main terrestrial biomes.
Source: Frontier et al. (1993).

2.1.6 Ecological factors

An **ecological factor** is any element of the environment capable of acting directly or indirectly on living organisms (animals or plants) at least during a part of their development cycle. Ecological factors are of two types: abiotic and biotic factors.

Abiotic factors

It is the set of physicochemical factors that exert an action on the living organisms of the environment. Abiotic factors include:

- climatic factors: temperature, rainfall, light, wind, etc.;
- soil factors: soil texture and structure, chemical composition; and,
- hydrological factors: characteristics of water.

There are several other abiotic factors that are equally important in terms of ecology such as relief (altitude), latitude, continental or maritime dimensions.

Biotic factors

Biotic factors are interactions between plants, between animals, between plants and animals and human action. These interactions are of two types, namely homotypic interactions and heterotypic interactions.

Homotypic or intraspecific interactions are interactions between individuals of the same species.

There are three types:

- **The group effect:** it refers to the morphological, physiological or behavioral changes that occur when several individuals of the same species live in a given space with sufficient food and other resources. Group effect occurs when changes occur in animals of the same species; generally the group effect is beneficial to individuals (fight against enemies, search for food, etc.); for several species, survival is conditioned by the number of individuals in the colony, known in ecology as the minimum population principle;
- **Mass effect:** it occurs when the environment is overcrowded and is generally harmful to individuals; and,
- **Intraspecific competition:** it consists of the same active search for the same resource in the environment. In this case, individuals act unfavorably on each other. Two types of competitions are observed: *active competition* when an individual by its behavior prohibits access to a coveted resource; a *passive competition* in which behavior does not intervene. The competition for the possession of the same resource is all the greater between two species that are neighboring from a genetic point of view. Ultimately, it is assumed that two species with exactly the same needs cannot cohabit, one of them being forced to disappear in the more or less long term. This rule is known as *the principle of competitive exclusion*.

Heterotypic or interspecific represents interactions between individuals of different species. We distinguish:

- **Neutralism:** in this case the species in question are independent, they have no influence on each other;
- **Amensalism:** an association between two species that is detrimental to one of the species but has no effect on the other. A common example of amensalism is the release of chemical toxins by plants that can inhibit the growth of other plant species (see allelopathy);
- **Mutualism:** it is an association between two individuals of different species in which the two partners benefit from the association. Two types of mutualism are distinguished: *cooperation* which is an optional association with mutual benefit between two individuals of different species; *symbiosis* which is an intimate, lasting and compulsory association between two individuals of different species in which everyone benefits from the presence of the other. The compulsory nature of the association derives from the fact that one or the other of the partners cannot live without the presence of the other;
- **Commensalism:** it is an optional and temporary association between two individuals of different species in which only one species takes advantage of the life in common without however harming the life of the one that does not profit from it;
- **Predation:** the predator can be defined as a free organism that seeks live animal or plant food. Predators can be polyphagous (attacking a large number of species), oligophagous (feeding on a few species), or monophagous (subsisting only on one species); and,
- **Parasitism:** it is a relationship in which the parasite benefits at the expense of the other called host.

2.1.7 Concept of ecological potential

The ecological potential of a forest species characterizes its degree of competitiveness compared to other mixed species. This potential is the result of a combination of internal (genetic) and external (station-forestry combination) factors, some of which are determining factors. If shade tolerance plays an essential role in expressing the degree of competitiveness of an essence, the more the essence in question will be located in its ecological optimum, the better this degree can be expressed.

2.1.8 Fundamental theories

The determination of trophic relationships in an ecosystem requires knowledge of the diets of the different species that inhabit it. There are different methods for this, which give very precise quantitative as well as qualitative results.

Trophic relationships can be presented in two different ways:

- through food chains that highlight the notion of transfer of matter from one link to the next: the food chain is defined as the dependencies of organisms that eat some before being eaten in turn by others; it is the circulation of organic matter or energy between the different levels, from the autotrophic producers to the final consumers; and,
- by trophic networks that highlight the complexity of the relationships that exist in environments.

A trophic network is the set of food chains in an ecosystem. The study of the networks shows that the same animal can occupy several different trophic levels in different chains of the same ecosystem.

2.1.9 Carrying capacity

It is the maximum size of populations that can be supported by an ecosystem without being adversely affected. Reports of species population sizes should take into account the relationship between trophic levels. Charge capacity is a particularly important measure for understanding the equilibrium of the ecosystem on rangelands and for setting hunting quotas. Its measurement is thus important to regulate the sizes according to the available food. When the charge capacity is exceeded, the environment undergoes reversible or non-reversible degradation depending on the stage, thus affecting the resilience of the ecosystem.

2.1.10 Concept of climax

In its original expression, climax is the ultimate term for the evolution of the vegetation of an ecosystem (the mature stage), after a succession of intermediate stages, in the absence of natural or anthropogenic disturbance . It is a so-called stage of equilibrium between the plant community and its environment, constituted by soil and climate, towards which in theory any terrestrial ecosystem tends. Climax refers to the state of dynamic equilibrium reached by spontaneous vegetation under the action of the natural abiotic and biotic environment, excluding direct or indirect human action.

2.2 Factors and indicators of ecosystem disturbance

Definitions of disturbance

The disturbance of an ecosystem consists of event (s) altering - in time and in space - the relationships between living organisms and their habitats (Wali, 1987).

The ecology of perturbations represents a complex field, difficult to synthesize and for which attempts to generalize seem to be a particularly delicate exercise (White and Jentsch 2001). The term “perturbation”, polysemic, vague and ambiguous (Rykiel 1985), conceals a great diversity of situations and points of view which do not spare the forest domain itself, and the concept of disturbance must be defined according to the ecological context and the objectives of the study. Perturbation refers to any discrete event in time and space causing a reduction in biomass or mortality of the fundamental entities of the system, such as trees in a forest stand. This definition of the perturbations corresponds to those of Huston (1994) and Grime (1979), as well as that of Pickett et al. (1989), widely used in disturbance studies.

A disturbance of the ecosystem is a rapid modification of one or more parameters leading to a break in the ecological balance. These variations can be:

- biological: significant intake or disappearance of organisms constituting biocenosis;
- physical: modification of abiotic factors such as pH, temperature; and,
- chemical: various pollution. At this level, the main disrupting factors are hydrocarbons, antibiotics, detergents, pesticides (organochlorines, organophosphates, carbamates), minerals, heavy metals, etc.

Deforestation is the phenomenon of regression of forest covers. It is the result of deforestation and clearing operations, linked to the extension of agricultural land, the exploitation of mineral resources in the subsoil, urbanization and even the excessive or anarchic exploitation of certain tree species. However, it is important to define what deforestation is. Deforestation is an anthropic or natural action that causes the permanent disappearance of a forest.

Deforestation causes the destruction of *habitats* of thousands of animal and plant species, often condemned to disappear, and it disrupts the balances and assemblages of species, often combined to the effects of agriculture, *roadkill* or urbanization. It is also a factor of ecosystem fragmentation that reduces forests´ *ecological resilience*.

Disturbance processes

Three main stages accompany the disturbance process: (i) occurrence of a disturbance agent (e.g. wind), (ii) effect on the system (e.g. windthrow, mortality) and (iii) response of the system (e.g. regeneration, growth). This distinction has the advantage of separating the cause from the effect, often confounded in disturbance studies (Rykiel, 1985; Collins et al., 1995).

Disturbance: a fundamental ecological factor

Disturbances are discrete events, often unpredictable, acting at all spatial scales and affecting the majority of terrestrial ecosystems (Pickett et al., 1999; White and Jentsch, 2001). Since the important synthesis of White in 1979, numerous articles or books attempt to identify and analyze the effects of disturbances on the structure and functioning of different ecological systems, particularly plant communities (Pickett et al., 1999; Laska, 2001; White and Jentsch, 2001; Frelich, 2002), while specifying the core notion of disturbance (Pickett et al., 1989; Laska, 2001). Due to their spread and distribution, forest ecosystems are affected by a wide variety of disturbances: fires, storms, hurricanes, cyclones, tornadoes, insect pests, ice storms, landslides, avalanches, torrential erosions (White and Jenstsch , 2001), with important consequences for biodiversity, nutrient cycles, the water cycle (Aber et al., 2000) and increased social and environmental vulnerability (Gillian, 2008).

Contribution of livestock to ecosystem disturbance

Based on a report by FAO, livestock is one of the main causes of major environmental problems: global warming, land degradation, atmosphere and water pollution and loss of biodiversity. Indeed, grazing and cattle are the main threats in terms of degradation, especially of the Sahelian ecosystems. Overgrazing is always a cause of degradation of biological resources and of soil exposure to various weather conditions, making them vulnerable to any form of erosion and consequently a significant decrease in the resilience of the associated ecosystems.

2.2.1 Methods of assessment of disturbances

Environmental Impact Assessment (EIA) is a “procedure for examining the beneficial and harmful consequences that a proposed development program or project will have on the environment and to ensure that these consequences are duly taken into account in the design of the project or program” (OECD, 1992a). The EIA as described in this book takes into account both biophysical and human impacts. It includes a range of specialized assessments on social impacts, economic impacts, health impacts and risk analysis.

The environmental assessment consists of a set of processes that take into account the environment in the planning of operations or the development of projects, programs, plans or policies. We define it as a systematic process of assessing and documenting the possibilities, capabilities and functions of resources, natural and human systems in order to facilitate planning for sustainable development and decision-making in general, and particularly to anticipate and manage the negative impacts and consequences of land use proportions.

EIA can be seen as an activity within a general framework of rationalization of human activities. This involves integrating it into the management and planning processes of the various administrations and authorities involved. Its action is also carried out by the “internalisation” of the cost of environmental damage. This means that environmental damage, including “social costs”, is taken into account in the usual project accounting, which is generally not the case.

The term “environmental impact assessment” contains three distinct terms that encompass fairly well its area of investigation. These three major concepts, evaluation, impact and environment, determine three sets, which, integrated into a whole, represent EIA.

The concept of “evaluation” refers to the more or less systematic study of a question or a problem, depending on the needs of the procedure in question and the concrete possibilities of examination. This study is usually a sum of specific studies on specific subjects. Moreover, since this is a planning exercise, the assessment in question is rather an estimate, viz an approximation of the anticipated changes. Given the multiple possible EIA procedures and the varying magnitude of the projects involved, as well as the different actors involved (internal and external), there are several types of evaluations, from the simplest to the most comprehensive. However, it is not an evaluation of the type of fundamental theoretical research on a "socially neutral" subject, but rather a prospective and operational practice on an issue confronting diverse points of view and multiple interests. Finally, more than just a study followed by the writing of a report, "evaluation" in the context of the EIA is actually a review process. This process also involves discussions, talks and negotiations. The EIA is, in short, part of the movement of environmental negotiation and the search for trade-off, even consensus to development,

EIA is usually conceived as having two objectives: "to assess the significance of the biophysical and social impacts of a project, to assess its appropriateness, taking into account its environmental benefits and impacts, and, if necessary, develop a solution of least impact for its realization" (Lacoste et al., 1988). More normatively, some believe that the two objectives of the EIA are: "to facilitate optimal and integrated decision-making" and to "achieve or support the fundamental objectives of environmental protection and sustainable development" (Sadler, 1996).

More systematically, therefore, the three objectives of the EIA are to:

- know the environmental consequences of the project being studied;
- reduce negative environmental impacts and optimize positive impacts; and,
- allow project approval by the actors involved.

2.2.2 State and change in forest ecosystems

The extension of the notion of health of ecosystems starts from the evidence of a dysfunction of many ecosystems under the effect of human activities. A healthy system is defined as a system capable of maintaining its organization and functional autonomy over time.

At the operational level, indicators of health status are provided in part by biotic, or physico-chemical indicators. But it is also necessary to take into account the aspirations of society that are linked to its system of values and representations. Thus, it is generally accepted that the term "ecosystem health" is used to describe the **desired state of an ecosystem**, generally defined by a group of stakeholders. One criterion may be, for example, to fish certain species of fish, or to observe certain species of birds. Perception may be different depending on the type of ecosystem and era, and the concept of health is therefore relative.

Canadians have developed the rather similar concept of *ecosystem integrity*. The biotic integrity of ecosystems can be defined as the capacity of an environment to house and maintain a balanced and adapted community of organisms with a specific composition, diversity and functional organization comparable to natural habitats of the region (or at least the least disturbed habitats). The concept of integrity, like the concept of health, calls for social values. In the face of disturbances, the ecosystem must retain the ability to react itself and progress to a final stage that is either normal or "good" for the ecosystem.

The notions of health or integrity bear ethical and moral meaning: there are states of ecosystems that are “normal” and others that are “abnormal”. For the latter, we refer to dysfunction.

2.2.3 State and species dynamics

The status of species in an area describes their indigenous status. The conservation status of a species is used as an indicator to assess the population status of a species at a given time and is therefore likely to evolve. Some species may be healthy when others are on the brink of extinction or extinct. There are varying levels of threat.

The IUCN Red List classifies threatened species into three categories, depending on the extent of their risk of extinction: “vulnerable”, “endangered” and “critically endangered”. A somewhat similar classification exists for domesticated breeds of agricultural interest.

In biology, **evolution** is the transformation of living species expressed through changes in their genetic traits over generations. These successive changes can result, from a single species, in the formation of new “daughter species”. The phenomenon of evolution is the source of biodiversity on Earth.

Invasive species: A species is said to be invasive when, naturally occurring and breeding in a non-native geographical area, it becomes an agent of disturbance and interferes with biological diversity. These “invasives” can disrupt natural environments and cause discomfort for human activities (water quality, irrigation, agriculture, fishing, etc.) or public health (allergies, toxicity, transmission of diseases, etc.).

Threatened species and types of threats: A species is declared threatened if it meets specific criteria (habitat loss, significant decline in population, genetic erosion, hunting or overly intensive fishing, etc.). These criteria, generally established or validated by the International Union for Conservation of Nature (IUCN), enable us to refine the risk of extinction of the species (current, short and medium term) and to grant it a conservation status and sometimes protection (protected species).

Endemic species: Endemism characterizes the natural presence of a biological group exclusively within a defined geographical area. This concept, used in biogeography, can be applied to species as well as to other taxa and can concern all kinds of living organisms: animals, plants or others. An endemic species is a species (animal or plant) present naturally in a given territory, even if it has been planted or dispersed throughout the world. Some known endemic species are: the lemur, endemic to Madagascar; the cypress, endemic to California; and, the koala, endemic to Australia.

These different species are so biologically and ecologically important to the planet that any change in the environment (including climate) can cause their extinction.

2.2.4 Biogeography

Biomes are terrestrial or aquatic ecosystems characteristic of large biogeographic areas that are subject to a particular climate.

Biomes can be divided into three categories: ***terrestrial biomes*** (tropical forest, savanna, desert, Mediterranean forest, temperate grassland, temperate deciduous forest, taiga, tundra); ***freshwater biomes*** (ponds and lakes, watercourses); and, ***marine biomes*** (estuaries, intertidal zones, coral reefs, pelagic oceanic biome, benthos).

The distribution of biomes in the world results from the interaction of different **abiotic factors:** ***temperature*** (it affects biological processes, and most organisms are unable to precisely regulate their body temperature), ***water*** (freshwater and marine organisms are prone to water imbalance if the concentration of intracellular solutes does not match that of solutes in the surrounding water), ***light*** (it provides the energy that drives almost all ecosystems), ***wind*** (it increases loss of heat due to vaporization and convection and loss of water due to vaporization in animals and transpiration in plants, and has an effect on the shape of plants), ***rocks and soil*** (physical structure, pH and mineral composition that limit the distribution of plants and herbivores), and ***periodic disturbances*** (fires, hurricanes, tornadoes, volcanic eruptions, etc). When they are very rare and unpredictable in time and space, organisms cannot adapt. On the other hand, many plants have adapted to fires occurring frequently in some communities).

2.2.4 Phytogeography

Phytogeography (from the Greek *phuton*, plant, *ge*, Earth, and *graphein*, to write), or *botanical geography* or *geobotany* is a science at the crossroads of botany and geography, which studies the distribution of plants on the surface of the globe and the causes of this distribution as well as the relationships existing between plant species or communities on one hand, and the geographical, mesological (climate, soil) and biological (all living organisms) characteristics on the other hand.

Summary

This session has presented ecology clarifying its concepts and foundations through the ecosystem. Thus, the ecosystem is approached through its characteristics, organization and functioning. Disturbance factors are presented as well as their impact on the dynamics of ecosystems and species have also been covered in this session.

2.3 Biodiversity concepts

Objectives

At the end of this training, learners will be able to:

a) highlight the key concepts of biodiversity;
b) Describe the evaluation methods;
c) Explain the current dynamics; and,
d) assess the importance of biodiversity.

Activity 1 (Brainstorming) (20 minutes)

- How do you define ecology?
- How do you define the ecosystem?
- Are there multiple ecosystems? If so, what are the differences?
- How to recognize a balanced ecosystem?

2.3.1 Definition and concepts of biodiversity

The term biodiversity was formed by the contraction of the words biology and diversity. It refers to the diversity of living organisms (fauna, flora, bacteria, etc.) and the ecosystems present on Earth. The concept of biodiversity was enshrined at the Rio Conference in 1992, with the adoption of the ***Convention on Biological Diversity (CBD),*** where biodiversity is defined as: “The variability among living organisms from all sources including, i.a. terrestrial, marine and other aquatic ecosystems and the ecological complexes of which they are a part; this includes diversity within and between species and ecosystems” (Article 2).

Vandermeer and Perfecto (1995) in Altieri (1999) present biodiversity with a simple definition: *“Biodiversity refers to all living, interacting plants, animals and micro-organisms within an ecosystem”.*

These interactions, directly or indirectly, condition the functioning, stability and productivity of an ecosystem. Thus, biodiversity is not limited to a group of living organisms but it is also the source of many ecological, agronomic and heritage functions, ensuring the ecosystem balance. The complexity of the phenomena that govern biodiversity makes its measurement tricky.

The International Convention on Biological Diversity adds that biodiversity *“comprises three distinct levels: the gene, the species and the ecosystem”.*

The complexity of the definition of biodiversity lies specifically in the perimeters of the concept: genetic diversity within a species, diversity of species, functional or ecosystemic diversity of the relationships between the aforementioned diversity and ecosystems.

Biodiversity is usually subdivided into three levels: genetic diversity, specific diversity and ecosystem diversity:

Genetic diversity is the diversity of genes within a species. Population geneticists and quantitative geneticists use different parameters to estimate genetic variability within a population.

To avoid confusion of vocabulary, the polymorphism of molecular markers will be called genetic diversity as opposed to that of phenotypic characters called genetic variability. The first notion essentially relies on the study of the distributions of allelic frequencies while the second one relies on the components of the genetic variance of quantitative characters.

The specific diversity corresponds to the diversity of species. The concept of specific diversity thus takes into consideration the relative abundance of species in addition to their number. Specific diversity also takes account of taxonomic diversity. Species diversity is often assimilated to the number of species. Beyond the number, it is mainly the heterogeneity between species that is appreciated.

Ecosystem diversity refers to the variety and temporal variability of habitats. It is generally considered that the species richness depends on the diversity of habitats and the number of potentially usable ecological niches. Ecosystems, due to their biological diversity, play a global role in the regulation of geochemical cycles (fixation, storage, transfer, recycling of nutrients, etc.) and of the water cycle.

Biological diversity in the ecological sense is therefore a system of interactions within and between the organizational levels of the living world, as well as with the physico-chemical environment.

2.3.2 Biodiversity assessment

Opinions differ on how to measure biodiversity. There are no universal measures and those that are used really depend on the objectives pursued. At the theoretical level, all aspects of biodiversity should be assessed in a given system. But this is a practically unachievable task and one has to settle for an approximate estimate by referring to indicators that may concern genetics, species or stands, habitat structure, or any combination that provides a relative but relevant assessment of biological diversity.

The species richness (number of species) that can be determined for all taxa present in an environment, or for subsets of taxa, is the most common unit of measurement, There is sometimes a tendency to misappropriate biodiversity and species richness. Of course, the higher the number of species, the more likely it is to include greater genetic, phylogenetic, morphological, biological and ecological diversity. For some groups that are well known taxonomically, the list of species is relatively weak to establish.

There are generally three types of diversity:

- **alpha diversity** is the species richness within a local ecosystem; Various indices are used to measure specific diversity:

SIMPSON probabilistic index:

$$D = \frac{\sum n(n-1)}{N(N-1)} \qquad \text{(equation 4)}$$

n = the total number of organisms of a particular species
N = the total number of organisms of all species

SHANNON index derived from the theory of information:

$H= -\sum_{i=1}^{S} p_i ln\ (p_i)$ (equation 5)

where pi is the proportion of characters belonging to the ith type of letter in the string of interest. In ecology, pi is often the proportion of individuals belonging to the ith species in the dataset of interest.

This index is also used with natural logarithms or with decimal logarithms. Its value varies from 0 (a single species) to log *S* (when all species have the same abundance). The values taken by these indices of diversity depend on both the specific richness *S* and the distribution of numbers among the various species.

- **Beta diversity** consists of comparing species diversity between ecosystems or along environmental gradients. It reflects the change in alpha diversity when moving from one ecosystem to another in a site;

  $\beta(Y)=\sum j=1Pwj\times\beta(yj)=1-\sum j=1Pwj\times EVE(yj)$

The weights w j (with $0 \leq$ w j ≤ 1) and $\sum Pj=1wj=1$ can be determined according to the users' requirements within the specific context of the analyses. If all species are considered equally important, like for presence and absence data, the weights can be uniformly set to 1/P. On the other hand, for species abundance data, a reasonable approach is to set the weights proportional to the total species abundances within the community composition table, such that w j = y j+/y++ where $y{+}{+}=\sum Pj=1\sum Nn=1yjn$ is the grand total of all species abundances in Y.

- **Gamma diversity** corresponds to species richness at regional or geographical level. It is the diversity of the entire landscape (regional species pool). Among these, alpha and gamma diversity are fairly straightforward. It's harder to grasp what beta diversity means, since it's usually used quite loosely. It's something of a bridge from the local (alpha) to the regional (gamma) scale.

2.3.3 Genetic erosion, speciation, endemism

Genetic erosion is the loss of genetic diversity between and within populations over time due to human intervention or environmental changes. According to FAO, the replacement of local varieties with improved or exotic varieties is a major cause of genetic erosion in the world.

Speciation is, in biology, the evolutionary process by which new living species appear. A species, in the sense of the biological concept of species, is defined as having a community of ancestry within which any individual interferes with others and gives fertile offspring.

Endemism refers to species or subspecies of animals and plants (or their populations) whose range is limited to a particular area. Endemism can be described throughout the entire range of the geographic scale: an organism may be endemic to a single mountain or lake, a mountain range or a watershed, an island, a country or even a continent. The term is often used at the species level, but it can also be applied to subspecies, genera, families and other taxonomic groups. In general, the longer a region has remained isolated from other similar regions, the higher its proportion of endemic species. Very old islands such as Madagascar and New Zealand have a very high rate of endemism.

2.3.4 Global indicators of biodiversity measurement

Measuring natural capital is particularly difficult. Indeed, who can or should judge its exploitation and overexploitation (i.e. the damage to regeneration capacities)? It is not easy to agree on the definition of *alert thresholds* or even measure the *resilience* of ecosystems or the degree of *reversibility* of damage.

Direct biodiversity indicators are constructed from *taxonomic data* directly measuring one or more components of biodiversity: genetic diversity, species abundance, number of species in a particular group, etc. They may reflect the state of biodiversity at a given time or the dynamics of its evolution over a given period of time. For example, birds are generally considered to be good direct indicators of the functionality of ecosystems and the state of conservation of habitats due to their high position in food chains and their speed of response to environmental changes. However, the scientific literature shows that in a given environment, the diversity of *a taxon* is not generally strongly related to the diversity of other components of biodiversity.

Indirect indicators. In the case of forest biodiversity, they are generally based on the characteristics of forest stands with a more or less quantitative link with biodiversity (fragmentation of the landscape, diversity of tree species, etc.). Easier and less costly to inform, they are often available on larger scales and could potentially integrate the responses of broad components of biodiversity. Nevertheless, their field of validity as well as their robustness, reliability and accuracy are not well known.

Commonly used global indicators: Today the most widely used indicators are:

- **WWF Living Planet Index:** this indicator measures the status of 1,686 vertebrate species across 5,000 populations worldwide. It reflects the state of the planet's ecosystems. In the past 35 years the index has dropped by 30%.
- **IUCN Red List:** this list of species in danger of extinction is updated regularly. It exists at international, national or even regional level.
- **Ecological Footprint:** it measures humanity's demand for the biosphere in terms of "biologically productive land and sea surfaces" needed to provide the resources we use and absorb the waste we produce. It is calculated by country. On average, per capita demand in 2005 was 2.7 hectares.
- **Biocapacity:** It is calculated by country by multiplying the productive land and sea surfaces by their bioproduction, each country having an available supply. Productivity gains are often made at the cost of increased use of resources or increased waste produced. On average, at the global level, in 2005, each human had 2.1 hectares.
- **Water footprint:** This new indicator makes it possible to know, by country, the quantity of water needed for production activities and consumption. Many countries through the massive import of products outsource their water deficit.
- **Ecological space:** The concept of ecological space was proposed by the Friends of the Earth in 1995 in a report on solidarity Europe. The principle of equal access to resources implies for each type of resource the definition of a minimum threshold as well as a maximum consumption ceiling which takes into account the capacity for regeneration of renewable

resources and the stock of non-renewable resources. The amount of energy, water, land, non-renewable raw materials and wood that can be used in a sustainable way is called “ecological space”.

Indicators of forest biodiversity are the restriction of biodiversity indicators applied to the forest domain. A distinction will be made between ecological indicators that describe forest biodiversity from the point of view of forest ecology and socio-economic indicators that deal with the social and economic dimension of biodiversity.

Activity 2

Students should discuss:

- the impact of human population growth on forest ecosystems;
- the main causes of the dynamics of the ecosystem; and,
- the consequences of the degradation of biodiversity on the lives of local populations.

2.3.5 Status of biodiversity based on IUCN categories

There are different systems for assessing the conservation status of a species. The most common is that provided periodically by IUCN, which consists of nine categories:

- *Extinct* (EX): No known surviving individual;
- *Extinct in the Wild* (EW): Survivors known only in captivity, or outside original habitat;
- *Critically Endangered* (CR): extremely high risk of extinction in nature;
- *Endangered* (EN): high risk of extinction in nature;
- *Vulnerable* (VU): high risk of endangering;
- *Near Threatened* (NT): probability of being in danger in the near future;
- *Least Concern* (LC): does not meet the criteria for an endangered category; widespread and abundant animals are included in this category;
- *Data Deficient* (DD): not enough data to assess the risk of extinction; and,
- *Not Evaluated* (NE): has not yet been evaluated.

2.3.6 Biodiversity conservation

There are traditional modes of in situ and ex situ conservation of biological diversity. Indeed, in some localities of countries, agrarian landscapes are constituted of species with multiple uses, deliberately preserved during the successive clearing. These landscapes, which are formed by different parks, are the expression of a traditional method of in situ conservation of plant species and formations. At the institutional level, the establishment of many protected areas during the colonial period in African countries contributes to better conservation of biodiversity. Thresholds are set at the global level to encourage different states to protect fragile and rich ecosystems in biological resources. The signing of the various conventions, including the Convention on Biological Diversity, aims at engaging each State in a spirit of conservation and sustainable use of biodiversity. At the community level, different populations have identified species that they save and protect in agricultural areas through agroforestry.

2.3.7 Ecosystem services

By definition, ecosystem services are the benefits men derive from ecosystems. The importance of biodiversity is mainly found in ecosystem services. Biodiversity is indispensable to man because it intervenes in all areas of everyday life. The Millennium Ecosystem Assessment identified four categories: *support, procurement, regulation* and *cultural and social* services,

Table 3. Categories of ecosystem services

Regulation services	Supply services	Support services	Socio-cultural services
• Climate control • Reduction of diseases, pests and odors • Purification of water and air • Erosion and flood control • Pollination • Seed dispersal	• Food • Pure water • Combustible • Fiber • Ornamental species • Pets • Biochemical elements • Genetic resources	• Immune system development • Human development	• Spirituality • Recreation and tourism • Aesthetics • Education and Inspiration • Sense of belonging • Cultural heritage

(Adapted from the Millennium Ecosystem Assessment, 2005)

Support services

These are the ones that are needed for the production of all other ecosystem services. They are different from the other three categories of services because their effects on human beings are either indirect or occur over long periods of time. Thus, some services, such as erosion control, can be characterized as "support" or "regulation" depending on the time scale of the effects of its changes on human beings. For example, humans do not use ecosystem soil training services directly (support services), although changes in this service would indirectly affect human beings through the effect on food production.

Supply services

They enable humans to obtain marketable goods through exploitation of ecosystems, e.g.;

- *Food, fiber:* this category includes a broad category of food products derived from plants, animals, bacteria, as well as materials such as wood, jute, hemp, silk;
- *Fuel:* wood energy, peat, manure and other materials that serve as energy sources;

- *Genetic resources:* include genes and genetic information used for animal husbandry, plant cultivation and biotechnology;
- *Chemical substances:* many medicines, biocides, food additives such as alginates, and biological materials are derived from ecosystems;
- *Medicinal plants;*
- *Ornamental resources:* products such as skins and shells, flowers used as ornaments; the value of these resources is often determined by the cultural context of their use;
- *Construction materials* - wood, sand, etc.; and,
- *Huntable wildlife*.

Regulation services

These are benefits obtained from the regulation of ecosystem processes, such as:

- *Maintenance of air quality*: ecosystems bring chemicals and extract chemicals from the atmosphere, thus influencing air quality;
- *Climate regulation*: ecosystems influence climate both locally and globally; for example, on a local scale, changes in land use can influence both temperatures and precipitation patterns; on a global scale, ecosystems can play an important role in climate, either by sequestering or by emitting greenhouse gases;
- *The water cycle*: recurrence and importance of runoff, flooding and recharge of aquifers can be influenced by changes in land use, by alterations that can change the storage potential of water at ecosystem level; such alterations can be determined by the conversion of wetlands or forests into agricultural areas, or such areas into urban areas;
- *Erosion control:* vegetation cover plays an important role in soil retention and prevention of landslides;
- *Water purification and waste treatment:* ecosystems can bring impurities into the water but can also help filter and decompose organic waste introduced into wetlands, inland waters and marine ecosystems;
- *The regulation of human diseases:* changes in ecosystems can directly change the abundance of pathogens (e.g. cholera) and of disease vectors (e.g. mosquitoes);
- *Biological control:* changes in ecosystems may affect the prevalence of diseases and predators of crops and livestock;
- *Pollination:* changes in ecosystems may affect distribution, abundance and effectiveness of pollination; and,
- *Protection against storms and floods* - for example, the presence of forest ecosystems can reduce the intensity of winds and/or waters.

Socio-cultural services

These are non-material benefits obtained by humans from ecosystems through spiritual enrichment, cognitive development, reflection, creation, aesthetic experiences, including:

- *Employment*, as a result of management, restoration, protection etc. of ecosystems;
- *Educational values:* ecosystems and their components provide a basis for education in many societies;
- *A source of inspiration* - for art, folklore, national symbols, architecture and advertising;
- *Aesthetic values:* many people find beauty or aesthetic values in various aspects of ecosystems; this is reflected, for example, in visits to parks, "landscapes" and in the choice of locations to build houses;
- *Social relations*: ecosystems influence social relations; e.g. enjoying the aesthetic and recreational aspects of ecosystems (forests, parks, etc.) can contribute to strengthening social ties (e.g. between young people or between neighbors, etc.);
- *"Heritage" values*: many societies appreciate the maintenance of historically important landscapes ("cultural landscapes") or plant/animal species of cultural significance; and,
- *Recreation and eco-tourism*: e.g. people often choose places of their holidays according to the natural characteristics of the place.

2.3.8 Causes of biodiversity degradation

Biodiversity is nowadays experiencing serious threats that also negatively affect humans. The new benchmarks of human well-being have taken precedence over other components governing the necessary balance of ecosystems, viz. the social and ecological dimensions of biodiversity. New technologies, a growing population and the thirst for more economic well-being, have led to over-exploitation of resources, resulting in weakening of the system that supports life on Earth. The over-exploitation of resources has repercussions on the global climate because there is no doubt about the very close links between biological resources and the regulation of climatic phenomena. The situation is such that today, even if man stops all exploitation of resources, it would take several decades to restore the equilibrium of the ecosystems. Given the pressure on biodiversity and current trends, it would take at least twice the same planet to satisfy the current needs of man. We can summarize the role of human society in the face of degradation as follows:

- human negligence, even aggressiveness to nature;
- ignorance about the importance of biodiversity and inadequacies of public policies to combat the erosion of biodiversity; and,
- increased competition between activities due to human population growth and the development of activities based on the use of natural resources.

2.3.9 Fundamental principles of ecophysiology

Stress ecophysiology

This includes all stress factors that contribute to make plants suffer. They are either biotic or abiotic (*bios* = life in Greek) according to whether they are due to living organisms (insects, viruses, bacteria, etc.) or to other factors (drought, lack of luminosity, etc.).

Stress indicators and responses

For Girardin (1999) cited by Pindard (2000), there is stress in the plant when the hydric state disrupts the metabolism. This implies that there are more or less direct repercussions on organ growth and development. The first manifestation of water stress in a plant is wilting but research has shown that foliage wilting cannot be used to detect stress because metabolic functions are affected in a stressed plant before stress is visible. Plant- or soil-level measurements or estimates should be used (Pindard, 2000). Among the methods of measuring the water state, mention may be made of:

- micromorphometry: it consists of measuring the micro-variations of the diameter of the stem of the plant which reveal variations of the water state of the plant; and,
- measurement of sap flux: a method based on the measurement of sap flow in the xylem.

Mechanisms of adaptation to water deficit

Water deficit manifests itself as the combination of the restriction of the water availability of the soil and the increase in evaporative demand. Drought tolerance is the ability of the plant to grow and provide satisfactory yields in areas prone to episodic water deficits (Chaves et al., 2002; Tardieu et al., 2006). Thus, in arid areas, plants have developed regulatory mechanisms that ensure their survival, generally at the expense of productivity. However, the adaptation strategies used by the plant to protect itself from water stress depend on the intensity of the deficit to which it is subjected. They will be different for a plant that is under severe stress involving its survival, than for a crop plant which, depending on the local climate risk, will only be subjected to a more moderate water deficit. The main reaction of the water-deficient plant is to actively reduce its perspiration by closing its stomata as soon as the water deficit appears and by reducing its leaf area: reduction in the growth rate of leaves or their number, accelerated leaf senescence (INRA, 2006). The first adaptation strategy of plants to drought is to “avoid” any water stress and the second is the ability to “tolerate” it.

Phenology has recently emerged as an important priority for ecological research because it is a very good indicator of local climatic conditions and therefore of climate change, being very sensitive to thermal variations (Chmiliewski & Rötzer, 2001; Sparks & Menzel, 2002). Thompson & Clark (2004), through monitoring 27 stations around the world, revealed that the beginning of the seasonal cycle of atmospheric CO_2, i.e. its fixation by plants, has been advanced in recent decades.

Phenology is the distribution over time of cyclic biological events (of flora or fauna) that are influenced by the environment (Schwartz, 2003). The field of study of phenology can also be extended to the study of factors influencing it (Defila & Clot, 2001). In trees, two categories of phenological events occur within a year. The first category concerns foliar phenology, and affects photosynthesis, productivity and survival of individuals (bud break in spring, leaf senescence in autumn). The second category concerns the flowering and maturation of the fruit, and affects the reproduction and progeny of the tree. Thus, phenology is crucial for plant fitness (Fenner, 1998; Bennie et al., 2010) because it affects their growth, survival and reproduction. In temperate trees, phenological events are generally seen as a means of adapting to environmental stresses, enabling them to persist within a local temporal niche (Pau et al., 2011). Phenological studies can be used for different purposes. They enrich the knowledge of the autecology of species, their adaptive capacities and have recently been used to study the response of vegetation to climate change.

For foresters, these studies can make it possible to choose the species and provenances best suited to a particular climatic context, or even to provide tools in genetic improvement programs.

Activity 3. Comprehension questions

- What are the different methods used for biodiversity assessment?
- What are the causes of the degradation of biodiversity?
- Give the different categories of ecosystem services available with examples.
- What are the mechanisms of plant adaptation to water stress?

Summary

Biodiversity is the basis of life. This session is devoted entirely to the fundamental concepts of biodiversity. Thus, it is defined through its 3 scales (genetic, specific and ecosystem). The importance of biodiversity, the factors of degradation as well as the assessment methods are presented to the learners.

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Chapter 3: Sustainable Forest Management

3.0 Chapter Overview

Sustainable forest management (SFM) can not only help to mitigate adverse effects of climate change, but also enhance other environmental services, such as protecting soils from the effects of floods. Forests can also contribute to rehabilitating degraded lands and maintaining water quality by trapping sediments, promoting nutrient uptake and neutralizing toxic substances. This chapter provides learners tools and approaches for SFM, including: forest inventory techniques, forest economics, cartography and remote sensing, forest resource exploitation, environmental management and forest certification.

Objectives

At the end of this chapter, learners will be able to:

a) conduct an inventory of forest resources;

b) analyze inventory data;

c) conduct a forest certification;

d) list some forest certification systems around the world;

e) describe various methods for economic valuation of ecosystems;

f) analyse the natural resources management and the processes involved;

g) analyze production and marketing channels of forest products; and,

h) analyze local knowledge and practices.

Activity 1 Discussion (15 minutes)

- Analyse the various notions about sustainable forest management.
- Highlight the key concepts of sustainable forest use.

Session delivery plan

This chapter is made up of five sessions of an average 4 hours length each. Details on these sections and the required materials are described in the table below.

Sessions	Time required	Approach	Educational materials
Definition of basic concepts of SFM	4 hours	Theoretical courses, iterative exchanges, question and answer sessions	Computers, video projector
Forest inventory	4 hours	Theoretical courses, fieldwork, iterative exchanges	Computers, video projector, field outfit
Phytosociology	4 hours	Theoretical courses, fieldwork, iterative exchanges	Computers, video projector, field outfit
SFM and certification	4 hours	Theoretical courses, fieldwork, iterative exchanges	Computers, video projector, post-it
Environmental assessments	4 hours	Theoretical courses, fieldwork, iterative exchanges	Computers, video projector, field outfit

3.1 Definitions of basic concepts in sustainable forest management

Objectives

At the end of this session the learner will be able to”

Explain basic concepts for a of SFM.

Describe technical and scientific vocabularies and have a broad knowledge about the global understanding of SFM.

Activity 1 (Brainstorming) (20 minutes)

- What is sustainable forest management?
- What precautions should be taken to ensure sustainable management ?

3.1.1 Definition of some concepts

Phytosociology: it is the descriptive and causal study of plant associations (Bergonzi and Lanly, 2000) or of the pattern of plants grouping in communities. It is the branch of ecology with the purpose of describing the phytocenosis structure; the analysis of the plant groups from which plant associations are defined and the study of the evolution of plant communities over time (ecological successions). It is based on a prior floristic inventory from which plant groups can be identified; functional links among plant communities and the natural environment are described and explained.

The word “**dendrometry**” comes from two greek terms: Dendros = tree and Metrons = meter, measure. Etymologically, dendrometry is the method of tree measurement.

The concept of **forest management** is also based on the research of sustainability in forest production. However, it is based on a planning process aimed at “regulating logging” (Guillard, 1999). For foresters, it is a question of “imitating nature, hastening its work” (Lanly, 1999). This concept seems to have been created in France in the 18th century (Boutefeu, 2005).

Sampling is the selection of a part in a whole.

The word **biometry** means “measure of living organisms”, and in a very broad sense stands for the quantitative study of living beings.

The **sampling rate** is the proportionality ratio between the sample size and the size of the mother population.

In botany and biogeography, a **plant formation** is a community of plant species characterized by a certain physiognomy which determines a characteristic landscape. This physiognomy, also called “vegetation”, enabling a general description on a rather extensive scale, depends on the species which compose the plant formation and the environment which hosts it. Examples of plant formation include forests, mangroves, steppes, savannah, moor, and so on. Within these broad categories, we can identify more specific plant formations, taking into account the ecological conditions that characterize them: in this way we can, for example, distinguish different types of forest.

Plant association is a redundant community or colony of associated species (Moreau, 1960). It is an original combination of species, some of which, termed as characteristic, are particularly linked, others being called companions. It is also a plant group of determined floristic composition with a uniform physiognomy and growing under uniform stationary conditions (Lebrun and Gilbert, 1954).

Vegetal grouping is a concrete plant community in which the floristic, structural and ecological composition that would facilitate its classification into a phytosociological, physiognomic or phytoecological system is yet to be determined (Evrard, 1968).

Biological form: it refers to the physiognomy of a species during its life cycle in relation to the behavior vis-à-vis environmental factors and, in particular, its ability to withstand hard seasons (Schmitz, 1971).

3.1.2 History and concepts of sustainable forest management

The literature review we conducted indicate that the term “sustainable forest management” (SFM) emerged in the scientific literature in 1990. Presented at the Earth Summit in Rio de Janeiro 1992, it has been widely used since then by a very wide variety of local and international actors. As we shall see later, it is based on several approaches and has gradually become the “model” of tropical forest ecosystems management. Practices implemented under this term do not date from the 1990s: they were strongly inspired by the different managerial models already used and have therefore to be partially apprehended as a legacy of preexisting practices.

A definition of *sustainable forest management* was proposed by the "Ministerial Conference on the Protection of Forests in Europe" in 1993 and has since been adopted by FAO: "*Sustainable forest management is the management and use of forests and woodlands in a way, and at a rate, that maintains their biological diversity, productivity, regeneration capacity, vitality and their potential to fulfill, now and in the future, relevant ecological economic and social functions, at local, national and global levels, and that does not cause damage on other ecosystems*".

The generally accepted definition of sustainable development is that proposed by Brundtland: *"Sustainable development is the one that meets the needs of the present without compromising the ability of future generations to meet their own needs"*. The key word is to ensure a positive balance between three fundamental pillars: the economy, the social and the environment.

Nevertheless, in 1992 at Rio, developing countries (DCs) strongly advocated that economic development must remain one of the prerequisites for ecological progress (Le Prestre, 2005). A consensus was reached and clarified in principles 3 and 4 of the Rio Declaration: "Principle 3 - The right to development must be fulfilled so as to fairly meet development and environmental needs of present and future generations. Principle 4 - In order to achieve sustainable development, environmental protection shall constitute an integral part of the development process and cannot be considered in isolation from it".

Developed at the Earth Summit in Rio de Janeiro in 1992, SFM is based on the concept of sustainable development, widely used by the Brundtland Report of the *United Nations Commission on Environment and Development* (1987). However, at this conference, States were unable to agree on the signing of the forest convention. This is why the forest has only been the subject of a legal and operational declaration.

The Rio Declaration on Forests brings together international vows and ***recommendations*** for SFM. However, the Biodiversity Convention contains principles of theoretically compulsory application, some of which concern the forest, and should include the bio-diversity of soil fauna, often overlooked due to its non-visibility, but vital for the processes of sylvigenesis, natural formation and maintenance of the "*fractal*" dimensions of the soil and in particular forest humus.

3.1.3 Assessment criteria of sustainable management

Criteria and indicators have since been developed to assess and sometimes to measure and certify, in a more or less credible and independent way, progress towards sustainable management at the levels of states and management institutes, often with certain owners, managers and NGOs.

The concept of SFM usually refers to operations carried out to manage and exploit forests so that they sustainably fulfill certain relevant ecological, economic and social functions. All the definitions of this concept imply that forests managed under such a regime are subject to periodic or permanent human intervention, at least in part. The three pillars of SFM include economic, environmental and socio-cultural aspects.

Criteria & Indicators (C&I) of SFM are policy instruments by which sustainability of forest management in the country/region, or progress towards SFM, may be evaluated and reported on. C&I is a conjunctive term for a set of objectives and the variables/descriptions allowing to evaluate whether the objectives are achieved or not.

There are many sets of C&I in the world that are used by particular regional SFM processes (e.g. FOREST EUROPE, Montréal Process), international organisations and their activities (e.g. FAO Global Forest Resources Assessment) or certification of forest management and forest products (e.g. Forest Stewardship Council, Programme for the Endorsement of Forest Certification).

Pan-European criteria and indicators for SFM include:

Criteria characterise or define the essential elements or set of conditions or processes by which SFM may be assessed (MCPFE, 1998b). There are 6 criteria:

1. Maintenance and appropriate enhancement of forest resources and their contribution to global carbon cycles;
2. Maintenance of forest ecosystem health and vitality;
3. Maintenance and encouragement of productive functions of forests (wood and non-wood);
4. Maintenance, conservation and appropriate enhancement of biological diversity in forest ecosystems;
5. Maintenance and appropriate enhancement of protective functions in forest management (notably soil and water); and,
6. Maintenance of other socioeconomic functions and conditions.

Indicators monitor quantitative and qualitative changes over time for each criterion and describe the progress made towards their objectives (MCPFE, 1998a).

- ***Quantitative indicators*** are expressed in measurement units and the necessary data are collected via regular forest inventories, other field surveys, remote sensing, etc. Periodically measured indicators show the direction of change regarding the criterion. The list of quantitative indicators includes, for example, the forest area and growing stock (volume of living wood) for Criterion 1, forest damage for Criterion 2, increment and fellings for Criterion 3, deadwood volume or naturalness classes for Criterion 4, the area of protective forests for Criterion 5, and contribution of forests to GDP or the area of recreation forests for Criterion 6.
- **Qualitative indicators** are those that have to be described and assessed, and the data are collected using questionnaires. They are used to describe legal and institutional frameworks of forestry, as well as the policies and instruments for implementing SFM.

Summary

This session is devoted to defining the key concepts of sustainable forest management, the history of sustainable forest management, and assessment criteria based on key indicators. These indicators show how forest management can be sustainable.

3.2 Forest inventories

Objectives

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

a) describe the various inventory types;

b) discuss the different inventory techniques; and,

c) Explain the importance of forest inventories.

Activity 1 (Brainstorming) (20 minutes)

- What is a forest inventory?
- How important is the forest inventory for the development of your region or country?
- What are the requirements for conducting a forest inventory?

3.2.1 Definitions and concepts

Probably derived from the principle of “Better knowledge to manage better”, the forest inventory is a process of collecting data on forests such as areas, age of trees and amount of wood available. Data collected can also expand to the wooded and non-wooded area, the distribution of species, and the various forest formations.

Forest legislation generally holds that an inventory of resources available in forest areas be established and updated by forest administrations. Inventories form the basis for quality monitoring of forest control and inspection, and may have an impact on illegal logging.

3.2.2 Inventory objectives

In general, forest inventories aim at assessing the current state and dynamics of woody vegetation.

Vegetation inventory is a valuable tool for decision-making in the management of plant formations (Fonweban, 1995; Rondeux, 1999; Kangas & Maltamo, 2007). Since plant formations are often too extensive for exhaustive inventory, it is almost always based on sampling (Picard, 2006; Van Laar & Akça, 2007). Consequently, the minimization of sampling errors during the completion of the inventory is crucial for a greater reliability of data collected. Otherwise, a particular emphasis should be placed on the sampling technique that impacts the sampling error.

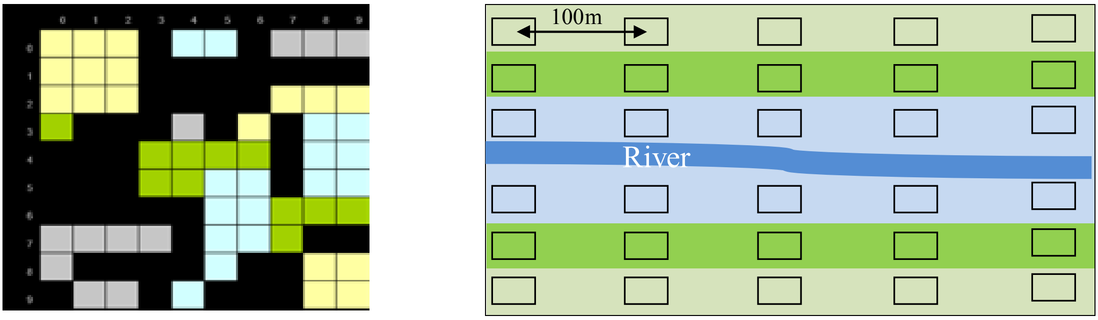
Forest inventory is an integral part of the planning process for the sustainable management of forest resources (Kaboré, 2004). It aims at providing necessary data on species in order to establish forestry standards, to simulate the production and evolution of resources and to analyze station-production relationships (Bergeret & Couteron, 1995; Couteron & Serpantié, 1995; Fonweban & Houillier, 1997). These results constitute the basis for decision making in forestry, forest economics, forest policy and forest engineering. Inventories are used for the planning of exploitation and play an increasingly important role in spatial planning and in the protection of the environment.

3.2.3 Non-wood forest products

Non-wood forest products (NWFP), also known as secondary forest products, have various definitions. They are “any biological resources, and any market services, except all forms of timber, from the forest or any other ecosystem with similar functions” (Chandrasekharan, 1995). They are also “goods of biological origin other than wood, derived from forests, other woodlands and trees outside forests”. They can be harvested from wild or produced in forest plantations, or by trees outside forests (FAO, 1999). Tsiamala-Tchibangu and Ndjigba (1998) reported that “they include food, edible mushrooms, medicaments, animals and animal-derived products, raw materials for handicrafts and products used in construction or during cultural or religious events”. Overall, NWFPs are considered to be “any biological materials that can be extracted from natural forests, woods, fallows or forest plantations as well as their use for recreation, park or reserve purposes”.

3.2.4 Types of inventories

Forest inventories are intended to identify all forestry information necessary for evaluating the potential for rational and sustainable management. There are several types of inventories ranging from national to local scale. The forest inventory currently carried out focuses on woody potential through the collection of information on population structures (measurements of dendrometric parameters such as diameter and height), their health status, their phenology and the potential for regeneration. Important informations that contribute to better management of forest areas can be derived from forest inventories. National forest inventories are essential tools for identifying all national information on biological potential, species distribution, population structure, productivity, and wood and carbon sequestration potential. National inventories should be for executed every 20 years.



Random sampling (Source: Thiombiano, X)

Systematic sampling (source: Sambaré, 2013)

Figure 14. Sampling design

3.2.5 Sampling methods

Because forests are often too extensive for a comprehensive inventory, forest inventory is almost always based on a sampling (Picard, 2006). The types of sampling used in forest inventory include random and simple sampling, systematic sampling, stratified sampling, cluster sampling, multi-stage sampling and multi-phase sampling (Picard, 2006).

3.2.6 Sampling design

Plots for punctual observations (non-permanent plots)

Temporary plots are single-use plots because they are not marked out in the field (Picard et al., 2010). They are plots measured only once and characterize different stands at a given time, without considering the growth kinetics (Pauwels et al., 1999). Such an inventory makes impossible to timely follow variables such as growth. Temporary plots can be used to obtain assessments of the current state of the forest.

Permanent plots

Permanent plots refer to forest sampling sites that are bounded or simply identified and remeasured at different points in time (Köhl et al., 2006). Unlike temporary plots, the technique of permanent plots consists in following over time changes in vegetation on the same space. In permanent inventories, the units are materialized indirectly via a metal stake embedded in the center and trees are marked by the angle of view under which they are seen from the center and by the distance separating them from the stake (Rondeux, 1999). They are plots established on the ground for a rather long period (several years, even decades), which enables to compare successive inventories.

To estimate tree carbon stock changes, permanent or temporary plots can be used for long-term sampling. The use of permanent plots for trees has more benefits (efficient verification of results) than draw-backs. Permanent plots are generally considered to be statistically more efficient in calculating changes in forest carbon reserves than temporary plots.

Form and size of plots according to the type of inventory

The nature, shape and size of sample plots are a trade-off between exactness, accuracy, time and cost of measurement.

As regards the shape of plots, plots of fixed size and plots of variable size are usually distinguished. Plots of fixed size are the most widely used in West Africa. The inventory plots can have a circular, square or rectangular shape (Kenkel & Podani, 1991; Rondeux, 1999; Kangas & Maltamo, 2007). The circular plots represent the geometric figure with the lowest perimeter for a given shape; then they reduce the number of edge trees compared to other plot shapes with the same area (Kangas & Maltamo, 2007) and are therefore the most widely used in national and international forest inventories (Lecomte & Rondeux, 2002). Nevertheless, rectangular plots whose length coincides with plantation lines are more suitable in forest plantations (Van Laar & Akca, 2007). Indeed, for the same area, rectangular plots allow the identification of more species than the other shape (Jyrki et al., 1998). In tropical formations, it is more appropriate to use square or rectangular plots (Van Laar & Akça, 2007). This is confirmed by recent studies indicating that square plots are the most recommended in tropical rainforests (Houéto et al., 2013; Salako et al., 2013).

The size of inventory plots is an important feature in the accuracy of estimation of vegetation parameters. The choice of the optimal size of the plots depends on several characteristics related to the stand considered. Indeed, the density of trees, their age, size and spatial structure in the stand all influence the optimal size of plots (Rondeux, 1999; Van Laar & Akça, 2007). The "classical" method of inventorying savannah formations is a systematic stratified inventory using plots of fixed size, often between 1,000 and 1,250 m^2 (in particular rectangles of 20 × 50 m or 25 × 50 m) (Arbonnier, 1990) but up to 2,500 m^2.

3.2.7 Dendrometry and dendrochronology

Dendrometry

The assessment of the volume of wood and forest products dates far back in human history, since man started selling wood. During the 18th and 19th centuries, many foresters tried to find methods to determine the volume of trees and forest stands: **the science of measuring trees** was slowly being created.

The word "dendrometry" is composed of two greek terms: "Dendros" = tree and "Metrons" = meter/measurement. Etymologically, dendrometry is the method of tree measurement.

Dendrochronology

Dendrochronology (from Greek *dendros*, tree, and *chronos*, time) is the study of tree growth over time. It is concerned with the study of tree rings, which are records of tree growth variations under natural conditions (Fritts, 1976; Schweingruber, 1988), enabling us to reconstruct the chronologies and weather/climatic variations of the past. It is a technique that enables archaeological sites containing wood to be dated with great precision.

This discipline is an interesting way of detecting the impact of climate change and the increase in CO_2 on forest productivity (Graumlich et al., 1989). Some authors even believe that dendrochronology has a major role to play in the context of research on global change (Cherubini, 2000), the strength of this discipline being to analyze data for which time and space are perfectly controlled. In this context, dendrochronological series can serve as both historical and reference controls to simulate future variations.

Dendrochronology generally uses statistical models, response functions to quantify the relationship between rings-climate, and then to make climatic reconstructions (Cook & Kairiukstis, 1990). Response functions have recently been used to assess the impact of climate change on tree growth (Keller et al., 1997, 2000). However, no model has yet been able to assess the impact of the increase in atmospheric CO_2 on the growth of trees.

In climatic regions which impose a period of activity and a period of rest to the vegetation in the same year, trees develop each year on the periphery of their trunk a growth or annual ring. The influence of climatic factors results in a wide ring in a year when weather conditions fitted the climatic requirements of the species but a thin ring if not. As a result, quite similar sequences of rings can be observed on the series of all the trees of the same species growing under the same climate and thus constitute chronological landmarks.

Summary

This session on forest inventories first presents key definitions and concepts. In addition, it presents the objectives of the forest inventory, the types of inventories, the sampling method, the monitoring devices (punctual or long-term), dendrometry and dendrochronology.

3.3 Phytosociology

Objectives

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

a) Describe basic notions of phytosociology;

b) Demonstrate techniques for conducting phytosociological records; and,

c) Explain the importance of phytosociology in monitoring of the dynamics.

Activity 1 (Brainstorming) (20 minutes)

- Define the term "phytosociology"?
- What precautions should be taken to conduct a phytosociological survey?
- What is the importance of phytosociology for you?

3.3.1 Definition and object

From floristic, ecological, dynamic, chronological and historical points of view, phyto-sociology can be defined as the study of plant communities. The most commonly used definition is the study of plant associations; a plant association being a plant group with determined floristic composition and homogeneous physiognomy and stationary conditions. According to Blanquet (1932), the plant association is a more or less stable plant group in equilibrium with the surrounding environment, characterized by a specific floristic composition in which some exclusive elements or characteristic species reveal by their presence a specific and autonomous ecology. There are many other definitions for the concept of plant association, showing the complexity of this notion.

For the phytosociologist, the first step in the determination of plant associations based on their floristic composition is the establishment of lists of species in the field. Thus, records shouldn't be perfomed haphazardly. The choice of the location and the dimensions of the vegetation surfaces analyzed is very decisive for the phytosociologist.

3.3.2 Phytosociological records

Determination of the minimum area

It is usual in phytosociology to specify the record area. However, the indication of the total area of the record is not sufficient to judge whether the minimum area is reached or if the maximum area is exceeded (Gillet, 2000).

A record will only be considered representative of the individual of the studied association if it is carried out on an area at least equal to the *minimum area*, or in other words a “sufficiently” large area to contain almost all species present in the association (Guinochet, 1973). A too small area would make the survey fragmentary and not representative, since it would contain only a limited part of the usual floristic mix of the community of interest. Conversely, a too large area would make the survey heterogeneous, with the risk of containing a too large proportion of adjacent associate individuals (Gillet, 2000). The minimum area, representative of the sample of the study area (i.e. containing 90-95% of the species) is gradually determined by doubling the consecutive record area (start with 1 m^2 for the herbaceous stratum and 5 or 10 m^2 for the tree stratum): this is the minimum area.

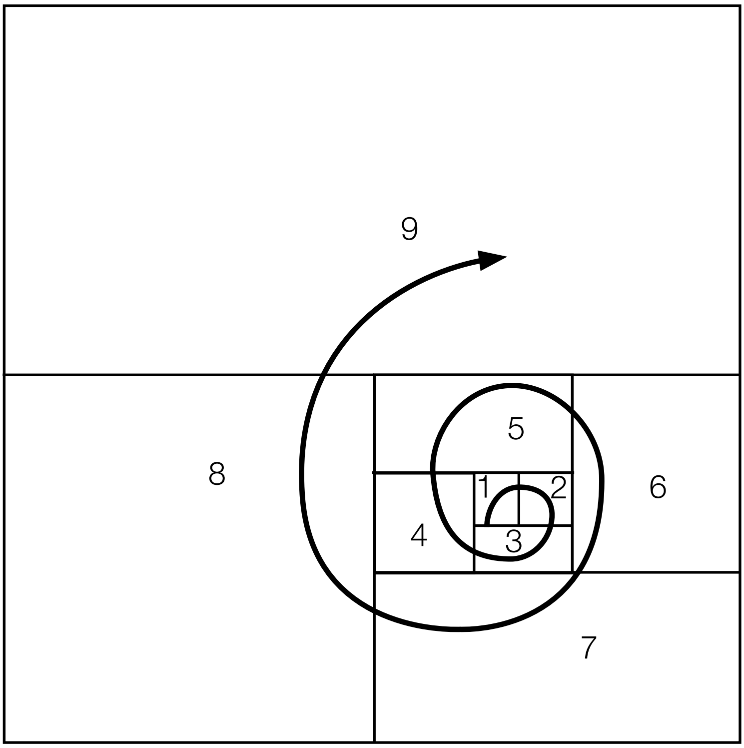


Figure 15. Minimum area determination technique.

Records and characterization of plant groups

The record consists of identifying all species that are present on the plot by assigning to each of them a coefficient of abundance-dominance which permits an estimate of the weight of each species in the ecosystem. To do this, the method of Braun-Blanquet (1932) is generally used. Abundance-dominance is assessed through a scale that combines the number of individuals and their relative importance in terms of overlap. The Braun-Blanquet scale used for this purpose is as follow:

1: 0-1%; **RM = 0.5%**;

2: 1 - 5%; **RM = 3%**;

3: 5-25%; **RM = 15%**;

4: 25-50%; **RM = 37.5%**;

5: 50-75%; **RM = 62.5%**;

6: 75 - 100%; **RM = 87.5%.**

The primary objective of records being the plant associations, records arrangement based on the floristic similarity forms the basis for data analysis. Plant associations or plant groups identified will constitute basic forest ecosystems for any conservation or restoration action that should comsider the balance established within this association. The plant associations illustrate the environmental conditionss of the ecosystem through the specific requirements of some species (described as characteristic species). The inventoried flora helps to:

- monitor changes in floristic composition over time; and
- make a typology of plant formations that characterize the observatory and update the existing typologies.

Plant associations are identified through their characteristic species that have a significantly higher index value in the grouping they characterize. Several tools exist that permit the generation of either dendrograms (Figure 16) or tables.

3.3.3 Biological types as indicators of evolution in plant groups

The analysis of a plant formation points out relationships that are sometimes obvious between the constitution of plants and important characteristics of their environment. Thus, plants of the semi-desert are to some extent adapted to survive long periods of drought. These observations show that it is interesting to distinguish groups of plants having as their main traits the same port, the same conformation, the same behavior, and, in a general way, the same biological form. The various biological forms recognized in plants may be interpreted and classified taking into account environments factors.

The Danish botanist Raunkiaer has classified vascular plants in temperate countries into a number of biological types according to the degree of protection that their persistent shoots (branches) benefit from during the rest period in winter. According to Raunkiaer, this protection mainly depends on the situation of the shoots with respect to the soil and then to the phytosociological and morphological characteristics of the plants.

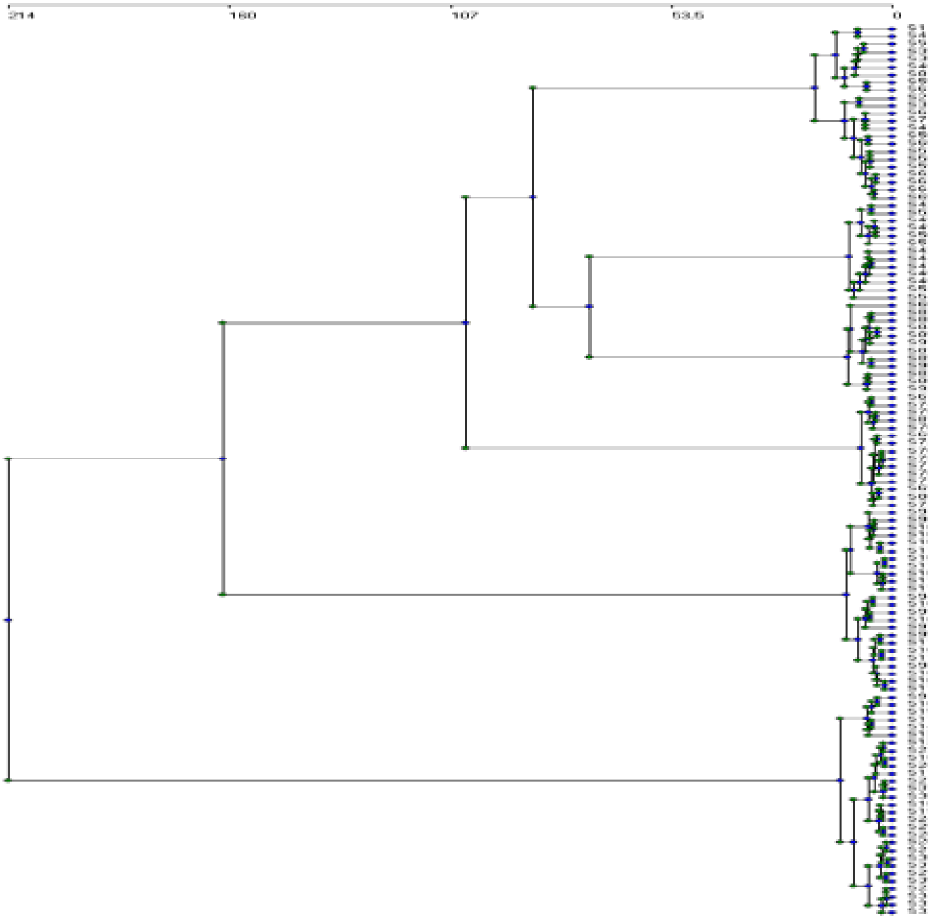


Figure 16. Dendrogram illustrating the different groups (Savadogo, 2013).

The Raunkiaer system originally included only species from temperate countries. It has been extended, notably by Rübel, Braun Blanquet and more recently by Ellenberg and Mueller-Dombois, by considering the plants of all climatic zones. These biological types are found in tropical countries with marked dry season. It should be pointed out that the biological type of a plant is the resultant on its vegetative part of all biological processes, including those which are modified by the ecology during the plant life and which are not, consequently, hereditary.

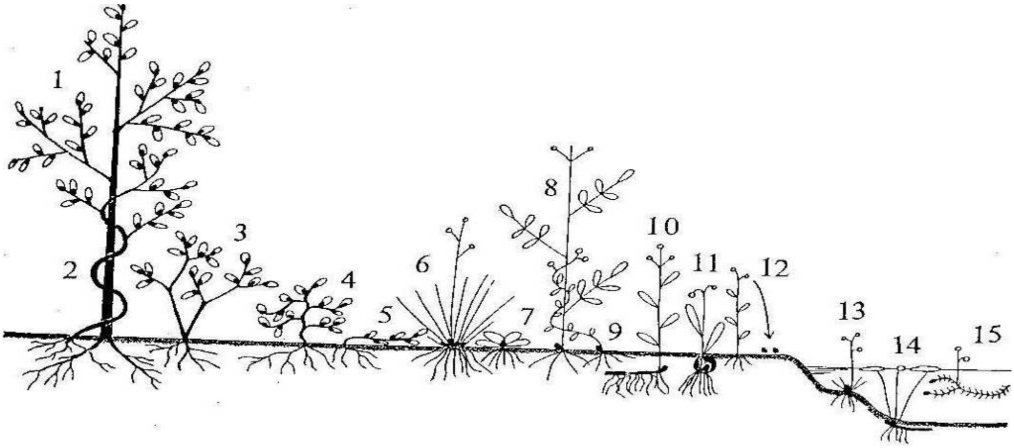
There are five basic biological types: phanerophytes, chamephytes, hemicryptophytes, cryptophytes and therophytes.

The name **phanerophytes** encompasses woody trees, shrubs, and vines, as well as great perennial grasses, whose stem-plant grows more than 25-50 cm above the ground. We distinguish nanophanerophytes whose size is between 2 and 5 m, the mesophanerophytes high from 5 to 50 m and the megaphanerophytes that exceed 50 m in height. They are found in areas with a long warm season.

Chamephytes prolonge phanerophytes in the paths of involution (regressive evolution). Their stem, whatever its architecture or adaptive character, does not rise more than 50 cm above the ground. These plants benefit from the particular microclimate that occurs in their immediate surroundings. They are miniature shrubs or herbs that can be erect or creeping. Chamephytes are in general very polycaules and pollacanthes (flower several times during their existence). They live on average shorter than phanerophytes. Chametophytes are found in mountain areas with long cold season and dry climate.

In the semi-hidden plants, or **hemicryptophytes**, the very involuntary caulinarian apparatus has withdrawn into the soil. It consists of a rhizome or a tubercle whose buds are very close to the surface of the soil and which develops, at favorable times, leafy stems growing above the ground. Hemicryptophytes are particularly prevalent in high cold regions and savannas. In the tropics, they are represented by the grasses and cyperaceae of savannas.

Cryptophytes are invisible plants during the bad season and thus subtracted from the adverse effects of unfavorable periods. In the case of Geophytes, organs are perennial and hidden in the soil. As for the hydrogeophytes, their perennial organs are hidden in the mud.



Representation of main life forms with 1: mesophanerophyte, megaphanerophyte; 2: phanerophytic liana; 3: nanophanerophyte; 4: frutescent chamephyte; 5: creeping chamephyte; 6: cespiteous hemicryptophyte; 7: rosette hemicrytoptophyte; 8: erect hemicrytoptophyte; 9: hemicryptophytic liana; 10: rhizome geophyte; 11: bulb geophyte; 12: therophyte; 13: hydrohemicryptophyte; 14: hydrogeophyte; 15: floating hydrophyte.

Figure 17. Biological types

Therophytes refer to plants that live only during the summer. These are annual plants which pass through the bad season in the state of diaspore. They are hapaxanthes (flower only once during their life). Therophytes can be assimilated to inflorescences bearing the number of assimilative leaves strictly necessary for the formation of a maximum of flowers and fruits. The maximum life duration of therophytes is only a few months to many tens days. These plants are found in all climates. However, they are admirably prepared to live in dry or cold climates. They are found in sub-desert and desert regions.

To the five main biological types we may add **epiphytes** which have no roots in the soil and develop on other plants. An epiphyte is a plant that lives on another plant without being harmful to it. These plants use the other plants as mere supports. They do not exploit nutrients from them and therefore are not parasites. Epiphytes are characteristic of dense inter-tropical wet forests.

3.3.4 Phytogeographic types

Indicators of spatial distribution of plant groups

Phytogeography studies the distribution of plant species at the surface of the globe. The determination of chorological affinities of the different species was made using subdivisions at the level of the globe.

Types of phytogeographic distribution were established according to the major chorological subdivisions existing for Africa (White, 1986). The main types of distribution (TP) used are:

- Broadly distributed species:

  Cos = cosmopolitan, species present in tropical and non-tropical countries;

  Pan = pantropical, species distributed in all tropical regions;

  Pal = palaeotropical, species present in tropical Africa, tropical Asia, Australia and Madagascar;

  Aam = Afro-American, species present in Africa and tropical America;

- African pluri-regional species:

  SZ = Sudano-Zambesian, species present both in Sudanian and Zambesian Endemism Regional Centers;

  AT = Afro-tropical, species distributed throughout tropical Africa;

  AM = Afro-Malagasy, species distributed in Africa and Madagascar;

  P-A = African multi-regional species whose range extends to several Regional Centers of Endemism;

  GC = Guineo-Congolese species, species widely distributed in the Guinean Region;

  SS = Sahelo-Saharan species, both Sahelian and Saharan species;

  S-S = Sahelo-Sudanian species, both Sahelian and Sudanian species.

  S = Sudanian species, species widely distributed in the Sudanian Endemism Regional Center.

3.3.5 Other methods of vegetation studies

Phytoecology, synusial phytosociology

Phytoecology is the study of the relationships between environment and vegetation. Integrated synusial phytosociology was developed in 1980s based on the work of three researchers: B. de Foucault, F. Gillet and P. Julve. It draws its roots from the concepts developed at the beginning of the century by, among others, Lippmaa, Braun-Blanquet, Gams, Du Rietz, Tüxen and Raunkiaer. It has been further developed by the introduction of landscape integration, systemic and structuralist concepts, and the contribution of precise methodologies (dynamic, architectural and ecological analysis).

One of the central concepts of synusial phytosociology is based on the definition of plant synusia. From an ecological functional point of view, synusies are very homogeneous communities. They include species that live together and have similar life strategies.

Summary

Phytosociology is a science that studies the pattern of plant groupings. This session which deals with the question begins with a definition of the concepts before presenting the phytosociological record itself through its main stages before ending with the distinction of plant groups. In addition, the notions of biological types, phytogeographic types and other related study methods are discussed.

3.4 Sustainable forest management and certification

Objectives

At the end of this session the learner will be able to:

a) identify the necessary tools for good forest management;

b) Explain the techniques and importance of forest certification; and,

c) Describe the various standards in forest certification

Activity 1 (Brainstorming) (20 minutes)

- What is forest certification?
- What is the importance of forest certification?
- How to carry out a forest certification?

3.4.1 Sustainable forest management indicators

An indicator is a quantitative, qualitative or descriptive attribute which, when periodically measured or controlled, indicates the direction of change.

Indicators should be used to quantify the monitoring of the application of regional forest management schemes and guidelines, as well as instruction on the inclusion of biodiversity in forest management and development. Sustainable management indicators integrate many factors, including floristic richness, recovery rate, density and population structures.

3.4.2 Forest certification

Definition, origin and evolution of the concept

Forest certification is rooted in the concept of **sustainable development**, the term used by the International Union for Conservation of Nature (IUCN) in the early 1980s. The term was subsequently adopted by the *World Commission on Environment and Development in* 1987 in *Our Common Future* report*.* This book, commonly known as the “Brundtland Report”, in reference to the commission chair Dr. Gro Harlem Brundtland, defined the concept of sustainable development as *“development that meets the needs of the present without compromising the ability of future generations to respond to theirs”*. Sustainable develop-ment can also be expressed as an activity that is “*economically viable, socially acceptable and environmentally friendly”.*

Since the concept of sustainable development is closely linked to natural resources, the forest sector has received particular attention, especially at the Earth Summit held in Rio de Janeiro in 1992, when world leaders agreed on the adoption of an international framework for sustainable forest management, thus referring to the sustainable development of forests.

Deforestation in tropical regions mobilizes different categories of stakeholders that call for the attention of the international community, particularly since the late 1980s (Tsayem and Fotsing, 2004). This mobilization is essentially carried out by numerous international non-governmental organizations established in developed countries arguing strongly for the protection/conservation of tropical forests in developing countries. The pressure exerted by these international NGOs, very often with the support of the media, has led developed countries and the international community in general to adhere to the wish to implement a “sustainable management” of tropical forests, considered as “reservoirs of biodiversity”, “global genetic and biological heritage” and/or “planetary good”, which are victims of overexploitation and extinction. The international conferences inf Rio de Janeiro (1992) and Johannesburg (2002) integrated this paradigm to become part of the concept of sustainable development.

In order to realize and evaluate this sustainable management, forest certification, initiated in 1989 by the American International NGO Rainforest Alliance, has been progressively promoted as a quality standard aimed at ensuring western consumers of timber and related products that these materials come from production and management systems that respect the principles and criteria of sustainability. More than fifty forest certification systems are currently distributed around the world, leading sometimes to a sort of “label war” (Arnould, 1999). These certification systems are based on different processes and use assessment tools that characterize and differentiate each other. Unlike the European and American continents, forest certification remains very low in Africa and particularly in Central Africa.

Some forest certification systems around the world

The most common forest certification systems include: the Forest Stewardship Council (FSC), the Programme for Endorsement of Forest Certification Scheme (PEFC) and the International Organization for Standardization (ISO). To these three main certification systems, are added the Pan African Forest Certification (PAFC) which was created to be applied especially in Africa.

The **Forest Stewardship Council** (FSC) certification system was established in 1993 under the leadership of WWF supported by Greenpeace and Friends of the Earth. Today, It is based in Bonn, Germany, and comprises members representing various socio-professional categories: economic operators (industries and timber trade), environmental and human rights NGOs, trade union organizations, etc. Wishing to have an international dimension, the FSC has developed and published a set of principles and criteria for SFM. These principles and criteria are ten and include compliance with law, land tenure, rights of indigenous peoples, environmental impacts, management plans, etc. (Smouts, 2001). They serve as a basis for the development of FSC certification standards applicable to public or private enterprises operating in the field of timber exploitation and processing, and wishing to obtain the FSC certificate. The FSC certification process involves several steps:

- the accreditation of independent certifiers of SFM in accordance with the principles and criteria published by the FSC;
- the verification of the sustainability of forest management by accredited certifiers;
- the allocation of certificates of sustainable management and traceability of timber for a period of five years;
- the control of accredited certifiers; and,
- the monitoring audits for the continuous respect by FSC certificate holders of the principles and criteria of sustainability.

The FSC certifies the sustainability of forest management and the traceability of timber products. This certification leads to the labeling of products according to two types of labels: the label FSC 100% and the label Mixed Sources. The labeling of timber products ensures buyers that the timber comes from a certified forest and that it has been transformed according to sustainability standards.

The **Program for Endorsement of Forest Certification Schemes (PEFC), o**riginally known as Pan European Forest Certification, is a non-profit, non-governmental association created in 1999 on the initiative of the presidents of national federations of forest owners from six European countries (Austria, Finland, France, Germany, Norway and Sweden). Created to apply in Europe, PEFC has since 2001 expanded its scope beyond Europe (Canada, United States).

PEFC advocates the principle of subsidiarity, which allows each geographical level to define and specify the rules for SFM according to local situations. It inscribes certification in the ISO standardization process, respecting its verification rules and its control methods. The rules for SFM are specified according to local circumstances. Thus, for the European level, SFM rules stem from intergovernmental processes such as the Helsinki (1993), Lisbon (1998) and Vienna (2003) processes. The Helsinki process defines six major criteria for SFM, including maintaining the viability of forests and their timber production functions, conserving and improving biodiversity, benefits and socio-economic conditions of people.

The intergovernmental processes define the broad lines of SFM that will serve as a basis for defining the national standards and patterns on which the PEFC certification assessment is based. National forest management schemes are specific and adapted to the local realities of each country where national and regional PEFC bodies exist. The PEFC certification approach is part of a participatory dynamic of its stakeholders and continuous improvement of practices within PEFC national and regional entities. The national and regional PEFC entities of each country are made up of three colleges: producers, processors and consumers. The national entity defines, on the basis of criteria derived from inter-governmental processes, the national PEFC certification scheme or reference framework of principles and recommendations for SFM.

The **International Organization for Standardization** (ISO) was established in 1947 and was initially interested in technical standards related to products. With an international vocation such as FSC or PEFC, ISO is an NGO that brings together 140 national standards organizations. It brings together large and small companies, governments and NGOs. Since the Rio conference in 1992, ISO has been interested in the production process and supplies, through its series 14000, a framework for the certification of environmental management systems. This series 14000 is an initiative of companies seeking to improve their image vis-à-vis public authorities, the public, environmental NGOs and financial partners. These companies commited to comply with the requirements of the ISO standard in order to improve the control of environmental impacts of their activities.

Certification of environmental management systems is based on the ISO 14001 standard, worldwide known as a reference system enabling any organization or body requesting certification to set up an environmental management system (EMS). The EMS designates all means and processes implemented as part of a formal approach to environmental management. It is based on the precise definition of the rules of procedure and organization and aims at the continuous improvement of the performance of the organization through the implementation of five principles defined by ISO. These principles are related to the environmental policy and its planning by the company, its implementation and monitoring

The **Pan African Forest Certification** (PAFC) was initiated in the mid-1990s by positioning itself as the forest certification system that integrates the socio-cultural and economic values and realities of forest management in Africa. It is a tool for African timber producers to sustainably manage forests and to adapt to changing international timber markets. Proposed as an alternative to the monopoly of international forest certification systems, it is based on the political will of leaders of African countries. It is a member of the African Timber Organization (ATO) with the aim of including forest certification in SFM priorities for forests of the Congo Basin. It uses the principles, criteria and indicators for SFM defined by ATO and ITTO (International Tropical Timber Organization). These principles, criteria and indicators have been validated by the forest administrations of country members of ATO. They include the use of forests and the maintenance of their functions, the provision of goods and services, and the improvement of the economic and social well-being of employees and local populations (ATO-ITTO, 2003). The PAFC certification approach is based on that of the PEFC, for example as regards the definition of national schemes.

3.4.3 Synthesis of FSC, PEFC, ISO and PAFC certification systems

A comparison of these four certification systems shows that each of them has its certification tools and approaches with characteristics that distinguish them while bringing them closer to each other. The cartographic representation of forest areas certified by FSC and PEFC, two of the most widespread certification systems in the world, indicates that temperate and boreal forests are more certified than tropical forests.

All certification systems focus on the environmental component. The social component is more taken into account by the FSC and the PAFC than the other systems. Many FSC and PAFC principles and criteria overlap (FSC Principles 2 to 10 and PAFC Principles 2 to 4). The FSC and ISO systems are open to managers, owners, loggers and industrialists who apply for them without any obligation to join these systems, in contrast to the PEFC whose certificate and label can only be attributed to members of the PEFC entities or forest stakeholders in countries with a certification system recognized by the PEFC Council. However, the PEFC certification approach seems interesting in several respects: the development of national certification schemes adapted to the context of application, the possibility of certification of small forest areas, and pooling of financial resources by groups of forest stakeholders to support certification charges.

Unlike on the European and American continents, forest certification remains very low in Africa (RODA, 2001). With about 1,523,000 ha of certified forests (all systems combined), Central Africa has a small certified forest area. The first forest certification experiment in Central Africa dates back to 1996. It originates from the society Leroy Gabon implemented in Gabon. It resulted in the issuance of an FSC certificate after an assessment by Société Générale de Surveillance (a French-Swiss company accredited by the FSC).

Summary

This session discussed SFM and certification. Thus, definitions of key concepts are first given before addressing sustainable management indicators. In addition, the session on forest certification dealt mainly with definitions and main forest certification systems.

3.5 Environmental assessments

Objectives

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

a) Explain the concept of degraded ecosystem;

b) Describe concepts and different steps in environmental assessment; and,

c) Clarify techniques for economic assessment of resources.

Activity 1 (Brainstorming) (20 minutes)

- How can we recognize a degraded ecosystem?
- What measures can be taken to mitigate the impacts of any management?
- What is an environmental assessment?
- How do we conduct an environmental assessment?
- Precautions to be taken to ensure a sound environmental assessment?

3.5.1 Assessment of ecosystem degradation

The degradation of arid ecosystems is traditionally linked to two factors: climate change and human activities. The former is considered inevitable throughout the century. However, the vegetation in arid zones is adapted to this type of recurring change, and its effects on species disappearance are generally limited (Darkoh, 2003). On the other hand, the impact of human activities (especially livestock) on vegetation remains to be defined in the short term. It is likely to be the cause of major and perhaps irreversible changes in vegetation cover and thus in living natural resources (Khresat et al., 1998; Darkoh, 2003).

3.5.2 Environmental assessment

A broad sense definition of *environmental assessment* refers to the assessment of the composition and conditions of the biophysical, human and non-human environments. Environmental assessment must take into account the environment as a whole (resources, biodiversity, natural or technological risks, energy, heritage, spatial planning, management, etc.) and make the decision making process clear through information and public participation. In particular, it provides a framework for cross-cutting analysis and allows a decompartmentalization of themes and studies.

Environmental assessment is an ongoing and iterative process. It enables the analysis of environmental effects of a project, plan or program and it prevents harmful effects on the environment. This analysis includes the state of the environment, foreseeable impacts, justification of the choices in relation to the possible alternatives, measures to avoid, reduce or even compensate for the effects on the environment, and a non-technical summary.

The integration of environmental concerns must be prioritized by applying the triptych avoid>reduce>compensate. That is, to seek to avoid and eliminate impacts before reducing them and, if significant residual impacts remain, compensate them to the possible extent. Also, focus must be on action at source and use of the best available economically acceptable technologies.

Environmental assessment is a decision-making tool. It must therefore be initiated as early as possible and be inserted early enough in the authorization or approval procedure in order to guide the choices of the petitioner and the decision-making authority.

3.5.3 Objectives of the environmental assessment

The environmental assessment process ensures that the environment is taken into account as far upstream as possible in order to ensure a balanced development of the land. It provides an opportunity to identify environmental issues and to ensure that directions envisaged in the plan or program are relevant. The objectives of environmental assessment are:

- to verify that all environmental factors have been taken into account at each stage of preparation of the plan or program;
- to analyze throughout the development process of the plan or program, the potential effects of development and management objectives and orientations on all environment components;
- to allow the necessary changes to ensure compatibility of the guidelines with the environmental objectives; and,
- to prepare a factual assessment of the effects of the plan/program on the environment.

The environmental assessment must be seen as an approach for a coherent and sustainable project. It must rely on all processes that enable to verify the inntegration of:

- the objectives of the protection policy and development of the environment, which must be reflected in commitments as precise as those relating to planning and development;
- dispositions to reduce negative impacts and strengthen the positive effects of the guidelines adopted;
- studies on environmental impacts; and,
- results of discussions on the compatibility of different territorial issues (economic, social and environmental).

3.5.4 Different types of environmental assessments

The environmental assessment must take into account the environment as a whole (resources, biodiversity, natural or technological risks, energy, heritage, spatial planning and management, etc.) and clarify decision-making in particular through information and public participation. In particular, it provides a framework for cross-cutting analysis and allows a decompartmentalization of themes and studies. For projects, the impact study has existed since 1976.

3.5.5 Economic assessment of ecosystems

Importance of the ecosystem in economic assessment

The concepts of ecosystem, biodiversity, and ecological goods and services deserve to be clarified in this text, since it will be possible to understand the different relationships between the components. This will enable us to measure values and then try to more effectively support the management of natural resources.

The symbiosis of two components, the biotope and the biocenosis, is necessary to satisfy the definition of an ecosystem (Olivier, 2011). The biotope is represented by an amalgam of abiotic factors, i.e. components of a physical and chemical nature that differentiate a given natural environment from another and create a wide variety of habitats. This physico-chemical environment must be relatively stable over time in order to allow biocenosis, i.e. the living world, to associate with it and find its niche. The biocenosis is composed of a specific community in which the interactions between populations, individuals and species are highly organized.

These result from the structural and functional units of the ecosystem. By definition, an ecosystem is therefore without spatial dimension since the only condition for being in the presence of an ecosystem is that there is a particular life in a specific habitat. The dimension is delimited by what is sought to be understood (*ib.*). This allegation is particularly important in an economic assessment context that assists decision-making as it is usually linked to a spatial constraint. Indeed, since ecosystems differ enormously from one another and therefore do not all provide the same ecological services, it is essential to undertake economic assessments on a specific time and space scale (UK NEA, 2011).

Ecological goods and services

Without biodiversity, no ecological goods or services can exist (Limoges, 2011). They are the benefits of ecosystems that contribute to human well-being. The quality and quantity of these ecological services seem to depend on the integrity of ecosystems and the maintenance of biodiversity. The more an ecosystem generates ecological goods and services useful to humans, the higher its economic value will be. It is therefore important to know and understand how ecosystems work and to what extent they generate their goods and services.

The resilience of ecosystems, i.e. their ability to adapt to disturbances and to continue generating goods and services, must be known to ensure their continuity over time (Sukhdev, 2010). However, a great deal of knowledge is lacking to accurately assess this resilience, which can cause the ecosystem to deteriorate beyond its critical threshold, its point of no return (*ib.*). This situation would entail the obligation to replace the services provided by this ecosystem. Such replacement could be more costly than if the ecosystem had been better managed in the first place.

Categories of ecological goods and services

Ecological services vary enormously from one ecosystem to another, making it difficult to identify those that are relevant to the case study. Given the complexity of ecosystem functioning and processes, one of the first steps to a proper understanding of the assessment is to group these processes into functions where it is possible to classify the various ecological goods and services (De Groot, 2002). This approach eases the comparison of the different benefits (Wallace, 2007) and also limits the possibility of double accounting of ecological services, which would bias the results of the economic assessment (UK NEA, 2011).

There is a wide range of ecological goods and services classification systems (UK NEA, 2011; DSS 2010; Limoges 2009; Wallace 2007; Boyd et al., 2006; De Groot 2002). However, the ranking of the MS appears to be the most frequently adopted (DSS, 2010) by independent scientists (UK NEA 2011, Brahic and Terreaux 2009) and by government entities (Reveret et al., 2008). According to the MA, services can be classified into four categories: procurement services, regulatory services, cultural services and support services.

3.5.6 Economic evaluation of goods and services

Economics includes the science of trade-off (Bourassa, 2011a). Indeed, since the totality of the resources and especially the natural resources are in limited quantity, choices as to their use are necessary. These choices can be informed by assessing alternatives to possible uses of natural capital by comparing benefits and costs (Sukhdev, 2008). To do this, it is advisable to reduce the comparison to a common unit, the dollar, and "*economics become, among other things, a "translator" into dollar of changes in physical units per ecosystem (m^3, No. of fish, etc.)*" (Bourassa, 2011a).

Concepts

Several economic concepts must be observed when evaluating ecological goods and services. First, it is important to note that economic valuation is based on an anthropocentric approach where environmental values are related to the concept of utility (Bourassa, 2011a, Nolet, 2011; National Research Council of the National Academies (NRC), 2004). In other words, and in its most simplified expression, economic assessment takes into account the utility of an ecological good or service and the welfare it provides to humans. However, the benefit that an individual derives from the use of any property is not necessarily perceived as a benefit to others, i.e. what is useful for one is not necessarily so for others. Inevitably, the values attributed to goods are relative and depend on the individual. Indeed, these depend on the needs and desires, constrained and influenced by the availability of the good, the income and the educational background of each one as well as the temporal variable (Brahic and Terreaux, 2009; NRC, 2004). In general, economic assessments seek the value that society attributes by aggregating individual values. Moreover, it is important to remember that the context and the time scale for the decision-making is inherent to economic evaluation (NRC, 2004; Sawyer et al., 2001).

Another important notion in economics refers to the fact that individuals have preferences for certain goods and services (Field and Olewiler, 2005). These preferences are reflected in the individual´s willingness to pay (WTP) (NRC, 2004). To know the value that an individual gives an asset, one must ask how much he is willing to pay for it or how much he is willing to receive to compensate for its loss or degradation (Field and Olewiler, 2005). Economic valuations attempt to identify these preferences for changes in the state of the environment and translate them into monetary terms (Defra, 2007). The notion of marginality is therefore particularly important (Field and Olewiler, 2005) since it is from the marginal value, i.e. from the last unit, that it will be possible to evaluate what simple change in the productivity of a given ecosystem can induce in term of human well-being (Brahic and Terreaux, 2009). In such a context, it is important to understand how a change in the quantity and quality of the environmental components that make up ecosystems and produce ecological goods and services will impact human well-being.

The market price corresponds to the point of equilibrium, i.e. when the supply curve crosses that of demand (Field and Olewiler, 2009). Price is a measure that demonstrates the importance of an asset in economic terms but underestimates the value of the asset because the consumer surplus is not considered in that price. Consumer surplus is an important concept in economics that equates to the net benefit a consumer derives from using a good (Poder, 2011). This benefit corresponds to the yellow hatched area in which "surplus to the consumer" is written under the curve of demand and above the fixed price. The WTP corresponds to all the hatched areas (gray and yellow) including the surplus to the consumer.

Total economic value

The total economic value (TEV) is an evaluation framework for determining the set of values generated by the ecological goods and services of an ecosystem (Brahic and Terreaux, 2009, Reveret et al., 2008; NRC, 2004). The advantage of using TEV to categorize the different values of ecological goods and services is that it favors an economically logical approach and includes all aspects of the environment value (Marbek, 2010). First, it seems essential to specify that the TEV resulting from economic evaluations corresponds to values that are relevant to decision-making and offers an order of magnitude to evaluate environmental compromises in relation to the objectives of the valuation (Bourassa, 2011c; Nolet, 2011). The TEV framework has been developed to categorize the diversity of these values or benefits (NRC, 2004). This classification can help to reduce the possibility of forgetting certain values in assessments or evaluating them twice (*ib.*). The TEV can be evaluated using use and non-use values (Bourassa, 2011a; Anielski and Wilson, 2005; NRC, 2004).

It is important to note that TEV does not mean that all values associated with ecological goods and services of an ecosystem should be systematically calculated. Rather, all values affected by individuals need to be assessed when there is a change in the ecological goods and services involved (NRC, 2004). The context of decision-making then becomes very important. Indeed, changes in the ecosystem depend on the issue to be considered which differs from one situation to another.

Use values

Use values derive from three sources: direct or indirect use of natural resources or option values. Direct use values are those directly consumed by population. Often, a market value is associated with the use of these ecological goods and services when the resource is extracted. When there are no resource withdrawals, direct use values may also include non-market benefits derived from, for example, recreational activities (Brahic and Terreaux, 2009; Anielski and Wilson, 2005; NRC, 2004). In both cases, the direct use requires some physical interaction between human and his natural environment (NRC, 2004).

Indirect use values are derived from ecological services that provide indirect support and protection for the maintenance of production of resources generating economic activities (Brahic and Terreaux, 2009; NRC , 2004). Regulatory and support functions are examples of this category of values. For example, wetlands present on the land may filter the water before it flows downstream into lakes. In this way, the phosphorus and nitrate input into the lake can be reduced, improving the recreational use of the lake (*ib.*).

Option values refer to potential future uses of natural capital, whether direct or indirect, that would be lost in the event of an irreversible change of an ecosystem (Bourassa, 2011a; Olivier, 2011; Brahic and Terreaux, 2009). These values correspond to the amount people would be willing to pay for preserving the environment in order to be able to use it and benefit from it later (Brahic and Terreaux, 2009; Field and Olewiler, 2005). An example of option value could be the permanent disappearance of a threatened species finding its niche in the area due to a housing project that would mortgage the existence of this species locally or on the planet.

Non-use values

As suggested by their names, non-use values represent values that humans give to the mere fact that resources exist in nature without necessarily being used or even perceived (NRC, 2004). Such environment values can, for example, be a particular heritage value (Bourassa, 2011a).

The so-called patrimonial value refers to the desire to transmit the environmental legacy from which future generations can benefit (Olivier, 2011). For example, residents in a particular case may actively preserve the upstream area of a lake so that the lake also can be used by future generations for recreational and other uses. The existence value is attributed based on the fact that an ecological good or service exists without necessarily being observed or used (NRC, 2004). A rare species or a particular ecosystem may be examples for which humans would give an existence value.

Methods of economic evaluation

Overall, it appears that measuring the economic value of procurement services is mostly direct since most of these services are traded on the market and therefore have a price as a basis for evaluation (Sukhdev, 2008). The assessment of regulatory services, support services and cultural services is more difficult because, in most cases, they have no price in the market, which makes them less tangible and less concrete. It is therefore less easy to estimate their value (*ib.*). However, economists have developed a set of methods for estimating the non-market value of ecological goods and services, either by analyzing alternative markets or by creating artificial markets (Bourassa, 2011b).

Methods can be categorized into three approaches: the revealed preference approach, the stated preference-based approach and the transfer of profits apprpach.

Approaches of revealed preference are based on the principle that it is possible to “deduce the value of the compromise using existing situations and behaviors and actual decisions made by individuals” (Bourassa, 2011b). The preferences of individuals are thus revealed according to behavior observed with respect to existing markets concerning traded goods (Brahic and Terreaux, 2009; Reveret et al., 2008). Many methods can be used, e.g.:

The ***market price method*** is applied for commercial goods, for example the price of timber. This way of assessing reflects real and individual preferences and requires relatively easy information to obtain (*ib.*). However, it can only apply to commercial goods, which have a market price. Another weakness of this valuation method relates to externalities that are often not taken into account in market prices and which biases the estimation of the economic value (Reveret et al., 2008; Field and Olewiler, 2005). Finally, this method does not take account of the surplus to the consumer.

In the ***hedonic pricing approach***, preference will be deduced from the variability of value of a property, which depends on certain environmental attributes that surround it and which are taken into account in market prices (landscape, water and air qualities, proximity to a watercourse, etc.) (Reveret et al., 2008). Thus, this technique implies the determination of the relative contribution of the environmental quality variables to the value of the property (Poder, 2011), which reflects the real preferences of individuals (Olivier, 2011). Should the value of these properties change, this approach could be used to assess the extent to which the change in environmental conditions contributed to this change in value. However, in addition to being applicable only to observable environmental variables, the hedonic price method requires a high level of expertise related to the econometric manipulation of variables as well as access to data often unavailable on the land market (*ib.*).

Another variant of the revealed preference approach is that of ***transport costs***. The principle underlying this method is that individuals, to enjoy nature, will move to natural destinations. They will generate spending (Field and Olewiler, 2005). These expenses can be used as a proxy for their WTP. Consequently, this latter method is mainly favored to estimate the value of recreational sites, wildlife reserves and natural parks (*ib.*), but it requires listing a lot of data, such as the number of visitors, their origin and distance traveled to the site, and their travel costs (*ib.*).

Stated preference approaches, unlike the previous ones, are not based on observed behavior, but on the hypothetical market creation supposed to reflect a market situation. The creation of a market enables us to know directly or indirectly the individual willingness to pay or to be compensated (*ib.*). These scenarios are submitted to individuals through surveys or questionnaires to investigate their individual preferences (Field and Olewler, 2005) as to the compromise to be made following a change in quality or quantity of an ecological good or service (Bourassa, 2011a).Two methods can be used in this approach: *contingent valuation* or *joint analysis* (Bourassa, 2011b). The main difference between these two methods is that contingent valuation directly invites individuals to indicate their WTP for a specific ecological good or service (Brahic and Terreaux, 2009), whereas joint analysis indirectly solicits individuals by using hypothetical scenarios and a statistical approach (Bourassa, 2011b). Moreover, because the joint analysis is a little more elaborate, it is possible to better account for the budget constraints of individuals in the different scenarios than the contingent evaluation (*ib.*).

This type of approach has the merit of being flexible in its application depending on the type of values being evaluated and the results obtained are relatively easy to interpret (Reveret et al., 2008). However, the development of questionnaires requires careful attention in order to avoid possible bias in the true intent of respondents (*ib.*). A good way of assessing the non-use values of ecological goods and services in is to conduct a field survey and interview the local community in order to know their WTP, for instance for the conservation of an area or their consent to receive compensation for the loss of that area.

Profits transfer approaches call for transposing the economic values of ecological goods and services obtained from studies of similar sites prior to the site under study, i.e. the site for which an economic value is sought (Bourassa, 2011a). For example, the economic assessment values of wetland services in the broader region could be transferred to the site under study to estimate a plausible services value of wetlands in this area. There are three types of transfer: *values transfer* (with or without expert judgment), *transfer of functions* and *meta-analysis* (*ib.*). Briefly, the values transfer simply implies to export previously estimated data from a study site that fits the observed site, whereas the transfer of functions and meta-analysis require adjusting or developing a value function specific to the characteristics of the site under study (Brahic and Terreaux, 2009).

The application of benefit transfer involves finding relevant studies that adequately represent benefits of ecological services sought to be estimated for a study site (Evri, 2011).

3.5.7 Tariff and taxation systems

Application of the polluter pays principle

The polluter pays principle stems from the ethics of responsibility, which consists in awaring economic actor about the negative externalities of his activity. Its principle was developed by the liberal economist Arthur Cecil Pigou in the early 1920s.

Measures under the polluter pays principle are aimed at restoring “price truth”: if an economic activity causes pollution, the cost of this pollution (borne by the community) must be taken into account at the polluter’s level. The polluter thus integrates in his economic choice the total costs linked to his production (private costs and external costs). However, internalization does not mean that the polluter pays for the cost of pollution control measures, but only takes it account.

The polluter pays principle was adopted by the OECD in 1972 as an economic principle for the polluter to take responsibility for the “costs of pollution prevention and control measures adopted by the government to maintain the environment in an acceptable condition”. This principle is one of the key principles underpinning environmental policies in developed countries. It is at the origin of the internalization of pollution costs by the perpetrators of pollution through regulatory instruments (standards, prohibitions, permits, zoning, quotas, restrictions on use and other direct regulations), economic instruments (royalties, subsidies, deposit systems, market creation, incentives for compliance), or tax instruments.

Summary

This session presents knowledge on environmental assessments, firstly through a definition of relative concepts. Subsequently, types of environmental and economic assessments are presented. A section is dedicated to ecological goods and services with an emphasis on their different categories. Finally, the economic methods of assessment are presented.

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Chapter 4: Processes, Drivers and Impacts of Climate Change

4.0 Chapter overview

This chapter introduces the concepts of global change, climate systems, climate change and variability, drivers of climate change and vulnerability to climate change, as well as related terminologies. It examines the linkages between greenhouse gases (GHGs) emissions and climate change and the trends of climate change at the global, regional, and national levels. Further, the chapter introduces learners to the three broad categories of drivers of climate change, viz. *external* (extra-terrestrial); *internal* (within the Earth system); and, *anthropogenic* (human activities), with more emphasis on anthropogenic factors that result in GHGs emissions and land use changes, including deforestation, urbanization, and transportation. Finally, the chapter introduces learners to concepts and determinants of vulnerability, approaches to its assessment, its dynamism, biophysical vulnerability and impacts, socio-economic vulnerability and impacts, impacts of climate change on different sectors, strategies to manage and reduce hazards, and how to reduce risks associated with climate change.

Learning outcomes

By the end of this chapter, the learners will be able to:

a) define the key concepts in global and climate change;

b) explain elements of global change and their implications on climate change;

c) distinguish components of climate systems;

d) synthesise evidence of climate change;

e) analyse the trends in climate change, and associated threats and opportunities at community (sub-national), national, regional and international levels;

f) explain drivers of climate change;

g) assess how various drivers of climate change cause climate variability and increase GHGs;

h) explain the concept of vulnerability to climate change;

i) analyze approaches to vulnerability assessment and their application in forestry and related sectors;

j) describe impact of climate change on socio-economic systems and forestry-related sectors;

k) explain risks due to climate change and how to undertake disaster risk assessment and reduction in forestry and related sectors; and,

l) evaluate the response of sub-national, national and regional level initiatives to vulnerability and impact of climate change.

4.1 Concepts in global and climate change

This session provides the basic definitions of terminologies and concepts relating to global and climate change. The session explains the importance of studying climate change and also explains the terminologies associated with climate change.

Studiying climate change is important because rising global temperatures are expected to raise sea levels and change precipitation and other local climate conditions. Changing regional climate could alter forests, crop yields, and water supplies, and affect human health, animals and many types of ecosystems. Deserts may expand into existing rangelands, and features of some of our national parks and national forests may be permanently altered.

Objectives

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

a) define all basic definitions relating to weather, climate, global change and climate change;

b) explain elements of global change and their implications for climate change; and,

c) distinguish between components of climate systems.

Activity 1 (Brainstorming) (20 minutes)

- Share your views on the concept of climate change
- Discuss the effects of the variation in temperature and rainfall on people, crops, animals and forest?

4.1.1 Climatology

Climatic parameters

Climate is the long term variability, usually around 30 years, of weather conditions of a given region. whereas *weather* is the short term variability,from minutes to months, of atmospheric parameters.

The determination of the climate is carried out using annual averages obtained from local atmospheric data: temperature, precipitation, sunshine, humidity and wind speed for a period of at least 30 years.

Precipitation refer to all water (rain, snow, hail) in solid or liquid form depending on the composition and temperature of the atmosphere. This meteorological term refers to hydrometeors (ice crystals or water droplets) on Earth, which, having been subjected to condensation and aggregation processes within clouds, have become too heavy to remain suspended in the atmosphere and fall to the ground or evaporate in virga before reaching it.

Temperature is a physical quantity measured by means of a thermometer and studied in thermometry. In everyday life, it is related to the sensations of cold and heat, resulting from the thermal transfer between the human body and its environment. In physics, it is defined in several ways: as an increasing function of the degree of thermal agitation of particles (in kinetic theory of gases), by the equilibrium of thermal transfers between several systems or from entropy (in thermodynamics and In statistical physics). Temperature is an important variable in other disciplines: meteorology and climatology, medicine and chemistry.

Hygrometry characterizes the humidity of the air, i.e. the amount of gaseous water present in the humid air (or other gas, in some industrial applications). It does take into account the water present in liquid or solid form. Three types of hygrometry can be defined, each has its associated measure:

- ***absolute***: the quantity of water in gaseous form (vapor) in a volume of air, expressed in units of mass per volume;
- ***relative***: absolute humidity in proportion to the maximum value, for a given temperature, expressed as a percentage;
- ***specific***: the ratio between two masses, that of water in gaseous form contained in a volume of air, and that of this volume of air.

Aridity is a climatic phenomenon involving low rainfall. In the so-called arid regions, precipitation is lower than the potential evapotranspiration (PET). Since aridity is a spatial concept, a region can be described as arid and not a period. It also occupy nearly 30% of continental lands distributed over various latitudes. There are arid zonal zones due to the presence of the descending part of the Hadley cells (a global scale tropical atmospheric **circulation** that features air rising near the equator, flowing poleward at 10-15 kilometers above the surface, descending in the subtropics, and then returning equatorward near the surface) and the non-zonal deserts due to various causes. *Aridification* is the gradual or abrupt change of climate leading to a situation of aridity.

Insolation is the measure of the solar radiation received by a surface during a given period, expressed in megajoules per square meter, MJ/m^2 (as recommended by WMO) or Watts-hours per square meter, Wh/m^2 (especially by the solar industry). This measurement divided by the recording time provides the power density measurement, called irradiance, expressed in watts per square meter (W/m^2).

Potential evapotranspiration is the maximum amount of water that can be evaporated under a given climate by a continuous vegetation cover that is well fed with water. It thus comprises the evaporation of the soil/substrate and the transpiration of the vegetation of a given region during the time considered. It is expressed in height of water.

Variation of climatic parameters

The global temperature is the average surface temperature of the entire planet. It is not easy to calculate since It is not a single thermometer that measures the overall temperature. The data comes from probe balloons, satellites and thousands of thermometers scattered throughout the world, and are combined with thousands of temperature measurements on the surface of the seas. Scientists have reconstructed the temperatures of the last 1,000 to 2,000 years and this research shows that the temperature has decreased slowly over the past 1,000 years, with a sharp turnaround during the 20th century. This graphic is known for its hockey stick shape. It is complicated to precisely calculate temperature changes. Prior to 1860, temperatures were not measured systematically. Fortunately, there are other ways of knowing whether in the past the temperatures were warmer or colder. A warming of 0.85°C seems at first sight very little and negligible. Impossible to feel the difference oneself. But if you look at that increase on a global scale, it is a very large and very rapid increase.

Causes of climatic variation

Several factors come into play in the variation in climate, whether it is a long-, medium- or short-term:

- On the scale of millions of years. it is the movement of the tectonic plates that make the continents move and have an influence on the marine currents which influence the oceanic and continental climate, cyclones, etc.;
- On the scale of thousands of years, it is the Milanckovich's law with astronomical variations (precession of equinoxes and perihelions, obliquity, variation of Earth orbit) that influence the climate on cycles of 10,000 to more than 100,000 years and which are most often the cause of glaciations and interglaciations. The theory describes the effects of the movement of the planet on the global climate. It explains how variations in the orbit around the sun, the angle of inclination of the Earth's axis, and the rotational motion of the Earth's axis influence the Earth's temperature. The latter cause a variation of the temperature on Earth and explain the successive passages of the glacial periods to the interglacial periods during the last 2.5 million years;
- On the scale of hundreds of years or more, it is the solar activity and the various solar cycles (Hallstattzeit cycle of 2300 years, Suess of 200 years) which influence the climate over very long periods and make changes in temperature driven by very long-term factors less regular;
- On the scale of decades, oceanic oscillations, such as Multi-decadal Oscillation (AMO) and Pacific Decadal Oscillation (PDO), which have cycles of 60-70 years, cause the exchange of energy between ocean-atmosphere to vary over decades and also influences changes in temperature;
- In the short term (a few years) there are also various oceanic oscillations such as El Niño and La Niña, which also influence the amount of energy exchange between the ocean-atmosphere from one year to the next. There are also significant volcanic eruptions which, for periods of 2-3 years, can decrease the the amount of energy reaching the ground and have other effects, such as aerosols, desert dust, soil change, all of which may cause changes in albedo; and,
- Finally, for the last 40-50 years, humans also influence the climate with CO_2 and other greenhouse gases emitted into the atmosphere through burning of fossil fuels and deforestation. This causes changes in temperature in the long run. Human effects may also be indirect, like the variation of the albedo caused by, for example, changes in the land-use.

4.1.2 Atmospheric circulations and ocean dynamics

It is a physical process resulting from the action of the wind which sets in motion surface layers of the ocean along the coasts and moves them towards the open sea, causing an upward vertical flow along the continental shelf to compensate for the imbalance at the coast. This results in the formation of a strong temperature gradient from the coast to the sea. On the Atlantic coast of Africa, the trade winds, which have a direction substantially parallel to the coast, are at the origin of the permanent or seasonal upwellings which develop along the coasts of the Gulf of Guinea to Mauritania.

Upwelling is an oceanographic phenomenon that occurs when strong sea winds (usually seasonal winds) push the surface water of the oceans, leaving a void in which the bottom waters can flow and with them a significant amount of nutrients. The phenomena of upwelling are identified by their results: a cold sea rich in phytoplankton. For for fishermen, upwelling results in a significant increase in the number of fish.

Downwelling is the opposite phenomenon of the upwelling. The surface waters accumulate near the coast.

The Gulf Stream is a warm, surface marine current that runs along the US coast from the Gulf of Mexico and travels northeast across the Atlantic Ocean, driven by the prevailing southwesterly winds, gradually cooling. The Gulf Stream is among the strongest currents. It moves hot water from the subtropical zones to the poles.

El Niño (literally “the Child (Jesus)” because it appears shortly after Christmas is a phenomenon that prevents the upwelling of cold water along the west coast of South America and whose consequences can be dramatic: abundant rain in Peru, deviation of the trajectory of the typhoons, and drought in Indonesia. Originally, it refers to a warm seasonal coastal current of Peru and Ecuador ending the fishing season. The term now denotes the particular climatic phenomenon, different from the normal climate, which is characterized by abnormally high water temperatures in the eastern part of the South Pacific Ocean, representing a southern extension of the Peruvian hot current. It has been linked to a cycle of variation in global atmospheric pressure between the eastern and western Pacific, called the Southern Oscillation. The phenomena are called *El Niño-Southern Oscillation* (ENSO).

4.1.3 Ocean-atmosphere heat exchanges

Like the atmosphere, the ocean plays an important climate role. The water heats up and cools down less quickly than the air. The ocean has a much longer “memory” than the atmosphere: of the order of a season with regard to surface currents and at least of a decade with regard to the large bodies of water in the deep ocean.

The heat thus stored in the water of the tropical zones is restored to the atmosphere at the highest latitudes. This is how the oceanic surface and deep currents are generated, which carry this heat from the equator to the poles. This helps to balance the excess solar radiation received by the equatorial regions. The Atlantic probably carries more heat from the equator to the north than the Pacific. It is estimated that the ocean contributes about 30% to the transport of heat, from the equator to the poles, achieved by the climate system.

4.1.4 Definitions of terminologies in global and climate change

Weather and climate

Weather describes the condition of the atmosphere over a short period of time e.g. from day to day, or week to week, while climate describes average conditions over a longer period of time. The difference between weather and climate is a measure of time. Some scientists define climate as the average weather for a particular region and time period, usually measured over 30 years.

Humidity, air temperature and pressure, wind speed and direction, cloud cover and type, and the amount and form of precipitation are all atmospheric characteristics of the momentary conditions we call weather. By contrast, the term “climate” describes the overall long-term characteristics of the weather experienced at a place. For example, Ghana in the tropics has a dry and wet weather, while Russia has a cold winter.

Ecosystems, agriculture, livelihoods and settlements of a region are very dependent on its climate. Climate therefore can be considered as a long-term summary of weather conditions, taking account of average conditions as well as the variability of these conditions. Fluctuations that occur from year to year, and the statistics of extreme conditions, e.g. severe storms or unusually hot seasons, are part of the climatic variability.

Global Change

Global change refers to planetary-scale changes in the Earth system. The system consists of the land, oceans, atmosphere, Polar Regions, life, the planet’s natural cycles and deep Earth processes. There is overwhelming evidence that from now on, the main driver of global change, is the growing human population’s demand for energy, food, goods, services and information, and disposal of its waste products. In the last 250 years, global change has caused climate change, widespread species extinctions, fish-stock collapse, desertification, ocean acidification, ozone depletion, pollution, and other large-scale shifts.

Climate change

Climate change refers to a change in the state of the climate that can be identified by changes in the mean and/or the variability of its properties, and that persists for an extended period, typically decades or longer. Climate change may be due to internal processes and/or external forces. Some influences, e.g. changes in solar radiation and volcanism, occur naturally and contribute to the variability of the climate system. Other external changes, such as the change in composition of the atmosphere that began with the industrial revolution, are the result of human activity. Climate change predictions are based on mathematical models called General Circulation Models (GCMs) that combine our knowledge of physical processes and interactions between the ocean, atmosphere and land. Climate specialists describe the predicted changes in climate in terms of variability of weather and frequency of extremes.

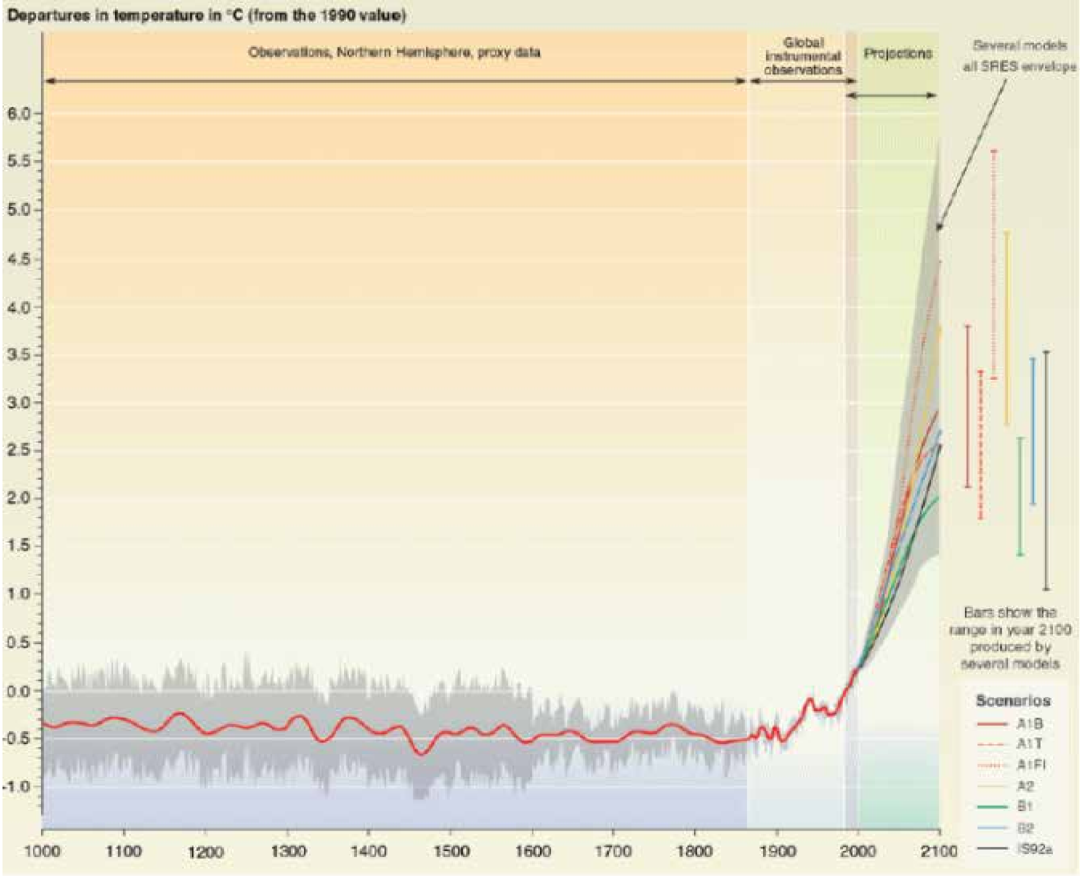

Figure 18. Variations in the surface temperature of the Earth from the year 1000 to 2100. SRES = Special Report on Emissions Scenarios (IPCC 2001).
Source: IPCC (2002).

Earth's climate system has changed since the preindustrial era, in part because of human activities, and this change is projected to continue throughout the 21st century. During the last 100 yr, the mean global surface temperature has increased by c. 0.6°C (see Fig. 18).

There is strong evidence of increases in average global air and ocean temperatures, widespread melting of snow and ice, and rising global sea levels. The Intergovernmental Panel on Climate Change (IPCC) Fourth Assessment Report concludes that the global warming is unequivocal. Atmosphere and ocean temperatures are higher than they have been at any other time during at least the past five centuries, and probably for more than a millennium. While there has been some controversy in the past, it is now widely accepted that human activities, in particular fossil fuel use and changing land-uses, are the dominant factors in this increase and are responsible for most of the warming observed over the past 50 years.

Two other variables that influence climate are deforestation and the hydrologic cycle. Deforestation has the potential to affect climate through the carbon and nitrogen cycles, which alter atmospheric concentrations of carbon dioxide. Changes in the hydrologic cycle, involving precipitation, evaporation and runoff, also affect the climate. Deforestation and desertification influence the amount of solar energy absorbed at Earth's surface (this is termed albedo or reflectivity).

The scientific consensus relating to climate change is that the average temperature of the Earth has risen between 0.4 and 0.8°C over the past 100 years. Scientists from IPCC carrying out global warming research have recently predicted that average temperatures could increase between 1.4 and 5.8°C by the year 2100. Changes resulting from global warming may include rising sea levels due to the melting of the polar ice caps, as well as increase in occurrence and severity of storms and other severe weather events.

The difference between "global warming" and "climate change" is that "global warming" refers to the long-term increase in Earth's average temperature. "Climate change" on the other hand refers to any long-term change in Earth's climate, or in the climate of a region or city. This includes warming, cooling and changes besides temperature. It is a change in the typical or average weather of a region or city. This could be a change in a region's average annual rainfall, for example. Or it could be a change in a city's average temperature for a given month or season. Climate change is also a change in Earth's overall climate. This could be a change in Earth's average temperature, for example. Or it could be a change in Earth's typical precipitation patterns.

Climate change corresponds to a lasting change (from the decade to the million years) of the statistical parameters (mean parameters, variability) of the global climate or its various regional climates. These changes may be due to processes intrinsic to the Earth, external forces or human activities.

In the recent context of ecological policy, the term "climate change" refers only to changes in the current climate that have emerged throughout the 20th century and are expected in the 21st century. In the the IPCC report, the term "climate change" refers to any changes over time, whether due to natural variability or human activities. According to the United Nations Framework Convention on Climate Change (UNFCCC), the term refers only to changes due to human activities. UNFCCC uses the term "climate variability" to refer to climate change of natural origin.

The international scientific community, represented on this subject by IPCC, attributes the current global warming to human origin. Its fourth and final report, involving more than 2,500 scientists from 130 different countries, states that the probability of global warming to be of human origin is more than 90%.

Box 4. What is the difference between climate change and global warming?

Global warming refers to an increase in the average temperature of the Earth in the long term whereas climate change refers to any change in the climate of the Earth or in the climate of a region or a city in the long term.

Climate variability

Climate variability is the way climate fluctuates yearly above or below a long-term average value. Scientists typically use average weather conditions over 30 year's intervals to track climate. These 30 years averages are used to determine, monitor or represent the climate of a particular location. It is the year-to-year fluctuations around the normal that is called climate variability. Common drivers of climate variability include El Niño and La Niña events, which are the "warm" and "cold" phases respectively of ENSO (see above).

Averages of weather and climatic conditions are used to make important societal decisions. For example, climatological normal precipitation and historical records of storm events are used to calculate probabilities of future rain events. Engineers can use these data to design community storm water drainage systems. The data also serve as a baseline against which to compare current weather and climate data. Without a baseline against which to compare we have no way to understand how current observations fit into the bigger picture.

In general, climate variability refers to the natural intra- and inter-annual variation of the climate,whereas climate change refers to a change in climate attributed directly or indirectly to human activities that alter the composition of the global atmosphere in addition to the natural climate variability observed over comparable periods of time (UNFCCC, 1992).

Box 5. Why study climate variability?

Even if the entire scientific community agrees on the reality of climate change and global warming in the future (IPCC, 2007), it is still difficult to distinguish between a real change and the natural variability of climate. It is not uncommon to hear, when extreme events occur, that it is still too early to attribute them to climate change, and that it is prudent to consider them as inter-annual climate variability. This is why it is necessary to study climatic variability.

Global warming

Global warming is the term used to describe a gradual increase in the average temperature of the Earth's atmosphere and its oceans, a change that is believed to be permanently changing the Earth's climate. There is a great debate on whether global warming is real. But climate scientists looking at the data and facts agree that the planet is warming.

The reason the Earth's surface is this warm is the presence of greenhouse gases (GHGs), resulting from human activities, which act as a partial blanket for the long wave radiation coming from the surface. GHGs are gases in an atmosphere that absorbs and emits radiation within the thermal infrared range. The primary GHGs in Earth's atmosphere are water vapour, carbon dioxide, methane, nitrous oxide and ozone. The combustion of fossil fuels and deforestation have caused a 26% increase in CO^2 in the atmosphere. Methane concentrations have more than doubled because of rice production, cattle rearing, biomass burning, coal mining and ventilation of natural gas. Nitrous oxide has increased by about 8% since pre-industrial times, likely as the result of human activity, especially agriculture. Chlorofluorocarbons, used as aerosol propellants, solvents, refrigerants and foam-blowing agents, have been present in the atmosphere only since their invention in the 1930s.

Activity 2 (Group Discussion) (20 minutes)

Explain why it is important to study the concept of climate change.

In text questions (10 minutes)

1. Identify and define commonly used terminologies in the field of climate change?
2. What are the implications of GHGs on climate?
3. What is the difference between “Climate Change” and “Global Warming”?
4. Why should we study climate change?

Summary

The session has dealt with the importance of studying and basic definitions of climate change. The differences and relationship between climate and weather have been dealt with. The session also described how the important weather elements have been changing as a result of changing climate. The next session introduces learners to the basics of climate science and biogeochemical cycles and how they affect life on Earth.

4.2 Basics of climate science and biogeochemical cycles

This session outlines the basics of climate science and biogeochemical cycles. It starts with an introduction and deals with implications of climate processes and concepts; effects of surface-atmosphere interactions on climate; and, hydrological, carbon and nitrogen cycles.

Objectives

By the end of this session, the learner should be able to:

a) describe layers and functions of the atmosphere;

b) explain the effects of surface-atmosphere interactions on the climate;

c) describe and explain the components, functions, effects and importance of the hydrological, carbon and nitrogen cycles; and,

d) analyze the effects and implications of changing climate on these cycles.

Activity 1 (Group discussion and presentations) (30 minutes)

- Group 1 should give a short presentation on the atmosphere.
- Group 2 should present on the causes of air pollution and their effects on the atmosphere.
- Group 3 should present on the importance of the hydrological cycle.
- Group 4 should present on the importance of the nitrogen cycle.
- Group 5 should present on the importance of the carbon cycle
- Groups 3-5 should stress on the effect of changing climate on these important life cycles.

4.2.1 Effects of surface-atmosphere interactions on the climate

Volcanic activity and Climate Change

A volcano is a rupture in the crust of the Earth that allows hot lava, volcanic ash and gases to escape from a magma chamber below the surface. Earth's volcanoes occur because its crust is broken into 17 major, rigid tectonic plates that float on a hotter, softer layer in its mantle. Therefore volcanoes are generally found where tectonic plates are diverging or converging. For example, a mid-oceanic ridge, such as the Mid-Atlantic Ridge, has volcanoes caused by divergent tectonic plates pulling apart; the Pacific Ring of Fire has volcanoes caused by convergent tectonic plates coming together.

Volcanoes can also form where there is stretching and thinning of the crust's interior plates, e.g., in the East African Rift and the Wells Gray-Clearwater volcanic field and Rio Grande Rift in North America. This type of volcanism falls under the umbrella of "plate hypothesis" volcanism. Volcanism away from plate boundaries has also been explained as mantle plumes. These so-called "hotspots", for example Hawaii, arise from upwelling diapirs[1] with magma from the core–mantle boundary, 3,000 km deep in the Earth. Volcanoes are usually not created where two tectonic plates slide past one another.

Volcanoes can impact climate change during major explosive eruptions where huge amounts of volcanic gas, aerosol droplets and ash are injected into the stratosphere. Injected ash falls rapidly from the stratosphere – most of it is removed within days to weeks – and has little impact on climate change. But volcanic gases like sulphur dioxide can cause global cooling, while volcanic CO_2, a GHG, has the potential to promote global warming.

The most significant climate impacts from volcanic injections into the stratosphere come from the conversion of sulfur dioxide to sulfuric acid, which condenses rapidly in the stratosphere to form fine sulfate aerosols. The aerosols increase the reflection of radiation from the Sun back into space, cooling the Earth's lower atmosphere or troposphere. Several eruptions during the past century have caused a decline in the average temperature at the Earth's surface of up to half a degree for periods of one to three years. The climactic eruption of Mount Pinatubo in June 1991, was one of the largest eruptions of the twentieth century and injected a 20-million ton sulfur dioxide cloud into the stratosphere at an altitude of more than 30 kms. The Pinatubo cloud was the largest sulfur dioxide cloud ever observed in the stratosphere since the beginning of such observations by satellites in 1978. It caused what is believed to be the largest aerosol disturbance of the stratosphere in the twentieth century. Its climate impact was significant - it cooled the Earth's surface for three years following the eruption, by as much as 1.3 degrees at the height of the impact. Still, it was probably smaller than the disturbances from eruptions of Krakatau in 1883 and Tambora in 1815. Sulfur dioxide from the 1783-1784 Laki fissure eruption in Iceland caused regional cooling of Europe and North America by similar amounts for similar periods.

While sulfur dioxide released in contemporary volcanic eruptions has occasionally caused detectable global cooling of the lower atmosphere, the Co_2 released in contemporary volcanic eruptions has never caused detectable global warming of the atmosphere. This is probably because the amounts of Co_2 released have not been of sufficient magnitude to produce detectable global warming. For example, all studies to date of global volcanic Co_2 emissions indicate that present-day subaerial and submarine volcanoes release less than a percent of the Co_2 released currently by human activities. While it has been proposed that intense volcanic release of Co_2 in the geologic past did cause global warming, and possibly some mass extinction, this is a topic of scientific debate at present.

Ash from volcanic eruptions can also be a threat to aircraft, in particular those with jet engines where ash particles can be melted by the high temperature. The melted particles then adhere to the turbine blades and alter their shape, disrupting the operation of the turbine. Large eruptions can affect temperature as ash and droplets of sulfuric acid obscure the sun and cool the Earth's lower atmosphere (or troposphere). However, they also absorb heat radiated up from the Earth, thereby warming the upper atmosphere (or stratosphere). Historically, so-called volcanic winters have caused catastrophic famines.

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[1] a domed rock formation in which a core of rock has moved upward to pierce the overlying strata

Air pollution and climate change

Processes such as fossil fuel burning in industry, motor vehicles and buildings emit substances that cause local and regional pollution. These pollutants include particulate matter (PM) and ground-level ozone (O_3) – the key ingredients of smog – along with Nitrogen oxides (NO_x), Sulphur oxides (SO_x), volatile organic compounds (VOCs) and carbon monoxide (CO).

The same processes also release greenhouse gases, mainly carbon dioxide (CO_2), methane (CH_4) and nitrous oxide (N_2O), which are linked to global climate change. In some cases, air pollutants contribute to climate change, and greenhouse gases contribute to air pollution:

- air pollutants such as ground-level ozone and soot (a portion of particulate matter) contribute directly to global warming, which is linked to climate change; and,
- methane, one of the most important GHGs, is a major cause of increased ground-level ozone.

Smog hanging over cities is the most familiar and obvious form of air pollution. But there are different kinds of pollution - some visible, some invisible - that contribute to global warming. Generally, any substance that people introduce into the atmosphere that has damaging effects on living things and the environment is considered an air pollutant.

Another pollutant associated with climate change is sulfur dioxide (SO_2), a component of smog. SO_2 and closely related chemicals are known primarily as a cause of acid rain. But they also reflect light when released in the atmosphere, which keeps sunlight out and causes Earth to cool. Volcanic eruptions can spew massive amounts of SO_2 into the atmosphere, sometimes causing cooling that lasts for years. In fact, volcanoes used to be the main source of atmospheric SO_2; today people are.

Industrialised countries have worked to reduce levels of SO_2, smog, and smoke in order to improve people's health. But a result, not predicted until recently, is that the lower SO_2 levels may actually make global warming worse. Just as SO_2 from volcanoes can cool the planet by blocking sunlight, cutting the amount of the compound in the atmosphere lets more sunlight through, warming the Earth. This effect is exaggerated when elevated levels of other greenhouse gases in the atmosphere trap the additional heat.

Climate change itself may have a direct impact on air quality. Modelling studies show that with warmer temperatures in the future, higher levels of ozone will be produced in North American cities. Addressing the issues of air pollution and climate change may seem daunting. However, the good news is that because they come from the same sources, many of the actions that reduce air pollution can also reduce greenhouse gas emissions.

Case study 1. Effect of surface ozone and particulate matter on climate change

The two air pollutants of most concern for public health are surface ozone and particulate matter. Ozone is produced in the troposphere by photochemical oxidation of carbon monoxide (CO), methane, and non-methane volatile organic compounds (NMVOCs) by the hydroxyl radical (OH) in the presence of reactive nitrogen oxides ($NO_x = NO + NO_2$). NMVOCs, CO, and NO_x have large combustion sources.

Vegetation is a large NMVOC source. Methane has a number of biogenic and anthropogenic sources. OH originates mainly from atmospheric oxidation of water vapor and cycles in the atmosphere with other hydrogen oxide (HO) radicals. Ozone pollution is in general mostly a summer problem because of the photochemical nature of the source. Ozone production is usually limited by the supply of HOx and NO_x, but can also be NMVOC-limited under highly polluted conditions and outside the summer season.

The principal global sink for tropospheric ozone is photolysis in the presence of water vapor. Uptake by vegetation (dry deposition) is also an important sink in the continental boundary layer (<2 km). Wet deposition is negligible as ozone and its major precursors have low solubility in water.

The atmospheric lifetime of ozone ranges from a few days in the boundary layer to weeks in the free troposphere. Ozone and its anthropogenic precursors ventilated from the source continents and transported on hemispheric scales in the free troposphere add a significant background to surface ozone which is of increasing concern for meeting air quality standards

Particulate matter (PM) includes, as principal components, sulfate, nitrate, organic carbon, elemental carbon, soil dust and sea salt. The first four components are mostly present as fine particles less than 2.5mm diameter (PM), and these are of most concern for human health. Sulfate, nitrate, and organic carbon are produced within the atmosphere by oxidation of SO_2, NO_x, and NMVOCs.

Carbon particles are also emitted directly by combustion. Nitrate and organic carbon exchange between the particle and gas phases, depending in particular on temperature. Seasonal variation of PM is complex and location-dependent; in general, PM needs to be viewed as an air quality problem year-round. PM is efficiently scavenged by precipitation and this is its main atmospheric sink, resulting in atmospheric lifetimes of a few days in the boundary layer and a few weeks in the free troposphere (similar to ozone).

Unlike for ozone, however, export of PM from the source continents is limited by the precipitation scavenging that usually accompanies continental outflow. The PM background in the free troposphere is thus generally unimportant for surface air quality. Exceptions are plumes from large dust storms and forest fires which can be transported on intercontinental scales.

Source: Jacob and Winne, 2009.

Desertification

Desertification is defined by the United Nations Convention to Combat Desertification (UNCCD) as a “reduction or loss, in arid, semi-arid and dry sub-humid areas, of the biological or economic productivity and complexity of rain-fed cropland, irrigated cropland, or range, pasture, forest, and woodlands resulting from land uses or from a process or combination of processes, including processes arising from human activities and habitation patterns, such as: (i) soil erosion caused by wind and/or water; (ii) deterioration of the physical, chemical and biological or economic properties of soil; and, (iii) long-term loss of natural vegetation”.

This definition, which is now being used worldwide to describe desertification and its impacts, leads to the need to consider carefully the two-way interactions between climate and desertification. Climate change might exacerbate desertification through alteration of spatial and temporal patterns in temperature, rainfall, solar isolation and winds. Several climate models suggest that future global warming may reduce soil moisture over large areas of semi-arid grassland in North America and Asia. Thus, climate change is likely to exacerbate the degradation of semi-arid lands that will be caused by rapidly expanding human populations during the next decade.

There has been a prediction of a 17% increase in the world area of desert land as a result of climate changes expected with a doubling of atmospheric CO_2 content. Any shift to a greater area of arid land potentially represents a permanent loss in the productive capacity of the biosphere on which all life depends.

According to UNCCD, over 250 million people are directly affected by desertification. In addition, some one billion people in over one hundred countries are at risk. These people include many of the world’s poorest, most marginalized, and politically weak citizens.

The effects of desertification on climate have been described mainly in terms of changes in land use and land cover leading to: land degradation; overgrazing; biomass burning and atmospheric emissions; agriculture’s contribution to air pollution; forest and woodland clearing and accelerated wind erosion; anthropogenic land disturbances and wind erosion; and, the impact of irrigated agriculture on surface conditions in drylands.

The consequences of desertification include decreased food production, famines, increased social costs, decline in the quantity and quality of fresh water supplies, increased poverty and political instability, reduction in land’s resilience to natural climate variability and decreased soil productivity.

El Niño and La Niña phenomena

Both El Niño and La Niña are opposite effects of the same phenomenon, the ENSO (El Niño Southern Oscillation). Both are an oscillation in the temperatures between the atmosphere and the ocean of the eastern equatorial Pacific region, roughly between the International Dateline and 120 degrees west. El Niño - the conditions for which build up between June and December - is caused by a change in the wind patterns. Here, the Pacific Trade Winds fail to replenish following the summer monsoons of Asia. This warmer air leads to an oscillation between the cooler and warmer waters, leading to warmer ocean temperatures than normal.

La Niña is effectively the opposite of El Niño, indicated by prolonged periods of sea temperatures in the same region, and the effects stated above are generally reversed. During non-El Niño years, atmospheric pressure is lower than normal over the western Pacific area and higher over the colder waters of the western Pacific. With La Niña, the Trade Winds are particularly strong in carrying warmer water westwards across the Pacific leading to colder than average temperatures in the east and warmer than average temperatures in the west. The result is that plankton increases in the areas where the temperature is cooler, leading to a positive effect on the marine life that depends on plankton or depends on those creatures that depend on plankton.

Research conducted over recent decades has shown the important role played by interactions between the atmosphere and ocean in the tropical belt of the Pacific Ocean in altering global weather and climate patterns. During El Niño events, for example, sea temperatures at the surface in the central and eastern tropical Pacific Ocean become substantially higher than normal. In contrast, during La Niña events, the sea surface temperatures in these regions become lower than normal. These temperature changes are strongly linked to major climate fluctuations around the globe and, once initiated, such events can last for 12 months or more. The strong El Niño event of 1997-1998 was followed by a prolonged La Niña phase that extended from mid-1998 to early 2001.

During the last several decades the number of El Niño events increased, although a much longer period of observation is needed to detect robust changes. The question is, or was, whether this is a random fluctuation or a normal instance of variation for that phenomenon or the result of global climate changes as a result of global warming. A 2014 study reported a robust tendency to more frequent extreme El Niños, occurring in agreement with a separate recent model prediction for the future.

Several studies of historical data suggest the recent El Niño variation is linked to anthropogenic climate change; in accordance with the larger consensus on climate change. For example, even after subtracting the positive influence of decade-to-decade variation (which is shown to be present in the ENSO trend), the amplitude of the ENSO variability in the observed data still increases, by as much as 60% in the last 50 years.

It may be that the observed phenomenon of more frequent and stronger El Niño events occurs only in the initial phase of the climate change, and then (e.g., after the lower layers of the ocean get warmer, as well), El Niño will become weaker than it was. It may also be that the stabilizing and destabilizing forces influencing the phenomenon will eventually compensate for each other. More research is needed to provide a better answer to that question. However, a new 2014 model appearing in a research report indicated unmitigated climate change would particularly affect the surface waters of the eastern equatorial Pacific and possibly double extreme El Niño occurrences.

Some climatologists suggest it is logical to believe that the recorded warming of the atmosphere will have an impact on the frequency, duration, and severity of El Niño and La Niña events. As the atmosphere warms, heat would be transferred to the oceans, with the potential for increased extremes between cold and warm periods. They also agree that the jury is still out on whether this likely scenario will occur, or is occurring, and what shape it will take.

El Niño's impacts depend on a variety of factors, such as intensity and extent of ocean warming, and the time of year. Contrary to popular belief, not all effects are negative. On the positive side, El Niño can help to suppress Atlantic hurricane activity. In the United States, it typically brings beneficial winter precipitation to the arid Southwest, less wintry weather across the North, and a reduced risk of Florida wildfires.

El Niño's negative impacts have included damaging winter storms in California and increased storminess across the southern United States. Some past El Niños also have produced severe flooding and mudslides in Central and South America, and drought in Indonesia.

"An El Niño event may significantly diminish ocean productivity off the west coast by limiting weather patterns that cause upwelling, or nutrient circulation in the ocean. These nutrients are the foundation of a vibrant marine food web and could negatively impact food sources for several types of birds, fish and marine mammals," NOAA scientists report. El Niño may be devastating to the fishing economies of Ecuador and Peru. Birds, sea lions and fishermen go hungry because there are not enough fish around. Also, torrential rainfall in the coastal zone frequently accompanies offshore warming, causing devastating floods.

Typically, El Niño comes around every five years and what usually happens is that warming in the oceans caused by the winds leads to diffusion of this warming all over the globe. It changes atmospheric pressures with consequences for rainfall, wind patterns, sea surface temperatures and can sometimes have a positive, and sometimes a negative effect on those systems. In Europe for example, El Niño reduces the instances of hurricanes in the Atlantic. The beginning of the El Niño system will be seen over North America in the preceding winter; typically it includes:

- mild winter temperatures over western Canada and north western USA;
- above average precipitation in the Gulf Coast, including Florida; and,
- a drier than average period in Ohio and pacific northwest.

Like El Niño, La Niña too affects atmospheric pressure and temperature, rainfall and ocean temperature. La Niña has less of an effect in Europe than El Niño, but it does tend to lead to milder winters in Northern Europe (the United Kingdom especially) and colder winters in southern/ western Europe leading to snow in the Mediterranean region. Elsewhere in the world, areas that are affected by La Niña experience the opposite of the effects they experience with El Niño. It is continental North America where most of these conditions are felt. The wider effects include:

- stronger winds along the equatorial region, especially in the Pacific;
- decreased convection in the Pacific leading to a weaker jet stream;
- temperatures above average in the southeast and below average in the northwest;
- conditions are more favourable for hurricanes in the Caribbean and central Atlantic area; and,
- greater instances of tornados in those states of the US already vulnerable to them.

In the western Pacific, the formation of cyclones shifts westwards which increases the potential for landfall in those areas most vulnerable to their affects, and especially into continental Asia and China. There is greater rainfall in the west too, especially in Australia, Indonesia and Malaysia and further westwards toward the southern countries in the African continent. Consequently, over US and Canada there will be lower than average precipitation and this pattern follows the coast southwards where the western portion of South America will also experience lower than average rainfall.

4.2.2 Concept of climate modeling

Overview of General Circulation Models (GCMs)

General circulation models (GCMs) are important tools in research on current climate change. GCM simulations are the main source of information for estimating the future impacts of climate change due to anthropogenic influences. Given the coarse spatial resolution of a GCM, these models provide large-scale information for climate projections. But the majority of studies on regional impacts and implications of climate change require a finer spatial resolution. Since the regional climate can be seen schematically as a result of the interaction of a large-scale atmospheric state and local physiographic constraints (von Storch, 1999), methods have been put in place to link climatic variables simulated by GCMs and local climate variables. These methodologies are generally known as "descent of scale" (Herrera et al., 2006).

Biogeochemical cycles

Life on Earth depends on the recycling of essential chemical elements. Since nutrient cycles involve biotic and abiotic components of ecosystems, they are called **biogeochemical cycles**. Since carbon, oxygen, sulfur and nitrogen can be in a gaseous state, their cycle takes place on a global scale. Others, such as phosphorus, potassium or calcium, have reduced mobility and their cycles are localized.

In the general model of nutrient recycling, there are four nutrient reservoirs defined by two characteristics: their **content** (organic or inorganic matter) and the **availability** (available or not) of their contents to organisms.

Activity 2 Essential questions on the chapter

- What are the causes of climate variability and change?
- List disturbances caused by climate variability and change?

In text questions (30 minutes)

1) Identify and discuss how certain air pollutants in industries in your country can contribute to climate change.
2) What can be done at personal, industry and government levels to reduce the effect of air pollutants on climate change?
3) Does the occurrence of El Niño suggest a larger climate issue? Are there any long lasting positive/negative effects of El Nino? How does the global warming crowd view El Nino?

4.2.3 Hydrological, carbon and nitrogen cycles

The Hydrological cycle

The water (H_2O) cycle, also known as the hydrological cycle, describes the continuous movement of water on, above and below the surface of the Earth. The mass of water on Earth remains fairly constant over time but the partitioning of the water into the major reservoirs of ice, fresh water, saline water and atmospheric water is variable depending on a wide range of climatic variables.

The water moves from one reservoir to another, such as from river to ocean, or from the ocean to the atmosphere, by the physical processes of evaporation, condensation, precipitation, infiltration, runoff and subsurface flow (Figure 19). In doing so, the water goes through different phases: liquid, solid (ice) and gas (vapour).

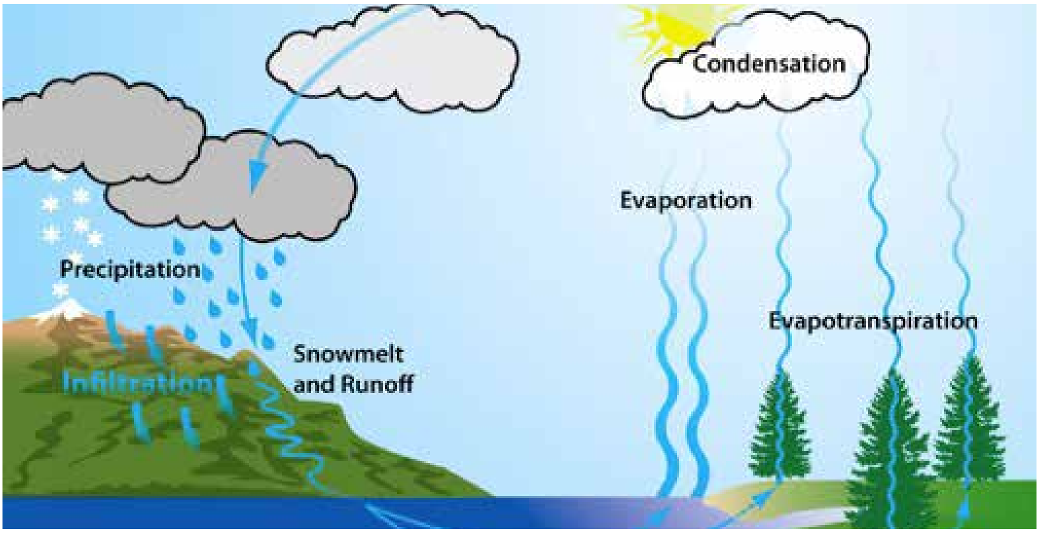

Figure 19. The hydrological cycle.

Source: http://www.state.nj.us/drbc/hydrological

The water cycle involves the exchange of energy, which leads to temperature changes. For instance, when water evaporates, it takes up energy from its surroundings and cools the environment. When it condenses, it releases energy and warms the environment. These heat exchanges influence climate. The evaporative phase of the cycle purifies water which then replenishes the land with freshwater. The flow of liquid water and ice transports minerals across the globe. It is also involved in reshaping the geological features of the Earth, through processes including erosion and sedimentation. The water cycle is also essential for the maintenance of most life and ecosystems on the planet.

The sun, which drives the water cycle, heats water in oceans and seas. Water evaporates as vapour into the air. Ice, rain and snow can sublimate directly into water vapour. Evapo-transpiration is water transpired from plants and evaporated from the soil. The water molecule has less density compared to the major components of the atmosphere, nitrogen and oxygen, N_2 and O. Due to this difference in molecular mass, water in gas form gains height in open air as a result of buoyancy. However, as altitude increases, air pressure decreases and temperature drops. The lowered temperature causes water vapour to condense into a tiny liquid water droplet which is heavier than the air, such that it falls unless supported by an updraft. Karge concentrations of these droplets in the atmosphere are visible as clouds.

Fog is formed if the water vapour condenses near ground level, as a result of moist air and cool air colliding or an abrupt reduction in air pressure. Air currents move water vapour around the globe, cloud particles collide, grow and fall out of the upper atmospheric layers as precipitation. Some falls as snow or hail and can accumulate as ice caps and glaciers, which can store frozen water for thousands of years. Most water falls back into the oceans or onto land as rain, where the water flows over the ground as surface runoff.

A portion of runoff enters rivers, with streamflow moving water towards the oceans. Runoff and water emerging from the ground (groundwater) may be stored as freshwater in lakes. Not all runoff flows into rivers, much of it soaks into the ground as infiltration. Some water infiltrates deep into the ground and replenishes aquifers, which can store freshwater for long periods of time. Some infiltration stays close to the land surface and can seep back into surface-water bodies (and the ocean) as groundwater discharge. Some groundwater finds openings in the land surface and comes out as freshwater springs. In river valleys and flood-plains there is often continuous water exchange between surface water and ground water in the hyporheic zone. Over time, the water returns to the ocean, to continue the water cycle.

Case study 2. The hydrological cycle and climate change

Among the most serious environmental policy issues confronting society are the potential changes in the Earth's water cycle due to climate change. The science community now generally agrees that the Earth's climate is undergoing changes in response to natural variability, including solar variability, and increasing concentrations of greenhouse gases and aerosols. Furthermore, agreement is widespread that these changes may profoundly affect atmospheric water vapour concentrations, clouds, and precipitation, runoff and stream flow patterns.

For example, as the lower atmosphere becomes warmer, evaporation rates will increase, resulting in an increase in the amount of moisture circulating throughout the troposphere (lower atmosphere). One consequence of this is the increased frequency of intense precipitation events, mainly over land areas. Because of warmer temperatures, more precipitation is falling as rain rather than snow.

Global climate change will affect the water cycle, likely creating perennial droughts in some areas and frequent floods in others. In parts of the Northern Hemisphere, an earlier arrival of spring-like conditions is leading to earlier peaks in snowmelt and resulting river flows. As a consequence, seasons with the highest water demand, typically summer and fall, are being impacted by a reduced availability of fresh water.

Warmer temperatures have led to increased drying of the land surface in some areas, with the effect of an increased incidence and severity of drought. The Palmer Drought Severity Index, which is a measure of soil moisture using precipitation measurements and rough estimates of changes in evaporation, has shown that from 1900 to 2002, the Sahel region of Africa has been experiencing harsher drought conditions. This same index also indicates an opposite trend in southern South America and the south central United States.

Source: Ichoku (n.d)

The Carbon cycle

All living things are made of carbon. Carbon is also a part of the ocean, air and even rocks. In the atmosphere, carbon is attached to some oxygen in carbon dioxide (CO_2). Plants use CO_2 and sunlight to make their own food and grow through photosynthesis. The carbon becomes part of the plant. Plants that die and are buried may turn into fossil fuels, made up of carbon, like coal and oil over millions of years. When humans burn fossil fuels, most of the carbon quickly enters the atmosphere as CO_2.

The carbon cycle is the biogeochemical cycle by which carbon is exchanged between the biosphere, pedosphere, geosphere, hydrosphere and atmosphere of the Earth (Figure 20). Along with the nitrogen cycle and the water cycle, the carbon cycle comprises a sequence of events that are key to making the Earth capable of sustaining life; it describes the movement of carbon as it is recycled and reused throughout the biosphere.

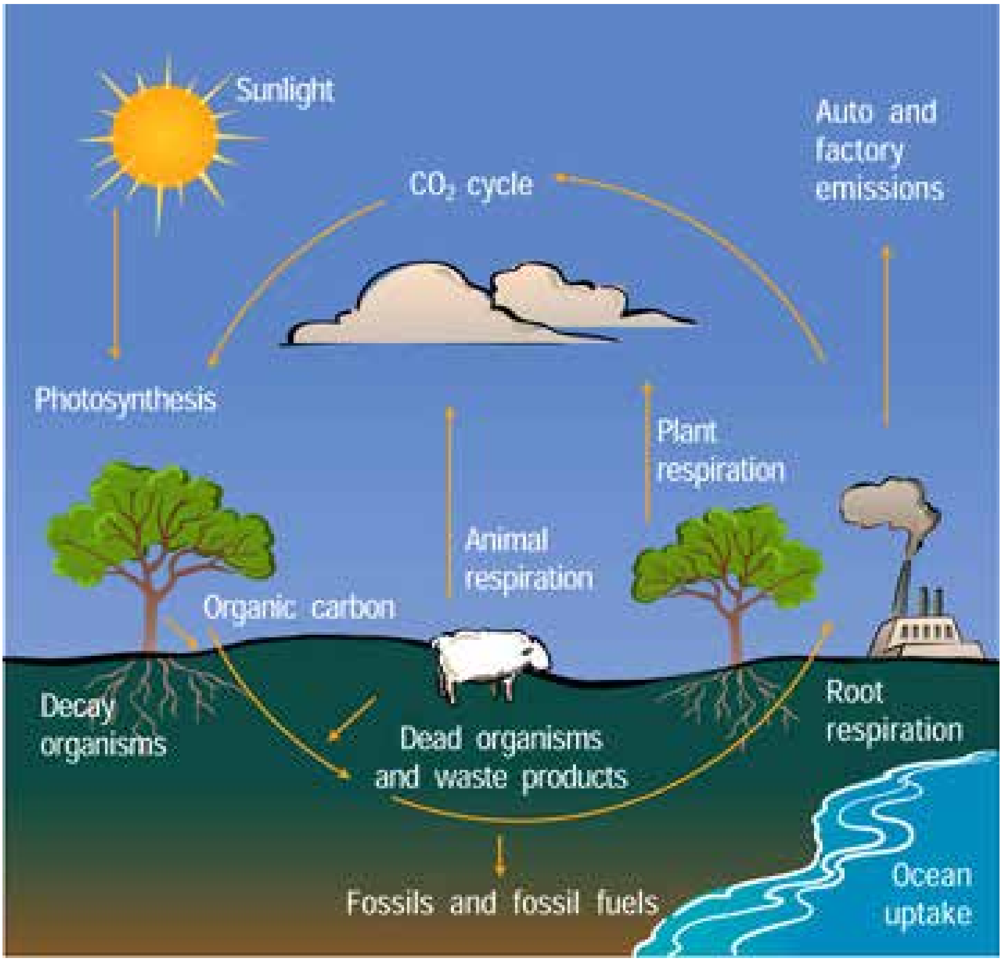

Figure 20. The carbon cycle. Source: The COMET programme (nd).
https://eo.ucar.edu/kids/green/cycles6.htm

Since the industrial revolution, human activity has modified the carbon cycle by changing its component's functions and directly adding carbon to the atmosphere. The largest and most direct human influence on the carbon cycle is through direct emissions from burning fossil fuels, which transfers carbon from the geosphere into the atmosphere. Humans also influence the carbon cycle indirectly by changing the terrestrial and oceanic biosphere.

Over the past several centuries, human-caused land use and land cover change (LUCC) has led to the loss of biodiversity, which lowers ecosystems' resilience to environmental stresses and decreases their ability to remove carbon from the atmosphere. More directly, it often leads to the release of carbon from terrestrial ecosystems into the atmosphere. Deforestation for agricultural purposes removes forests, which hold large amounts of carbon, and replaces them with agricultural or urban areas. Both of these land cover types store comparatively small amounts of carbon, so that the net product of the process is that more carbon stays in the atmosphere.

Other human-caused changes to the environment change ecosystems' productivity and their ability to remove carbon from the atmosphere. Air pollution, for example, damages plants and soils, while many agricultural and land use practices lead to higher erosion rates, washing carbon out of soils and decreasing plant productivity. Higher temperatures and CO_2 levels in the atmosphere increase decomposition rates in soil, thus returning CO_2 stored in plant material more quickly to the atmosphere.

However, increased levels of CO_2 in the atmosphere can also lead to higher gross primary production. It increases photosynthesis rates by allowing plants to more efficiently use water, because they no longer need to leave their stomata open for such long periods of time in order to absorb the same amount of CO_2. This type of CO_2 fertilization affects mainly C3 plants, because C4 plants can already concentrate CO_2 effectively.

Humans also affect the oceanic carbon cycle. Current climate change trends lead to higher ocean temperatures, thus modifying ecosystems. Acid rain and polluted runoff from industry and agriculture change the ocean's chemical composition, which can have dramatic effects on sensitive ecosystems such as coral reefs, thus limiting the ocean's ability to absorb carbon from the atmosphere on a regional scale and reducing oceanic biodiversity globally.

On 12 November 2015, NASA scientists reported that human-made CO_2 continues to increase above levels not seen in hundreds of thousands of years: currently, about half of the CO_2 released from the burning of fossil fuels remains in the atmosphere and is not absorbed by vegetation and the oceans

Case study 3. Climate change and the carbon cycle

Human generated climate change can be thought of as an enormous perturbation in the global carbon cycle. Prior to the modern industrial world, the global carbon cycle was determined by events such as volcanism, sea floor rifting and meteorite impacts. Now, human activities dictate much of the movement of carbon around the world. This is because burning of fossil fuels and landscape change have moved fossil carbon, which was once buried in deep sea and terrestrial sediments, and mobilized it into the atmosphere. Once in the atmosphere in forms such as CO_2 and methane, greenhouse gasses can change the thermal conductance of the atmosphere, the chemistry of seawater and the movement of our oceans.

In the past two centuries, human activities have seriously altered the global carbon cycle, most significantly in the atmosphere. Although CO_2 levels have changed naturally over the past several thousand years, human emissions of CO_2 into the atmosphere exceed natural fluctuations. Changes in the amount of atmospheric CO_2 are considerably altering weather patterns and indirectly influencing oceanic chemistry. Records from ice cores have shown that, although global temperatures can change without changes in atmospheric CO_2 levels, CO_2 levels cannot change significantly without affecting global temperatures. Current CO_2 levels exceed measurements from the last 420,000 years and levels are rising faster than ever recorded, making it of critical importance to better understand how the carbon cycle works and what its effects are on the global climate.

The global carbon cycle is now usually divided into the following major reservoirs of carbon interconnected by pathways of exchange:

- the atmosphere;
- the terrestrial biosphere;
- the oceans, including dissolved inorganic carbon and living and non-living marine biota;
- the sediments, including fossil fuels, fresh water systems and non-living organic material, such as soil carbon; and.
- the Earth's interior, carbon from the Earth's mantle and crust; these carbon stores interact with the other components through geological processes

The carbon exchanges between reservoirs occur as the result of various chemical, physical, geological and biological processes. The ocean contains the largest active pool of carbon near the surface of the Earth. The natural flows of carbon between the atmosphere, ocean and sediments are fairly balanced, so that carbon levels would be roughly stable without human influence.

Source: Marine Conservation Institute (n.d)

The nitrogen cycle

Nitrogen is one of the primary nutrients critical for the survival of all living organisms. It is a necessary component of many biomolecules, including proteins, DNA and chlorophyll. Although nitrogen is very abundant in the atmosphere as dinitrogen gas (N_2), it is largely inaccessible in this form to most organisms, making nitrogen a scarce resource and often limiting primary productivity in many ecosystems. Only when nitrogen is converted from N_2 into ammonia (NH_3) does it become available to primary producers, e.g. plants.

The nitrogen cycle represents one of the most important nutrient cycles found in terrestrial ecosystems (Figure 21). The store of nitrogen is about one million times larger than the total nitrogen contained in living organisms. Other major stores of nitrogen include organic matter in soil and the oceans. Most plants obtain the nitrogen they need as inorganic nitrate from the soil solution. Ammonium is used less by plants for uptake because in large concentrations it is extremely toxic. Animals receive the required nitrogen they need for metabolism, growth and reproduction by the consumption of living or dead organic matter containing molecules composed partially of nitrogen.

In most ecosystems nitrogen is primarily stored in living and dead organic matter. This organic nitrogen is converted into inorganic forms when it re-enters the biogeochemical cycle via decomposition. Decomposers, found in the upper soil layer, chemically modify the nitrogen found in organic matter from ammonia (NH_3) to ammonium salts (NH_4^+). This process is known as mineralization and it is carried out by a variety of bacteria, actino-mycetes, and fungi.

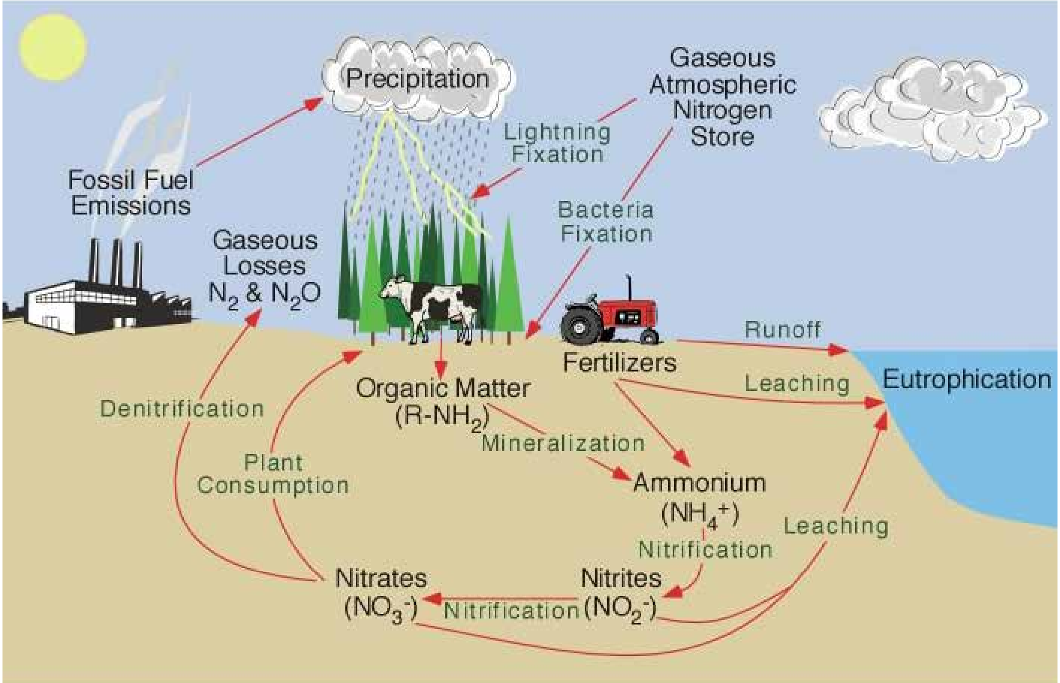

Figure 21. The nitrogen cycle

Source: http://www.physicalgeography.net/fundamentals/9s.html

Nitrogen in the form of ammonium can be absorbed onto the surfaces of clay particles in the soil. The ion of ammonium with a positive molecular charge is normally held by soil colloids. This process is sometimes called micelle fixation. Ammonium is released from the colloids by way of cation exchange. When released, most of the ammonium is often chemically altered by a specific type of autotrophic bacteria (belonging to the genus *Nitrosomonas*) into nitrite (NO_2^-). Further modification by another type of bacteria (belonging to the genus *Nitrobacter*) converts the nitrite to nitrate (NO_3). Both of these processes involve chemical oxidation and are known as nitrification. However, nitrate is very soluble and it is easily lost from the soil system by leaching. Some of this leached nitrate flows through the hydrologic system until it reaches the oceans where it can be returned to the atmosphere by denitrification. Denitrification is also common in anaerobic soils and is carried out by heterotrophic bacteria. The process involves the metabolic reduction of nitrate (NO_3) into nitrogen (N_2) or nitrous oxide (N_2O) gas. Both these gases then diffuse into the atmosphere.

Almost all of the nitrogen found in any terrestrial ecosystem originally came from the atmosphere. Significant amounts enter the soil in rainfall or through the effects of lightning. The majority, however, is biochemically fixed within the soil by specialized micro-organisms like bacteria, actinomycetes and cyanobacteria. Members of the *Leguminosae* family (legumes) and some other kinds of plants form mutualistic symbiotic relationships with nitrogen fixing bacteria. In exchange for some nitrogen, the bacteria receive from the plants carbohydrates and special structures (nodules) in roots where they can exist in a moist environment. Scientists estimate that biological fixation globally adds approximately 140 million metric tons of nitrogen to ecosystems every year.

In text questions (30 minutes)

1) Discuss the importance of the hydrological, nitrogen and carbon cycles to people and the ecosystem.
2) How does energy from the sun affect the hydrological cycle?
3) What are the effects of climate change on the hydrological, nitrogen and carbon cycles?
4) How do the activities of man impact on the hydrological and carbon cycles?
5) How does global warming affect the nitrogen cycle?
6) Discuss the importance of the hydrological, nitrogen and carbon cycles to people and the ecosystem.
7) How does energy from the sun affect the hydrological cycle?
8) What are the effects of climate change on the hydrological, nitrogen and carbon cycles?
9) How do the activities of man impact on the hydrological and carbon cycles?
10) How does global warming affect the nitrogen cycle?

Case study 4. Human influences on the nitrogen cycle

As a result of extensive cultivation of legumes (particularly soy, alfalfa and clover), growing use of the Haber–Bosch process in the creation of chemical fertilizers, and pollution emitted by vehicles and industrial plants, human beings have more than doubled the annual transfer of nitrogen into biologically available forms. In addition, humans have significantly contributed to the transfer of nitrogen trace gases from Earth to the atmosphere and from the land to aquatic systems. Human alterations to the global nitrogen cycle are most intense in developed countries and in Asia, where vehicle emissions and industrial agriculture are highest.

Nitrous oxide (N_2O) has risen in the atmosphere as a result of agricultural fertilizers, biomass burning, cattle and feedlots, and industrial sources. N_2O has negative effects in the stratosphere, where it breaks down and acts as a catalyst in the destruction of atmospheric ozone. N_2O is also a GHG and is currently the third largest contributor to global warming, after CO_2 and methane. While not as abundant in the atmosphere as CO_2, it is, for an equivalent mass, nearly 300 times more potent in its ability to warm the planet.

Ammonia (NH_3) in the atmosphere has tripled as the result of human activities. It is a reactant in the atmosphere, where it acts as an aerosol, decreasing air quality and clinging to water droplets, eventually resulting in nitric acid (HNO_3) that produces acid rain. Atmospheric NH_3 and nitric acid also damage respiratory systems.

The very high temperature of lightning naturally produces small amounts of NO_x, NH_3 and HNO_3, but high-temperature combustion has contributed to a 6 or 7 fold increase in the flux of NO_x to the atmosphere. Its production is a function of combustion temperature - the higher the temperature, the more NO_x is produced. Fossil fuel combustion is a primary contributor, but so are biofuels and even the burning of hydrogen. The higher combustion temperature of hydrogen produces more NOx than natural gas combustion.

Ammonia and nitrous oxides actively alter atmospheric chemistry. They are precursors of tropospheric (lower atmosphere) ozone production, contributing to smog and acid rain, damages plants and increases nitrogen inputs to ecosystems. Ecosystem processes can increase with nitrogen fertilization, but anthropogenic input can also result in nitrogen saturation, which weakens productivity and can damage the health of plants, animals, fish and humans.

Decreases in biodiversity can also result if higher nitrogen availability increases nitrogen-demanding grasses, causing a degradation of nitrogen-poor, species diverse heathlands.

Additional risks posed by increased availability of inorganic nitrogen in aquatic ecosystems include water acidification; eutrophication of fresh and saltwater systems; and, toxicity issues for animals, including humans. Eutrophication often leads to lower dissolved oxygen levels in the water column, including hypoxic and anoxic conditions, which can cause death of aquatic fauna. Bottom-dwelling creatures are particularly vulnerable because of their lack of mobility, though large fish kills are not uncommon. Oceanic dead zones near the mouth of the Mississippi in the Gulf of Mexico are a well-known example of algal bloom-induced hypoxia. The New York Adirondack Lakes, Catskills, Hudson Highlands, Rensselaer Plateau and parts of Long Island display the impact of nitric acid rain deposition, damaging fish and other species.

Ammonia (NH_3) is highly toxic to fish and the level of ammonia discharged from wastewater treatment facilities must be closely monitored. To prevent fish death, nitrification via aeration prior to discharge is desirable. Land application can be an attractive alternative to the aeration.

Nitrogen is arguably the most important nutrient in regulating primary productivity and species diversity in aquatic and terrestrial ecosystems. Microbially-driven processes, such as nitrogen fixation, nitrification and denitrification, constitute the bulk of nitrogen transformations, and play a critical role in the fate of nitrogen in the Earth's ecosystems. However, as human populations continue to increase, the consequences of human activities continue to threaten our resources and have already significantly altered the global nitrogen cycle.

Source: Vitousek, et al., 1997.

Summary

This session has introduced learners to the basics of climate science and biogeochemical processes. Topics covered included the layers of atmosphere and how they interact with other elements. The importance and effect of climate change as well as predictions of rising temperatures on the hydrological, nitrogen and carbon cycles have also been treated.

4.3 Drivers of global change

This session introduces the natural and human-induced factors that directly or indirectly cause a change in an ecosystem. These factors are referred to as “drivers.” A direct driver unequivocally influences ecosystem processes. An indirect driver operates more diffusely, by altering one or more direct drivers. A detail description of the drivers have been provided in chapter two.

Objectives

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

a) give examples of direct and indirect drivers of climate change in his/her country; and,

b) describe how those drivers contribute to climate change.

Activity 1 (Discussion and presentation) (30 minutes)

Students/participants should discuss:

- effect of increasing population on the forest ecosystems;
- effects on industrialisation on the environment;
- some reasons for increasing rate of urbanisation across the world; and,
- ways of reducing the rate of urbanisation.

4.3.1 Population growth

Global population doubled in the past 40 years and increased by two billion people in the last 25 years, reaching six billion in 2000. Developing countries have accounted for most recent population growth, but there is now an unprecedented diversity of demographic patterns across regions and countries. Some high-income countries, such as the United States, are still experiencing high rates of population growth, while some developing countries such as China, Thailand and North Korea have very low rates.

Both economic growth and population growth lead to increased consumption of ecosystem services, although the harmful environmental impacts of any particular level of consumption depend on the efficiency of the technologies used in the production of the service. These factors interact in complex ways in different locations to change pressures on ecosystems and uses of ecosystem services.

Case study 5. Effects of population growth on climate change

Areas of high population growth and high vulnerability to climate change impacts overlap. Evidence suggests that the poorest countries and poorest groups within a population are most vulnerable to climate-related hazards such as floods, droughts and landslides. Many developing countries are currently experiencing rapid population growth, increasing the number of people who will be exposed to projected impacts of climate change.

Increases in temperature are expected to negatively affect agricultural production in the tropics and subtropics, where crops already exist at the top of their temperature range. Under middle-range projections of population growth, agricultural production loss and an increase in the prices of crops due to climate change will place an additional 90 to 125 million people in developing countries at risk of hunger by 2080.

Though everyone will be affected by climate change, UN projected in 2009 that women will suffer most in most places. Physical and cultural factors contribute to women's disproportionate vulnerability to the impacts of climate change. In many societies, as the primary providers of water, food and fuel, women bear additional burdens as these resources become scarce or unpredictable in supply. Women are also more likely to die in the event of natural disasters.

Source: Population Action International (PAI) (n.d)

Demographic trends have an important connection to both challenges and solutions to the problem of climate change. Rapid population growth exacerbates vulnerability to the negative consequences of climate change, and exposes growing numbers of people to climate risk. Population growth is one of the drivers of the growth in greenhouse gases.

4.3.2 Urbanisation

About half of the people in the world now live in urban areas (although urban areas cover less than 3% of the terrestrial surface), up from less than 15% at the start of the twentieth century. High-income countries have populations that are 70–80% urban. Africa, long considered a predominantly rural continent, has a larger urban population than Northern America, close to two-fifths of its population. It has a high concentration of its largest cities in coastal areas.

Low- and middle-income nations now have three-quarters of the world's urban population. They also have most of the urban population at greatest risk from the increased intensity and/or frequency of storms, flooding, landslides and heat waves that climate change is bringing or will bring. The very high concentration of global deaths from extreme weather-related disasters in low- and middle income nations is well known. If more precise data were available, it is likely to show that a large and growing proportion of these deaths are in urban areas.

Without adaptation, climate change is likely to bring ever-increasing numbers of accidental deaths and serious injuries and increasingly serious damages to people's livelihoods, property, environmental quality and future prosperity. Climate change also has the potential to increase flooding risks in cities in three ways:

- from the sea (higher sea levels and storm surges);
- by heavier rainfall or rainfall that is more prolonged than in the past; and,
- from changes that increase river flows – for instance through increased glacial melt.

The IPCC Working Group II noted that heavy precipitation events are very likely to increase in frequency and will augment flood risk and the growing evidence of increased runoff and earlier spring-peak discharges in many glacier- and snow-fed rivers. In addition to flood hazards, more extreme rainfall events associated with climate change will also generate increased hazard from landslides in many urban centres.

In urban areas, the people most at risk from climate change are those who are:

- least able to avoid the direct or indirect impacts, e.g. by having good quality homes and drainage systems that prevent flooding, by moving to places with less risk or by changing jobs if climate change threatens their livelihoods;
- infants and older groups who are less able to cope with heat waves; and,
- least able to cope with the illness, injury, premature death or loss of income, livelihood or assets caused by climate change impacts.

4.3.3 Industrialization

Industrialization is the social and economic change that transforms a society from an agrarian economy into an industrial one, involving the extensive re-organisation of the economy for the purpose of manufacturing. The first transformation to an industrial economy from an agricultural one, known as the Industrial Revolution, took place from the mid-18th to early 19th century in certain areas in Europe and North America. The “Second Industrial Revolution” labels the later changes that came about in the mid-19th century after the refinement of the steam engine, the invention of the internal combustion engine, the harnessing of electricity and the construction of canals, railways and electric-power lines. The invention of the assembly line gave this phase a boost.

Industralisation is associated with climate change; urbanisation; migration (workers have to leave their family in order to come to work in the towns and cities where these industries are found); and changes in family structure.

Atmospheric CO_2 is at its highest level in 15 to 20 million years. Weart (2010) reported that atmospheric concentration of CO_2 has increased by 35% since the beginning of the age of industrialisation; 29 gigatons of CO_2 is produced every year.

4.3.4 Technological development/advancement

The development and diffusion of scientific knowledge, and technologies that exploit that knowledge, has profound implications for ecological systems and human well-being. The twentieth century saw tremendous advances in understanding how the world works physically, chemically, biologically and socially and in the applications of that knowledge to human endeavors.

Technological progress will be crucial in responses to climate change. It can provide the keys to reducing the cost of climate change mitigation. Policies and economics can propel technological change, and policy-makers and businesses both must play major roles in developing the necessary technologies to address climate change.

The impacts of technology on the environment can be positive or negative. Positive – better technology can help us study and better understand how we are affecting the environment. Negative – (i) advancements in things that require fossil fuels reduces the amount we have, and if burned, emits CO_2 into the air; (ii) advancements in other exploitation techniques can also reduce forests, aquifers, and other natural resources that we need.

4.3.5 Land use and land cover change

Land-use and land-cover change (LULCC) is a general term for the human modification of Earth's terrestrial surface. Though humans have been modifying land to obtain food and other essentials for thousands of years, current rates, extents and intensities of LULCC are far greater than ever in history, driving unprecedented changes in ecosystems and environmental processes at local, regional and global scales. These changes encompass the greatest environmental concerns of mankind today, including climate change, loss of biodiversity and the pollution of water, soils and air. Monitoring and mediating the negative consequences of LULCC while sustaining the production of essential resources has therefore become a major priority of researchers and policymakers around the world.

Land cover refers to the physical and biological cover over the surface of land, including water, vegetation, bare soil and/or artificial structures. **Land use** is a more complicated term. Natural scientists define *land use* in terms of human activities such as agriculture, forestry and building construction that alter land surface processes including hydrology, biogeochemistry and biodiversity. Social scientists and land managers define *land use* more broadly to include the social and economic purposes and contexts for and within which lands are managed (or left unmanaged), such as subsistence versus commercial agriculture, rented vs. owned, or private vs. public land.

While land cover may be observed directly in the field or by remote sensing, observations of land use and its changes generally require the integration of natural and social scientific methods (expert knowledge, interviews with land managers) to determine which human activities are occurring in different parts of the landscape, even when land cover appears to be the same. For example, areas covered by woody vegetation may represent an undisturbed natural shrub land, a forest preserve recovering from a fire (use = conservation), regrowth following tree harvest (forestry), a plantation of immature rubber trees (plantation agriculture), swidden agriculture (or shifting cultivation) plots that are in between periods of clearing for annual crop production, or an irrigated tea plantation. As a result, scientific investigation of the causes and consequences of LULCC requires an interdisciplinary approach integrating both natural and social scientific methods, which have emerged as the new discipline of land-change science.

Case study 6. Effects of land use and land cover change (LULCC)

Biodiversity loss. Biodiversity is often reduced dramatically by LULCC. When land is transformed from a primary forest to a farm, the loss of forest species within deforested areas is immediate and complete. Even when unaccompanied by apparent changes in land cover, similar effects are observed whenever relatively undisturbed lands are transformed to more intensive uses, including livestock grazing, selective tree harvest and even fire prevention. The habitat suitability of forests and other ecosystems surrounding those under intensive use are also impacted by the fragmenting of existing habitat into smaller pieces (habitat fragmentation), which exposes forest edges to external influences and decreases core habitat area. Smaller habitat areas generally support fewer species (island biogeography), and for species requiring undisturbed core habitat, fragmentation can cause local and even general extinction. Research also demonstrates that species invasions by non-native plants, animals and diseases may occur more readily in areas exposed by LULCC, especially in proximity to human settlements.

Climate Change. LULCC plays a major role in climate change at global, regional and local scales. At global scale, LULCC is responsible for releasing greenhouse gases to the atmosphere, thereby driving global warming. LULCC can increase the release of CO_2 to the atmosphere by disturbance of terrestrial soils and vegetation, and the major driver of this change is deforestation, especially when followed by agriculture, which causes the further release of soil carbon in response to disturbance by tillage. Changes in land use and land cover are also behind major changes in terrestrial emissions of other greenhouse gases, especially methane (altered surface hydrology: wetland drainage and rice paddies; cattle grazing), and nitrous oxide (agriculture: inorganic nitrogen fertilizers; irrigation; cultivation of nitrogen fixing plants; biomass combustion).

Pollution. Changes in land use and land cover are important drivers of water, soil and air pollution. Perhaps the oldest of these is land clearing for agriculture and the harvest of trees and other biomass. Vegetation removal leaves soils vulnerable to massive increases in soil erosion by wind and water, especially on steep terrain, and when accompanied by fire, also releases pollutants to the atmosphere. This not only degrades soil fertility over time, reducing the suitability of land for future agricultural use, but also releases phosphorus, nitrogen and sediments to streams and other aquatic ecosystems, causing a variety of negative impacts (increased sedimentation, turbidity, eutrophication and coastal hypoxia).

Mining can produce even greater impacts, including pollution by toxic metals exposed in the process. Modern agricultural practices, which include large inputs of nitrogen and phosphorus fertilizers and the concentration of livestock and their manures within small areas, have substantially increased the pollution of surface water by runoff and erosion and the pollution of groundwater by leaching of excess nitrogen (as nitrate). Other agricultural chemicals, including herbicides and pesticides are also released to ground and surface waters by agriculture, and in some cases remain as contaminants in the soil. The burning of vegetation biomass to clear agricultural fields (crop residues, weeds) remains a potent contributor to regional air pollution wherever it occurs, and has now been banned in many areas.

In text questions (30 minutes)

1) How does industrialisation contribute to climate change?
2) What can be done to reduce the contribution of carbon through industrialisation?
3) How can technological advancement reduce the effect of climate change?
4) To what extent does human population growth impact global warming, and what can be done about it?

Summary

This session has presented the drivers of climate change and how each driver contributes to changing climate. We have studied how population growth, urbanisation, industrialisation, technological development and land-use and land-cover change impact on the climate.

4.4 Climate systems

This session discusses the components of the climate systems, the interaction of the physical, chemical and biological processes of the climate system, and solar radiation. The climate system is a complex, interactive system consisting of the atmosphere, land surface, snow and ice, oceans and other bodies of water, and living things.

The climate system evolves in time under the influence of its own internal dynamics and due to changes in external factors that affect climate (called 'forcings[2]'). External forcings include natural phenomena like volcanic eruptions and solar variations, as well as human-induced changes in atmospheric composition. Solar radiation powers the climate system.

Objectives

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

a) describe the components of the climate systems;

b) explain how physical, chemical and biological components of the climate interact;

c) analyse the weather patterns and systems; and,

d) explain how a solar balance is obtained through radiation, absorption, scattering, reflection and Earth albedo.

Activity 1 (Discussion) (20 minutes)

In small groups, share your views on how the atmosphere, hydrosphere, cryosphere, biosphere and land surface interact to shape the climate systems.

4.4.1 Major climatic phases

There are four major climatic phases: glacial and interglacial periods, Holocene and Anthropocene.

Glacial periods are geological eras that have been marked by lower temperatures in the northern hemisphere, where continental cover is dominant, causing an expansion of glaciers at high latitudes.

An interglacial period is a period separating two glaciations and during which the mean temperatures are relatively high. The present interglacial period is the **Holocene**. It has lasted since the end of the **Pleistocene** about 12, 000 years ago.

The **Holocene** (12 000 years to today) is an interglacial, a hot period following the last pleistocene ice age. The Holocene is the fourth and last period of the Neogene, one of the many quaternary interglacials. The Holocene corresponds to the advent of the Mesolithic, the Neolithic and the later cultures. This is the beginning of the rapid expansion of the human species. Some scientists designate a new geological epoch succeeding the Holocene: the Anthropocene.

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[2] defined as the difference of insolation (sunlight) absorbed by the Earth and energy radiated back to space

The **Anthropocene** is a term of geological chronology proposed to characterize the period on Earth which began when human activities had a significant global impact on the terrestrial ecosystem. This term was popularized at the end of the 20th century by meteorologist and atmospheric chemist Paul Crutzen, Nobel laureate in chemistry in 1995, to designate a new geological epoch, which he said would have begun in the late eighteenth century with the industrial revolution, and would thus succeed to the Holocene. It is the period during which the influence of the human being on the biosphere reached such a level that it became a major "geological force" capable of marking the lithosphere.

4.4.2 Components of the climate systems

The climate system, as defined by the IPCC, is an interactive system consisting of five major components: the atmosphere, the hydrosphere, the cryosphere, the land surface and the biosphere, forced or influenced by various external mechanisms, the most important of which is the Sun (Figure 22). These essential components are not passive, and they don't work alone. Rather, Earth's climate is governed by an intricate and dynamic interaction among these five components.

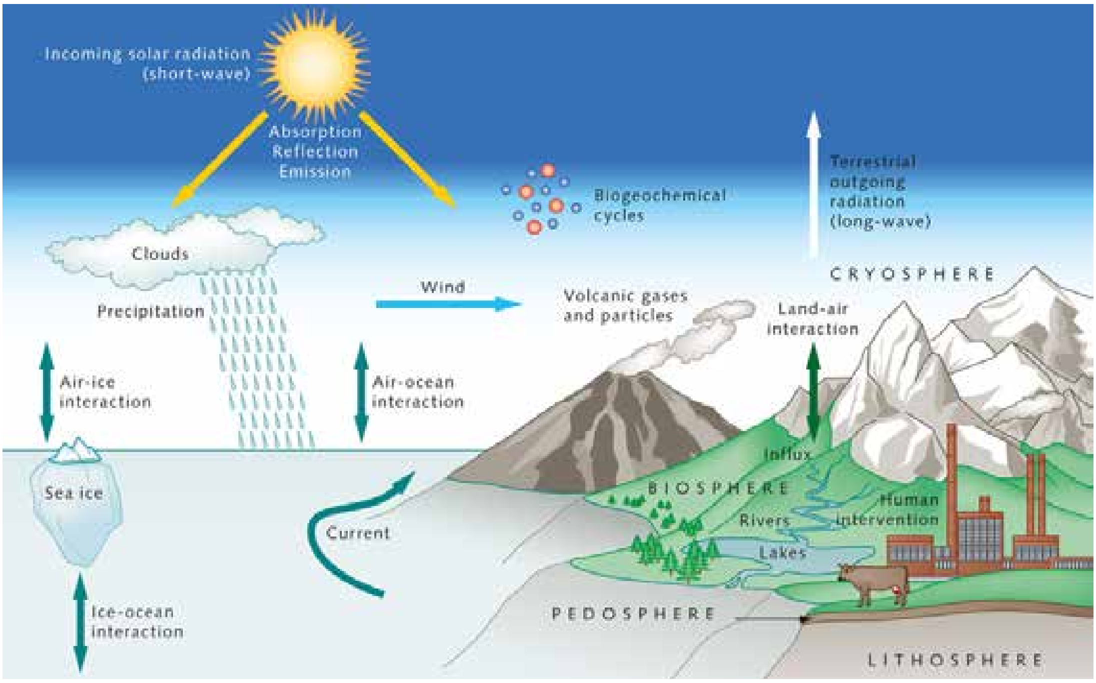


Figure 22. Components of the Climate system.

Source: http://worldoceanreview.com/en/wor-1/climate-system/Earth-climate-ystem/

The **atmosphere** is essentially the air that envelops the Earth's surface. Measured in volume, the dry air of the atmosphere contains 78.08 percent nitrogen, 20.95 percent oxygen, 0.93 percent argon and 0.038 percent CO_2. Although no concrete boundary defines the atmosphere, it does not exert any visible effects on climate after about 120 kms above Earth's surface. Of all the five components of climate, the atmosphere is the most dynamic and changeable. For instance, the heating and cooling of air creates wind currents that carry water vapor and move heat from one part of the Earth to another.

The fresh and salt waters of the Earth, including lakes, rivers, subterranean waters and oceans, make up the **hydrosphere**. The ocean accounts for about 70 percent of the planet's surface. The waters of the hydrosphere store and transport energy, break down minerals, store CO_2 and, especially in the case of oceans, retain a massive amount of heat. As this heat helps prevent drastic temperature changes, oceans serve as the planet's climate regulators.

The **cryosphere** is the ice on the Earth's surface. This includes ice sheets, glaciers, permafrost, sea ice and snow cover. In addition to storing great amounts of water, the ice of the cryosphere reflects solar radiation back into space. Perhaps most importantly, the cryosphere contributes to deep ocean water circulation. As large ice volumes accumulate and melt, the process causes variations in sea level.

The **lithosphere** is the Earth's solid land. As the outermost shell of the planet, the lithosphere includes soils, plains, mountains and anything geologically connected to them. In comparison to the other four components, the lithosphere exerts relatively little influence on climate, although the composition of land and soil affects how radiation from the sun is either absorbed or reflected back into the atmosphere. Additionally, the texture of the lithosphere affects the impact of wind as it travels over the Earth's surface. The surface texture of the Earth, for instance, creates rain shadow and deserts.

All of the living plants and animals on Earth compose the **biosphere**, including marine and terrestrial organisms. Living creatures exert a huge influence on the uptake and release of greenhouse gases. The Earth's plants store significant amounts of CO_2, making them key players in the carbon cycle. The biosphere also affects the planet's climate through surface albedo, or the reflection of light. The large-scale texture of plant growth in the biosphere influences the process of water transfer from land to the atmosphere, just as it influences the movements of wind. Large forests contribute to the creation of their own local climates.

4.4.3 Interaction of physical, chemical and biological processes of the climate system

Many physical, chemical and biological interaction processes occur among the various components of the climate system on a wide range of space and time scales, making the system extremely complex. Although the components of the climate system are very different in their composition, physical and chemical properties, structure and behaviour, they are all linked by fluxes of mass, heat and momentum: all subsystems are open and interrelated.

As an example, the atmosphere and the oceans are strongly coupled and exchange, among others, water vapour and heat through evaporation. This is part of the hydrological cycle and leads to condensation, cloud formation, precipitation and runoff, and supplies energy to weather systems. On the other hand, precipitation has an influence on salinity, its distribution and the thermohaline circulation.

Atmosphere and oceans also exchange CO_2, maintaining a balance by dissolving it in cold polar water which sinks into the deep ocean and by outgassing in relatively warm upwelling water near the equator.

Some other examples: sea ice hinders the exchanges between atmosphere and oceans; the biosphere influences the CO_2 concentration by photosynthesis and respiration, which in turn is influenced by climate change. The biosphere also affects the input of water in the atmosphere through evapotranspiration, and the atmosphere's radiative balance through the amount of sunlight reflected back to the sky (albedo).

Weather patterns and systems (e.g. Inter Tropical Convergence Zone, ITCZ)

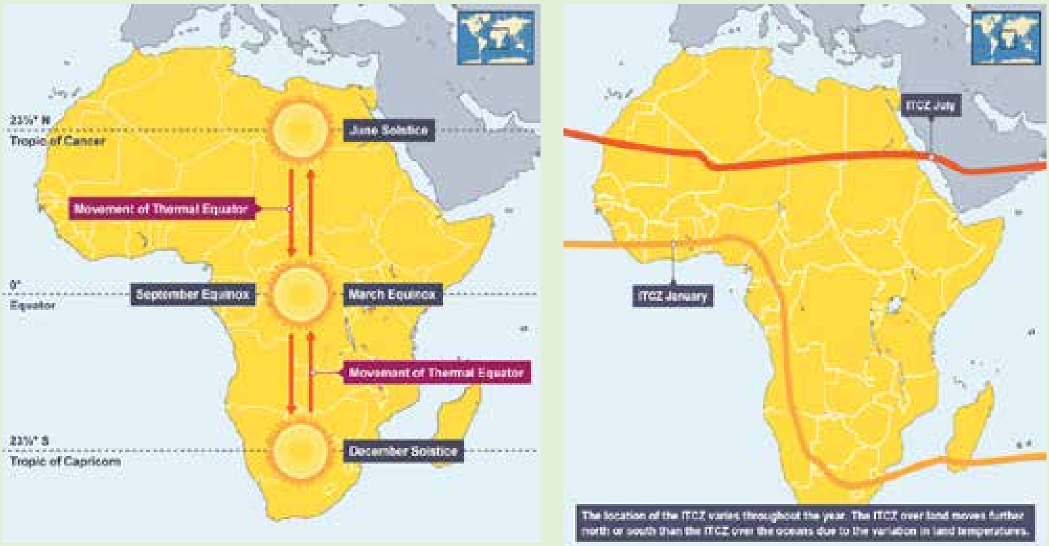
The Intertropical Convergence Zone (ITCZ), is the region that circles the Earth, near the equator, where the trade winds of the Northern and Southern Hemispheres come together. The intense sun and warm water of the equator heats the air in the ITCZ, raising its humidity and making it buoyant. Aided by the convergence of the trade winds, the air rises and expands and cools, releasing the accumulated moisture in a series of thunderstorms.

Seasonal shifts in the location of the ITCZ drastically affects rainfall in many equatorial nations, resulting in the wet and dry seasons of the tropics rather than the cold and warm seasons of higher latitudes. Longer term changes in the ITCZ can result in severe droughts or flooding in nearby areas.

Case study 7. Cause and impact of the ITCZ

The thermal equator receives the most intense heat from the Sun. Around 20 June each year the Sun is overhead at 23½°N, the Tropic of Cancer. Around 20 December the Sun is overhead at 23½°S, the Tropic of Capricorn. The movement of the thermal equator shifts the belts of planetary winds and pressure systems to the north and to the south annually (Figure 23).

When the tropical Maritime air mass (very hot with high relative humidity) that originates in the Atlantic Ocean/Gulf of Guinea meet with the tropical continental air mass that originates in the Sahara Desert (which is also very hot but with low relative humidity), moist air is forced upward. This causes water vapour to condense as the air cools and rises, resulting in a band of heavy precipitation around the globe.



The location of the ITCZ varies throughout the year. The ITCZ over land moves further north or south than the ITCZ over the oceans due to the variation in land temperatures.

Figure 23. Movement of ITCZ over the land

As the ITCZ moves north it carries the mT winds over the land. This will bring wet weather. At the same time, places to the north of the ITCZ will be experiencing hot dry weather, under the influence of the cT winds. Thunderstorms regularly occur directly beneath the ITCZ. Variation in the location of the ITCZ dramatically affects rainfall in many equatorial nations, resulting in the wet and dry seasons of the tropics.

Source: British Broadcasting Cooperation (BBC) (n.d)

Activity 2 (Group discussion and presentation) (20 minutes)

Students/participants should discuss the importance of interaction between the physical, chemical and biological components of the climate system.

4.4.4 Radiation balance

There are three fundamental ways to change the radiation balance of the Earth:

1) by changing the incoming solar radiation (e.g., by changes in Earth's orbit or in the Sun itself);
2) by changing the fraction of solar radiation that is reflected (called 'albedo'), e.g., by changes in cloud cover, atmospheric particles or vegetation; and,
3) by altering the longwave radiation from Earth back to space (e.g. by changing GHG). Climate, in turn, responds directly to such changes, and indirectly, through a variety of feedback mechanisms.

The amount of energy reaching the top of Earth's atmosphere each second on a surface area of one square metre facing the Sun during daytime is about 1,370 Watts, and the amount of energy per square metre per second averaged over the entire planet is one-quarter of this (Figure 24). About 30% of the sunlight that reaches the top of the atmosphere is reflected back to space. Roughly two-thirds of this reflectivity is due to clouds and small particles in the atmosphere known as 'aerosols'. Light-coloured areas of Earth's surface – mainly snow, ice and deserts – reflect the remaining one-third of the sunlight.

The most dramatic change in aerosol-produced reflectivity comes when major volcanic eruptions eject material very high into the atmosphere. Rain typically clears aerosols out of the atmosphere in a week or two, but when material from a violent volcanic eruption is projected far above the highest cloud, these aerosols typically influence the climate for about a year or two before falling into the troposphere and being carried to the surface by precipitation. Major volcanic eruptions can thus cause a drop in mean global surface temperature of about half a degree Celsius that can last for months or even years. Some man-made aerosols also significantly reflect sunlight.

The energy that is not reflected back to space is absorbed by the Earth's surface and atmosphere, approximately 240 Watts per square metre (W m^{-2}). To balance the incoming energy, the Earth itself must radiate, on average, the same amount of energy back to space. The Earth does this by emitting outgoing longwave radiation. Everything on Earth emits longwave radiation continuously. That is the heat energy one feels radiating out from a fire; the warmer an object, the more heat energy it radiates. To emit 240 W m^{-2}, a surface would have to have a temperature of around –19°C. This is much colder than the conditions that actually exist at the Earth's surface (the global mean surface temperature is about 14°C). Instead, the necessary –19°C is found at an altitude about 5 km above the surface.

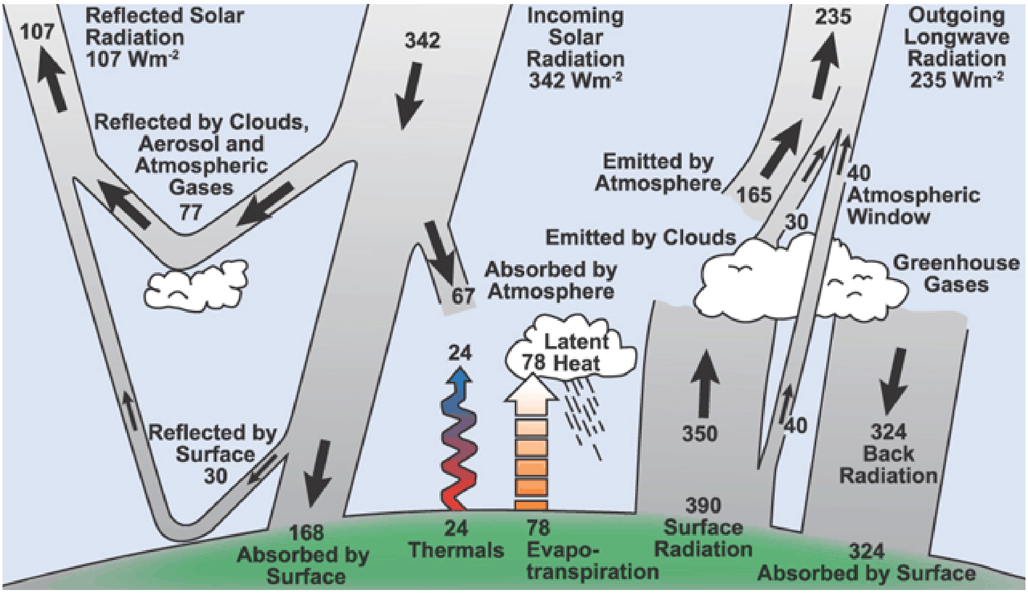


Figure 24. Estimate of the Earth's annual and global mean energy balance.

Over the long term, the amount of incoming solar radiation absorbed by the Earth and atmosphere is balanced by the Earth and atmosphere releasing the same amount of outgoing longwave radiation. About half of the incoming solar radiation is absorbed by the Earth's surface. This energy is transferred to the atmosphere by warming the air in contact with the surface (thermals), by evapotranspiration and by longwave radiation that is absorbed by clouds and greenhouse gases. The atmosphere in turn radiates longwave energy back to Earth as well as out to space.

Source: Kiehl and Trenberth (1997).

The reason the Earth's surface is warm is the presence of greenhouse gases, which act as a partial blanket for the longwave radiation coming from the surface. This blanketing is known as the natural greenhouse effect. The two most abundant constituents of the atmosphere – nitrogen and oxygen – have no such effect. Clouds, on the other hand, do exert a blanketing effect similar to that of the greenhouse gases. However, this effect is offset by their reflectivity, such that on average, clouds tend to have a cooling effect on climate (although locally one can feel the warming effect: cloudy nights tend to remain warmer than clear nights because the clouds radiate longwave energy back down to the surface). Human activities intensify the blanketing effect through the release of greenhouse gases. For instance, the amount of CO_2 in the atmosphere has increased by about 35% in the industrial era due to human activities, primarily the combustion of fossil fuels and removal of forests. Thus, humankind has dramatically altered the chemical composition of the global atmosphere with substantial implications for climate.

Because the Earth is a sphere, more solar energy arrives for a given surface area in the tropics than at higher latitudes, where sunlight strikes the atmosphere at a lower angle. Energy is transported from the equatorial areas to higher latitudes via atmospheric and oceanic circulations, including storm systems. Energy is also required to evaporate water from the sea or land surface, and this energy, called latent heat, is released when water vapour condenses in clouds (see Figure 24). Atmospheric circulation is primarily driven by the release of this latent heat. Atmospheric circulation in turn drives much of the ocean circulation through the action of winds on the surface waters of the ocean, and through changes in the ocean's surface temperature and salinity through precipitation and evaporation.

Due to the rotation of the Earth, the atmospheric circulation patterns tend to be more east-west than north-south. Embedded in the mid-latitude westerly winds are large-scale weather systems that act to transport heat toward the poles. These weather systems are the familiar migrating low- and high-pressure systems and their associated cold and warm fronts. Because of land-ocean temperature contrasts and obstacles, such as mountain ranges and ice sheets, the circulation system's planetary-scale atmospheric waves tend to be geographically anchored by continents and mountains although their amplitude can change with time. Because of the wave patterns, a particularly cold winter over North America may be associated with a particularly warm winter elsewhere in the hemisphere. Changes in various aspects of the climate system, such as the size of ice sheets, the type and distribution of vegetation or the temperature of the atmosphere or ocean will influence the large-scale circulation features of the atmosphere and oceans.

There are many feedback mechanisms in the climate system that can either amplify ('positive feedback') or diminish ('negative feedback') the effects of a change in climate forcing. For example, as rising concentrations of greenhouse gases warm Earth's climate, snow and ice begin to melt. This melting reveals darker land and water surfaces that were beneath the snow and ice, and these darker surfaces absorb more of the Sun's heat, causing more warming, which causes more melting, and so on, in a self-reinforcing cycle. This feedback loop, known as the 'ice-albedo feedback', amplifies the initial warming caused by rising levels of greenhouse gases. Detecting, understanding and accurately quantifying climate feedbacks have been the focus of a great deal of research by scientists unravelling the complexities of Earth's climate.

In text questions (20 minutes)

1) Describe how the components of the climate systems interact among themselves.
2) How does ITCZ influence the climate in the tropics?

Summary

This session has introduced learners to the components of the climate systems, the physical, chemical and biological interaction among the system, weather patterns and systems, and how solar radiation influence the changing climate. The next session presents the scientific basis of climate change.

4.5 Scientific basis of climate change

This session provides the scientific basis of climate change. Earth-orbiting satellites and other technological advances have been used to provide evidences based on rising sea levels, global rise in temperature, warming oceans, shrinking ice sheets, etc.

Objectives

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

a) explain the scientific basis of climate change; and,

b) use satellite images in collecting of scientific data on rising sea level and global rise in temperature.

Activity 1 (Discussion) (20 minutes)

Students/participants should discuss evidences of climate change that they know of.

4.5.1 GHG emissions and global warming

Energy from the sun reaches the Earth in the form of ultraviolet (UV), visible and infra-red (IR) radiation. Most of this energy, however, passes through the atmosphere without being absorbed or reflected (Figure 25). 26% of the total energy reaching the top of the atmosphere is reflected back to space by the atmosphere and clouds, while 19% is absorbed by the atmosphere and clouds.

Most of the remaining energy is absorbed at the Earth's surface. Because it is warm, the surface radiates far IR thermal radiation that consists of wavelengths that are much longer than the wavelengths that were absorbed (the overlap between the incident solar spectrum and the terrestrial thermal spectrum is small enough to be neglected for most purposes). Most of this thermal radiation is absorbed by the atmosphere, thereby warming it (in addition to sensible and latent heat fluxes from the surface). The atmosphere radiates energy both upwards and downwards; the part radiated downwards is absorbed by the Earth's surface. This leads to a higher equilibrium temperature than if the atmosphere was absent.

The GHGs cause the greenhouse effect (i.e. the process by which radiation from a planet's atmosphere warms the planet's surface to a temperature above what it would be in the absence of its atmosphere). The greenhouse effect is useful because trapping some energy keeps the temperatures on our planet mild and suitable for living things. Without its atmosphere and the greenhouse effect, the average temperature at the surface of the Earth would be below zero.

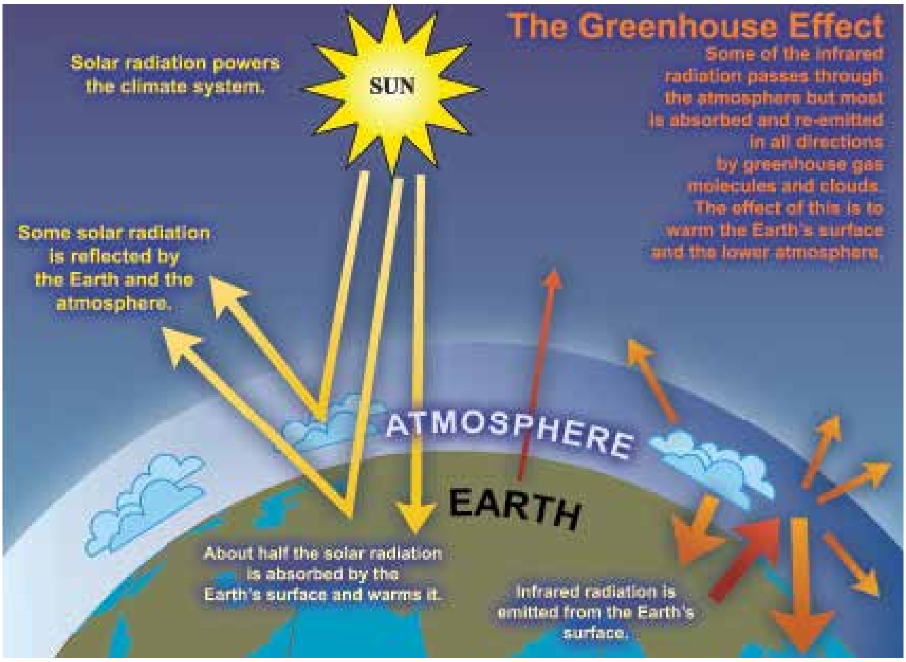


Figure 25. An idealised model of the natural greenhouse effect. Source: IPCC 2007.

However, too much GHG can cause the temperature to increase out of control. Such is the case on Venus where GHGs are abundant and the average temperature at the surface is more than 457 C^{o}. Emissions resulting from human or anthropogenic activities are substan-tially increasing the atmospheric concentrations of GHGs like CO_2, methane, chlorofluoro-carbons (CFCs) and nitrous oxides. The only exception is water vapour. For 1000 years before the Industrial Revolution, the amount of GHGs remained relatively constant. With the development of agriculture and increased industrialisation, the abundance of GHGs (except water vapour) increased significantly.

Activity 2 (Group discussion) (20 minutes)

Discuss the effects of increased greenhouse gases on farming and other rural livelihoods.

Summary

This session has dealt with the scientific basis of climate change. The session has introduced learners to the greenhouse effect and how it causes global warming. The next session presents trends in climate variables.

4.6 Trends in climatic variables

This session presents a historical outline of the changes in the important weather elements – temperature, precipitation and humidity.

Objectives

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

a) identify the changes in the important weather elements and the effects of changing climate on them; and,

b) project the important weather elements in coming years.

Activity 1 (Exercise) (30 minutes)

Students/participants should:

- obtain temperature, rainfall and relative humidity data from the Metrological Services Division in their country; and,
- identify the trend in the metrological data.

4.6.1 Trends in global mean temperatures

Trends in global mean surface temperatures are best revealed by plotting temperature "anomalies," which are changes from the long-term (120 year) average over the period for which we have instrument records.

Global land, ocean and land-ocean combined surface data show that the last 4-5 years have been near the record high year of 1998 (an El Niño year). The high temperatures in recent years are observed both over oceans and over land.

Global mean surface temperatures have increased over the past 120 years at a rate near 0.06 C/decade but with periods of larger and smaller trend. During the past 25-30 years this trend has been approximately 0.18 C/decade. The most recent period of increasing surface temperatures has a warming rate comparable to the rates projected by the global climate models using observed changed in greenhouse gases, stratospheric ozone concentration, volcanoes, and fluctuations of the output of the sun. This recent trend is expected to continue throughout the next century with continued increases of anthropogenic GHGs.

Temperature measurements above the Earth's surface have been made over the past 50 to 60 years using balloon-borne instruments (radiosondes) and for the past 28 years using satellites. These measurements show that the middle tropospheric temperatures (14 to 22 km above the surface) have been below average since the dissipation of the warming effects from the 1991 Mt. Pinatubo eruption. Depletion of the ozone in the lower stratosphere, combine with the effects of rising GHG concentrations, would lead to lower temperatures in the stratosphere of magnitudes consistent with these observations.

4.6.2 Trends in global mean precipitation

Global mean precipitation over the past 100 years shows a weak resemblance to global temperature history - low at the beginning of the record, increasing beginning in the 1940s, variable to 1980, and increasing since then. A global distribution of change from 1900-1994 generally shows increases at high latitudes and decreases in subtropical areas.

Precipitation has increased over land at high latitudes of the Northern Hemisphere, especially during the cold season. Decrease in precipitation occurred in steps after the 1960s over the subtropics and the tropics from Africa to Indonesia. These changes are consistent with available data analyses of changes in stream flow, lake levels and soil surface. Precipitation averaged over the Earth's land surface increased from the start of the century up to about 1960, but has decreased since about 1980. There is a lack of data on precipitation over the oceans.

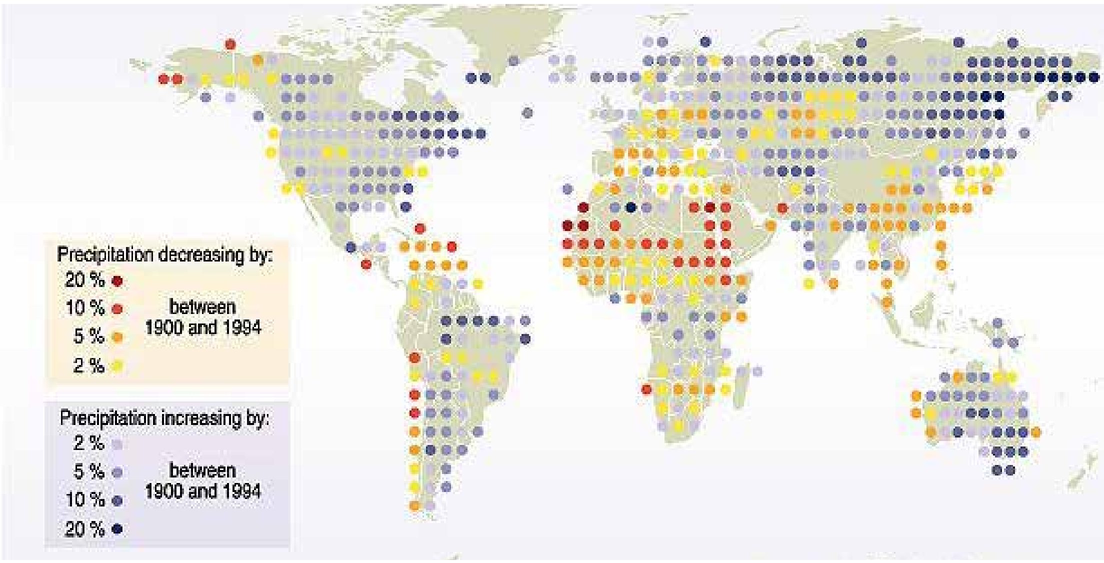


Figure 26. Trends in mean global precipitation. Source: UNEP 1995.

4.6.3 Trends in global mean humidity

Water vapour provides the most powerful feedback in the climate system. When surface temperature warms, this leads to an increase in atmospheric humidity. Because water vapour is a greenhouse gas, the increase in humidity causes additional warming. This positive feedback has the capacity to double the initial surface warming. So when temperatures rise, we expect humidity to also increase. However, one study using weather balloon measurements found decreasing humidity. To get to the truth of the matter, the full body of evidence regarding humidity is perused in a new paper. To give an overview of humidity trends, Dessler and David compare the results from Paltridge's (2009) paper to a number of other reanalyses of humidity. Figure 27 shows the trend in specific humidity from 1973 to 2007 over the tropics. The Paltridge analysis (thick black line) shows considerable divergence in the upper troposphere, with a strong negative trend while the other reanalyses all give consistent results, both with each other and theoretical expectations.

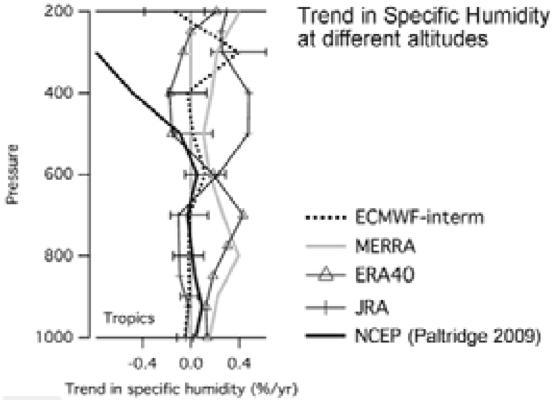


Figure 27. Various reanalyses showing the trend in specific humidity from 1973 to 2007 in the tropics. Dessler 2010 also looks at the Northern and Southern extra-tropics - only the tropic data is shown here for simplicity and as such, it shows the greatest contrast between Paltridge 2009 and the other reanalyses.

Source: Dessler 2010

To gain more insight into the nature of the observed water vapour feedback, Dessler and Davis examined the relationship between humidity and surface temperature. They plot specific humidity directly against surface temperature - this gives a measure of the amount of water vapour feedback. They compare the short-term trend (under 10 years) to the long-term trend (greater than 10 years) for the five different reanalyses:

For the short-term trends, all five reanalyses produce consistent results, with surface warming associated with increasing humidity (e.g. positive water vapor feedback). However, there is poorer agreement in the long-term trends. The Paltridge reanalysis is a distinct outlier, with long-term and short-term trends going in opposite directions, unlike the results from the other studies.

Water vapor feedback at different altitudes

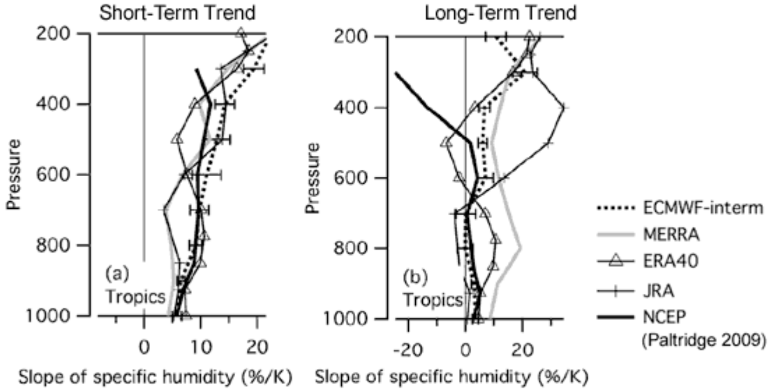


Figure 28. Short-term (a) and long-term (b) plots of the slopes of the regression between specific humidity and surface temperature, in the tropics. Trends are divided by the average specific humidity over the entire time period, so they are expressed in percent per degree K.

Source: Dessler 2010

This leads to an interesting question: could water vapor feedback be opposite over short and long-term time scales? There is no theory that can explain how short-term feedback could be positive while long-term feedback is negative. The water vapor response to a climate fluctuation with a time scale of a few years (e.g. ENSO) should be about the same as for long-term warming.

Long-term positive feedback is confirmed by several independent sources. An analysis of long-term measurements of upper tropospheric water vapor shows a positive water vapor feedback in 22 years of satellite data. In addition, analysis of long-term paleoclimate records is also inconsistent with a negative long-term water vapor feedback.

So why does Paltridge (2009) show decreasing humidity? The authors themselves point out the well-documented problems with radiosonde humidity observations in the upper tropo-sphere. Comparing Paltridge with satellite measurements (NASA's Atmospheric Infrared Sounder - AIRS) find the Paltridge reanalysis has large biases in specific humidity in the tropical upper troposphere. Also, Paltridge doesn't show any large increase in specific humidity during the 1998 El Niño. Direct measurements indicate the tropical atmosphere does moisten during El Niño events and such moistening is seen in the other reanalyses.

Two of the newer reanalyses shown in the figures above, MERRA and ECMWF-Interim, correct for well documented biases introduced by changes in the observing system. These newer reanalyses are in better agreement with theory, other reanalyses and independent observations.

To claim that humidity is decreasing requires you ignore a multitude of independent reanalyses, including newer ones with improved algorithms, that all show increasing humidity. It requires you accept a flawed reanalysis that even its own authors express caution about. It fails to explain how we can have short-term positive feedback and long-term negative feedback (indeed there is no known mechanism that can explain it). In short, to insist that humidity is decreasing is to neglect the full body of evidence.

In text questions (30 Minutes)

1) Analyse the mean temperature changes for the last 30 years.
2) What is the predicted rise in temperature in the next 20 years' time?

Summary

This session has provided evidence on changing climate by showing the rapid changing trend in important weather elements. Next session presents case studies on further evidence and impact of climate change in Africa.

4.7 Evidence and impact of climate change

Although climate change is a global problem, its impacts vary widely and are felt locally. Historically, risk management strategies have relied on the past as a guide to the future. But with global climate change, the future will no longer resemble the past. Studying regions with different vulnerabilities will provide insights and methods for conducting assessments in other regions and sectors.

The session presents case studies across Africa on evidence and impacts of climate change.

Objectives

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

a) Describe global evidences of the impacts of climate change; and,

b) provide specific examples of the impacts of climate change in their home countries.

Activity 1 (Discussion) (20 minutes)

Students/participants should describe some impacts of climate change in their home countries.

4.7.1 Evidence of a changing climate

According to IPCC, the scientific evidence for warming of the climate system is unequivocal. Ninety-seven percent of climate scientists agree that climate-warming trends over the past century are very likely due to human activities, and most leading scientific organisations worldwide have issued public statements endorsing this position.

Earth-orbiting satellites and other technological advances have enabled scientists to see the big picture, collecting many different types of information about our planet and its climate. This body of data, collected over many years, reveals the signals of a changing climate.

The heat-trapping nature of CO_2 and other gases was demonstrated in the mid-19th century. Their ability to affect the transfer of infrared energy through the atmosphere is the scientific basis of many instruments flown by NASA. There is no question that increased levels of greenhouse gases must cause the Earth to warm in response.

Ice cores drawn from Greenland, Antarctica and tropical mountain glaciers show that the Earth's climate responds to changes in greenhouse gas levels. They also show that in the past, large changes in climate have happened very quickly, geologically speaking: in tens of years, not in millions or even thousands.

Case study 8. The compelling evidence for rapid climate change

1. Sea level rise

Global sea level rose about 17 centimeters in the last century. The rate in the last decade, however, is nearly double that of the last century.

2. Global temperature rise

All three major global surface temperature reconstructions show that Earth has warmed since 1880. Most of this warming has occurred since the 1970s, with the 20 warmest years having occurred since 1981 and with all 10 of the warmest years occurring in the past 12 years. Even though the 2000s witnessed a solar output decline resulting in an unusually deep solar minimum in 2007-2009, surface temperatures continue to increase.

3. Warming oceans

The oceans have absorbed much of this increased heat, with the top 700 meters of ocean showing warming of 0.6° C since 1969.

4. Shrinking ice sheets

The Greenland and Antarctic ice sheets have decreased in mass. Data from NASA's Gravity Recovery and Climate Experiment show Greenland lost 150 to 250 km^3 of ice per year between 2002 and 2006, while Antarctica lost about 152 km^3 of ice between 2002 and 2005.

5. Declining Arctic sea ice

Both the extent and thickness of the Arctic sea ice has declined over the last several decades.

6. Glacial retreat

Glaciers are retreating almost everywhere around the world — including in the Alps, Himalayas, Andes, Rockies, Alaska and Africa.

7. Extreme events

The number of record high temperature events in the United States has been increasing, while the number of record low temperature events has been decreasing, since 1950. The U.S. has also witnessed increasing numbers of intense rainfall events.

8. Ocean acidification

Since the beginning of the Industrial Revolution, the acidity of surface ocean waters has increased by about 30 %. This increase is the result of humans emitting more CO_2 into the atmosphere and hence more being absorbed into the oceans. The amount of CO_2 absorbed by the upper layer of the oceans is increasing by about 2 billion tons per year.

9. Decreased snow cover

Satellite observations reveal that the amount of spring snow cover in the Northern Hemisphere has decreased over the past five decades and that the snow is melting earlier.

In text question (s) (20 minutes)

How can you convince a group of sceptics in your community that climate change is real?

4.7.2 Case studies in Southern Africa

Africa is one of the continent's most at risk from climate change. Observed temperatures have indicated a warming trend since the 1960s and IPCC projections suggest that annual temperatures in the region will rise by 3.4° C.

In southern Africa, annual rainfall is likely to decrease, with a higher mean rainfall in the northeast region, while the south and centre are expected to be drier. Only a smaller pocket of the northeast is expected to become wetter – and it is unclear where the geographic division between the 'wetter' northeast and 'dryer' south/central regions will be. The models generally agree on a drying trend for much of the 21st century, and some suggest shorter rainy seasons. Despite the expected drop in overall rainfall for the region, most models agree that what rainfall there is, will fall in a smaller area in the northeast. This suggests that the severity and incidence of heavy precipitation events in the northeast – including Mozambique – is expected to rise.

Mozambique, already more frequently and severely affected by natural disasters than virtually any other country in Africa, is therefore expected to see more precipitation in fewer, more extreme events. The frequency and severity of flooding in Mozambique is expected to increase as a result. In addition, with the expected change in sea water temperatures, the west Indian Ocean tropical cyclones are predicted to be more severe and more frequent in the future. However there is little detailed meteorological modelling on how these storm patterns would evolve.

By the end of February 2007, Mozambique was reeling from the double impact of two catastrophic natural disasters. While the Zambezi and Save rivers were already flooded, a Category Four cyclone brought more rain inland and devastated the southern coast, affecting 300-500,000 people. The disaster also caused c. US$ 171 million in damage to local infrastructure and destroyed 277,000 ha of crops – an estimated 80 % of the cereal crop in the affected areas.

For a country with 54 % of its population below the poverty line, these recurring disasters exacerbate people's existing vulnerabilities and represent major economic setbacks. The loss of assets – such as homes, livestock, clothing, agricultural tools and seeds – had a devastating impact for a population dependent on subsistence agriculture and fishing. Poverty, and the lack of viable alternatives to living in the flood plain, underlies this exposure to repeated shocks.

Ironically, damming the Zambezi to control flooding has put more people at risk. The ability to control annual floods encouraged encroachment into the lowlands of the lower Zambezi, where the land is very fertile. However, major flood events overwhelm the capacity of the dams and they are becoming more frequent. The communities currently living in the flood plain are essentially accepting the risk of major floods in return for better harvests and fishing. From a risk reduction perspective, one solution is to encourage permanent resettlement on higher ground, but many do not see this as a viable alternative to the more fertile flood plains. The national disaster management authority estimated that of those evacuated during the 2000, 2001 and 2007 floods, some 40 % returned to the flood plains.

4.7.3 Case studies in East Africa

Climate change poses the single greatest threat in history to the objectives of development professionals in ending poverty and promoting social justice. Rising temperatures, increasingly erratic rainfall and more extreme weather events all have significant consequences for the protection of livelihoods, particularly within the world's most vulnerable populations.

The Global Water Initiative in collaboration with CARE did an assessment rainfall and temperature condition for four East African countries (Table 4 below).

Temperature		**Rainfall**	
Past trend	**Future trend**	**Past trend**	**Future trend**
Ethiopia			
In 1960-2006, Ethiopia was characterised by increasing temperatures of 1.3°C .	It is anticipated that temperatures will continue to increase by 1.1-3.1°C by 2060	In 1960-2006, no statistically significant trend in mean rainfall was observed in any season. In Central Ethiopia, increasing temperatures have been observed by communities in recent years.	There is no indication of rainfall predictions for Ethiopia for the future due to lack of trends on past rainfall and data gaps. However, if the region's climate predictions apply, some parts of the country will experience increased episodes of intense rainfall. Also, rainfall seasons are increasingly unpredictable and some episodes of intense rainfall and flooding have been observed. Future climate projections for central Ethiopia have not been assessed currently.
Kenya			
In 1960 to 2003, mean annual temperatures have increased in Kenya by 1.0° C per decade.	Future temperature projections indicate that the mean annual temperature may increase by 1.0° to 2.8° C by 2060.	In terms of rainfall, there are no statistically significant trends observed.	Mean rainfall is projected to increase by up to 48% by the 2090s, and within this, the proportion of rainfall that falls in heavy events is projected to increase by 13% over the same duration.

Temperature		Rainfall	
Past trend	**Future trend**	**Past trend**	**Future trend**
Daily temperature observations show significantly increasing trends in the frequency of hot days and a large increase in frequency of hot nights. In 1960 to 2003, the average No. of hot days has increased by 57, and average No. of hot nights by 113. The average No. of cold days has decreased by 16, and the No. of cold nights has decreased by 42.	The frequency of cold days and nights will continue to decrease.	It has been observed that the proportion of rainfall occurring in heavy events has increased since 1960 (though this is not statistically significant).	
Tanzania			
No data available.	Mean daily temperatures are predicted to increase 3-5°C throughout the country and mean annual temperatures will rise by 2-4°C. In the Pangani River Basin, predicted 1.8-3.6°C increase in temperature will result in 6-9% reductions in annual river flowr.	No data available.	Areas with bimodal rainfall are expected to see an increase in rainfall of 5-45% and areas with unimodal rainfall will see a decrease of 5-15%.

Temperature		Rainfall	
Past trend	**Future trend**	**Past trend**	**Future trend**
Uganda			
Since 1960, mean annual temperature has increased by 1.3°C, with an associated increase in frequency of hot days. Also, the frequency of cold days has decreased and the that of cold nights has decreased even more dramatically.	Projections for the country indicate further increases in the No. of hot days and nights, and continued decreases in the No. of cold days and nights.	Trends across Uganda show a decrease in annual rainfall of about 3.4 mm per month (3.5% per decade). Extreme rainfall events are not showing significant shifts in frequency or intensity, with rainfall events varying by region and season.	Precipitation projections are consistent and show an increase in annual rainfall, particularly in the short-rain season (Oct-Dec), with an increasing proportion of rain falling during heavy rainfall events.

4.7.4 Case studies in West Africa

The Ecosystem Grant Programme of Netherlands and the Univ. of Cambridge programme for sustainable leadership note that, in the Sahel region of West Africa, some degree of climate variation is expected over time, and it can be difficult to distinguish between this and variation caused by climate change. However, direct environmental impacts observed by, and attributed to climate change, include:

- **Movement of climatic zones/desertification** – the 'Cocoa Belt' of Côte d'Ivoire has moved from the East to the South-West of the country;
- **Shift of seasons** – the rainy season in Togo, instead of coming at the start of March, now sometimes does not begin until May;
- **Variation in rainfall: drought and flooding** – the intrusion of saltwater along the River Gambia during dry seasons, as well as soil degradation, has led to decreases in areas of lowland rice planting; flash floods in the inner delta of the Niger River have led to loss of pastoral areas and breeding areas for fish. In the Grand Popo region of Benin, floods have occurred annually from July to November since 2000, making travel impossible without a canoe;
- **Effects on agriculture and livestock breeding** – agriculture has disappeared from northern Mali due to persistent drought over the past 25 years; many farmers are being forced to change the crops they grow; since the mid-'90s, an increase in the mired crop pest has brought about a loss of 25%-30% in cocoa production in Togo; scarcity of pasture is leading to livestock losses in Benin;

- **Biodiversity loss** – changes in rainfall have severely affected many species of trees, plants and wildlife; temperature increases in Guinea-Bissau have provoked a decrease in fish production caused by lower levels of phytoplankton;
- **Coastal erosion and rising sea levels** – more than 50% of Gambia's capital city Banjul now lies below sea level; Ghana is experiencing average sea level rise of 2.1 mm per year.
- **Increased temperature** – the intense heat in Côte d'Ivoire from January to April is one of the most palpable signs of climate change; hot, dry conditions have led to repeated, devastating bush fires in many countries, including Guinea.

4.7.5 Case studies in North Africa

The North African countries are in an arid to semi-arid region with a Saharan climate in the south, an oceanic climate in the west, and a Mediterranean climate in the north. The life of people is very much linked to the climate and its fluctuations. The economy is very dependent on water, agriculture, tourism and coastlines. This is particularly striking in Morocco and Tunisia.

Climate data gathered in the region during the 20th century indicate heating, estimated at more than 1°C, with a pronounced trend in the past 30 years. The data also show a marked increase in the frequency of droughts and floods. The region experienced one drought every 10 years at the beginning of the century, to a current state of five or six years of drought per ten years. The general circulation models, even though they are not accurate enough for the region, since there is no mesh model, converge to estimate probable warming in the region in the order of two to four degrees in the 21st century.

Climate change in this part of North Africa (Algeria, Morocco and Tunisia), which emits low levels of greenhouse gases (between 1.5-3.5 tonnes of CO_2 /inhabitant/year), represents a veritable threat to the region's socio-economic development and to its population. The extreme vulnerability of the region, coupled with the possible impacts climate change represents, stresses the need for adaptive strategies in key sectors in the region for the long term sustainable development of these countries.

In text question (s) (20 minutes)

Evaluate the impact of climate change on people and ecosystems in your country?

Summary

This session has presented unequivocal facts that climate change is real and poses a great threat to life on Earth in the years to come. It has also presented case studies on evidences/impacts of climate change across Africa. We now turn to threats and opportunities posed by climate to life on Earth.

4.8 Threats and opportunities of climate change

Climate change presents both threats and opportunities, and this session outlines these.

Objectives

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

a) Describe the threats posed by climate change;

b) Analyse the opportunities posed by climate change; and,

c) Describe the means available for taking advantage of the opportunities in their countries to influence climate dynamics.

Activity 1 (Discussion) (20 minutes)

Students/participants should discuss the:

- threats posed by climate change;
- opportunities that climate change presents; and,
- ways of taking advantage of the opportunities.

According to IPCC's Assessment Report (IPCC IV, 2007), impacts of climate change and their associated costs will fall disproportionately on developing countries, threatening to undermine achievements of the SDGs, reducing poverty, and safeguarding food security. Adaptation becomes an urgent economic challenge in a warming planet. Industry and governments are beginning to respond to climate change threats and, in some cases, find new business possibilities.

Global agriculture will be under significant pressure to meet the demands of rising populations using finite, often degraded, soil and water resources that are predicted to be further stressed by the impact of climate change. The ongoing build up of greenhouse gases in the atmosphere is prompting shifts in climate across the globe that will affect agro-ecological and growing conditions. In addition, agriculture and land use change are prominent sources of global GHG emissions.

The application of fertilizers, rearing of livestock, and related land clearing influences both levels of GHGs in the atmosphere and the potential for carbon storage and sequestration. Therefore, whilst ongoing climatic changes affect agricultural production, the sector itself also presents opportunities for emission reductions.

There are opportunities for mitigation in the agricultural and forestry sectors to help reduce the impact of climate change, and there is significant room for promoting pro-poor mitigation methods. In addition, as a change in climate has already begun, adaptation — or the modification of agricultural practices and production — will be imperative to continue meeting the growing food demands of modern society. Both mitigation and adaptation will require the attention of governments and policy makers in order to coordinate and lead initiatives. It is apparent that a system of regulation to ensure the economic value of carbon sequestration will be an important policy development in the agricultural sector. The UK Government Climate Change Risk Assessment (CCRA) identified and assessed domestic threats and opportunities to the UK (Table 5).

Table 5. Threats and opportunities of climate change by the UK Government Climate Change Risk Assessment (CCRA)

Threats	Examples
Damages to physical and financial assets abroad due to economic damages from extreme weather.	Hurricanes Katrina and Super storm Sandy. The Thai floods of 2011, which cost Lloyds of London £1.4bn
Increased frequency and urgency of humanitarian assistance.	The Horn of Africa Drought, which led to food shortages after rains in 2010/11, affected 12million people. UK aid fed 3.5 million between July 2011 and July 2012, through a £200m emergency response.
Increased volatility in food prices.	Food price pikes in 2008 and 2011 are attributed to a number of factors, but initially triggered by drought affecting production levels
Political or policy reactions affecting availability of food supplies (e.g. protectionist measures).	2011 Russian droughts resulted in ban of wheat exports. 43 developing countries reduced import taxes and 25 banned exports or increased export taxes during the food price pike in 2007/08.
Increased demand for UK Government services by overseas territories and citizens abroad	Climate related events such as wildfires, floods and hurricanes increase demands on consular services. Furthermore, many UK territories are small islands, at risk from sea level rise.
Opportunities	Examples
Increased potential to export UK adaptation goods and services.	The UK is a key provider of some technologies and services such as climate modelling, water and waste water treatment and insurance.
Reduced shipping costs from Arctic Opening.	Research estimates suggest that the Arctic is likely to attract investments exceeding $100bn over the next decade.
Greater international diplomatic cooperation.	International relations activity related to climate change is increasing - the UNFCCC is the largest and most complex global negotiation, with numerous supplementary bilateral and regional meetings and discussions (e.g. the Major Emitters Forum, ASEAN events, and the Cartagena Dialogue).

In text question (s) (20 minutes)

Analyse the various threats and opportunities available to Agriculture and Forestry on the Africa continent.

Summary

This session of chapter four has presented the threats and opportunities posed by climate change to man and life on Earth. Little information has been documented on the opportunities available to African countries. The next session presents a detailed study on the drivers of climate change.

4.9 External drivers of climate change

The drivers of climate change are classified into internal and external. This session describes the external drivers of climate and their impact on humans and the environment.

Objectives

By the end of this session, the learner should be able to:

a) describe how climate change is influenced by regular variations in the Earth's orbit around the sun;

b) examine changes in solar thermal output;

c) explain how fluctuating levels of solar magnetic activity influences climate; and,

d) evaluate the impacts by extra-terrestrial objects on climate.

Activity 1 (Brainstorming) (20 minutes)

What are the causes of global warming that are not caused by man.

4.9.1 Regular variations in the Earth's Orbit around the Sun

The Earth revolves around the sun along its orbit. Also, it rotates about its own axis. The axis is tilted away from the perpendicular to the plane of its orbit around the sun. At present, the tilt away from the perpendicular is about 23.5Â°.

4.9.2 Changes in solar thermal output

The sun is the source of most of the energy that drives the biological and physical processes around us - in oceans and on land it fuels plant growth that forms the base of the food chain, and in the atmosphere it warms air which drives our weather. The rate of energy coming from the sun changes slightly day to day. Over millennia, the Earth-Sun orbital relationship can change the geographical distribution of the sun's energy over the Earth's surface. It has been suggested that changes in solar output might affect our climate - both directly by changing the rate of solar heating of the Earth and atmosphere, and indirectly, by changing cloud forming processes.

The rate at which energy from the sun reaches the top of Earth's atmosphere is called "total solar irradiance" (or TSI). TSI fluctuates slightly from day to day and week to week. Super-imposed on these rapid short-term fluctuations is a cycle related to sunspots in the outer layers of the Sun that lasts approximately every 11 years.

The current TSI varies with season, time of day and latitude.Yet it is thought that small changes in this relatively small amount of absorbed solar energy can make a difference to our climate.

Case study 9. Might changes in the rate of solar absorption, called radiative forcing (RF), be influencing our climate today?

1. Direct changes in climate due to solar output

The average increase in solar radiative forcing since 1750 is much smaller (~ 0.12 W m^{-2}) than the increase in RF due to heat-trapping gases (~2.6 W m^{-2}) over the same time period. The slight increase in solar absorption is, moreover, more than offset by natural cooling. The twentieth century witnessed the eruption of major volcanoes - the most recent, Pinatubo, in 1991 - that spewed tiny reflective particles into the atmosphere. Incoming energy from the sun that encountered these particles was reflected back into space. In other words, natural processes alone would have brought about slight late twentieth century cooling - not the warming we have experienced.

2. Indirect changes in climate due to solar output

The variations of the rate of emission of solar radiation on the 11 year time scale, as well as the small long-term increase in TSI over the past few centuries, appear in some studies to be correlated with variations in cloud patterns. These changes in absorbed solar energy appear to be far too small to explain the major changes in our climate.

Two different hypotheses have been proposed to test whether solar radiation can explain climate change. The first relies on the fact that in both the 11 year cycle and, in the longer term, the changes in solar energy are highest at ultraviolet (short) wavelengths. The short wavelength radiation is particularly effective in modifying ozone concentrations in the level of the atmosphere above where typical weather occurs. According to this hypothesis, modifications in the ozone layer could in turn filter down to that level of the atmosphere where our weather is formed, potentially modifying clouds and temperatures there.

The second hypothesis relies on the fact that changes in solar activity also change the flow of small, charged, highly energetic particles (known as galactic cosmic rays) that travel through the atmosphere toward Earth. These particles in turn create more ions (charged atoms or molecules) from air molecules in the atmosphere, and it has been suggested that these ions might modify cloud formation, causing large changes in weather and temperatures below.

So far, there is no convincing evidence that either of these ideas adequately demonstrate a causal links between small changes in solar irradiance and the relatively large, measurable changes in Earth’s surface temperature over the past century.

Source: Hansen et al. (2005).

4.9.3 Fluctuating levels of solar magnetic activity

The current position of bodies like the IPCC is that climate change in the industrial age is predominantly caused by anthropogenic greenhouse gases primarily CO_2, with relatively small natural contributions due to solar irradiance and volcanoes.

However, in the last decade a new theory, developed by Henrik Svensmark, a physics professor at the Danish National Space Centre in Copenhagen, about how variations in the Sun's magnetic activity may have a very profound impact on climate on Earth has attracted growing interest in the scientific community. The theory proposes a link between fluctuations in the sun's magnetic activity and resulting changes in the solar wind around the Earth affecting how many cosmic rays hit the Earth, particularly the lower atmosphere, which in turn affect the rate of low level cloud formation which in turn drives climate variability.

It has long been acknowledged that there seemed to be a very good fit between solar magnetic activity, as evidenced by sun spot levels and the waxing and waning of solar cycles, and climate changes. The British Astronomer Royal, William Herschel, noticed a correlation between sunspots and the price of wheat in England. This marked the first observation that Earth's climate may be affected by variations of the Sun. The well-known Little Ice Age around the 17th and 18th centuries – when sunspots all but disappeared for 70 years during the Maunder Minimum, the cosmic ray flux increased and the climate cooled – seems to be merely the latest of around a dozen similar events over the last ten thousand years. However there was no proposed mechanism which could explain how changes in the solar cycle could affect the climate to the degree suggested by the historical record as the overall level of energy emitted by the sun, and thus the solar energy hitting the Earth, didn't seem to vary that much with the solar cycles.

4.9.4 Impacts by extra-terrestrial objects

An impact event is a collision between celestial objects causing measurable effects. Impact events have physical consequences and have been found to regularly occur in planetary systems, though the most frequent involve asteroids, comets or meteoroids and have minimal impact. When large objects impact terrestrial planets like the Earth, there can be significant physical and biospheric consequences, though atmospheres mitigate many surface impacts through atmospheric entry. Impact craters and structures are dominant landforms on many of the Solar System's solid objects and present the strongest empirical evidence for their frequency and scale.

Impact events appear to have played a significant role in the evolution of the Solar System since its formation. Major events have significantly shaped Earth's history, have been implicated in the formation of the Earth–Moon system, the evolutionary history of life, the origin of water on Earth and several mass extinctions. Notable events include the Chicxulub impact, 66 million years ago, believed to be the cause of the Cretaceous–Paleogene extinction event.

An 18-member international team of researchers that includes James Kennett, professor of Earth science at UC Santa Barbara, has discovered melt-glass material in a thin layer of sedimentary rock in Pennsylvania, South Carolina and Syria. According to the researchers, the material – which dates back nearly 13,000 years – was formed at temperatures of 1,700 to 2,200º C, and is the result of a cosmic body impacting Earth.

These new data are the latest to strongly support the controversial Younger Dryas Boundary (YDB) hypothesis, which proposes that a cosmic impact occurred 12,900 years ago at the onset of an unusual cold climatic period called the Younger Dryas. This episode occurred at, or close to, the time of major extinction of the North American megafauna, including mammoths and giant ground sloths, and the disappearance of the prehistoric and widely distributed Clovis culture. The researchers' findings appear today in the Proceedings of the National Academy of Sciences.

"These scientists have identified three contemporaneous levels more than 12,000 years ago, on two continents, yielding siliceous scoria-like objects (SLO's)," said H. Richard Lane, program director of National Science Foundation's Division of Earth Sciences. "SLO's are indicative of high-energy cosmic airbursts/impacts, bolstering the contention that these events induced the beginning of the Younger Dryas. That time was a major departure in biotic, human and climate history."

Morphological and geochemical evidence of the melt-glass confirms that the material is not cosmic, volcanic or of human origin. "The very high temperature melt-glass appears identical to that produced in known cosmic impact events such as Meteor Crater in Arizona, and the Australasian tektite field," said Kennett.

"The melt material also matches melt-glass produced by the Trinity nuclear airburst of 1945 in Socorro, New Mexico," he continued. "The extreme temperatures required are equal to those of an atomic bomb blast, high enough to make sand melted and boiled."

In text question (s) (20 minutes)

1) How does the orbiting of the Earth influence climate change?
2) How does solar thermal output influence changing climate?

Summary

This session has demonstrated how regular variations in the Earth's orbit around the sun; changes in solar thermal output; fluctuating levels of solar magnetic activity; and impacts by extra-terrestrial objects affect climate change. The next session looks at how some factors termed internal drivers also contribute to climate change.

4.10 Internal drivers of climate change

This session introduces the internal drivers of climate change. It describes how volcanic eruptions, Earth albedos and wildfires cause climate change.

Objectives

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

a) describe how volcanic eruptions, Earth albedos and wildfires cause climate change; and,

b) distinguish the natural from man-made causes of wildfires.

Activity 1 (Brainstorming) (20 minutes)

Analyse the internal drivers of climate change.

4.10.1 Volcanic eruptions, tremors, and plate tectonics

An Earthquake (also known as a quake, tremor or temblor) is the perceptible shaking of the surface of the Earth, resulting from the sudden release of energy in the Earth's crust that creates seismic waves. Earthquakes can be violent enough to destroy whole cities. The seismicity, seismism or seismic activity of an area refers to the frequency, type and size of Earthquakes experienced over a period of time. There are still debates on whether climate change can cause Earthquake among scientists.

4.10.2 Earth's albedo (radiation balance at the Earth's surface)

Albedo is a measure of the reflectivity of a surface. The albedo effect when applied to the Earth is a measure of how much of the Sun's energy is reflected back into space. Overall, the Earth's albedo has a cooling effect.

The most significant projected impact on albedo is through future global warming. With the exception of Antarctic sea-ice, recently increasing by 1% a year, nearly all the ice on the planet is melting. As the white surfaces decrease in area, less energy is reflected into space, and the Earth will warm up even more.

The loss of Arctic ice is of particular concern. Not only is albedo decreasing, but the loss triggers a positive feedback. By exposing the ocean surface to sunlight, the water warms up. This melts the ice from underneath, while man-made CO_2 in the atmosphere warms the surface. Humidity also increases and water vapour is a powerful greenhouse gas. More ice therefore melts, which exposes more water, which melts more ice from underneath.

This loop fuels itself, the effect getting more and more pronounced. This is a good example of a positive feedback. Increased water vapour also has another effect, which is to increase the amount of cloud. As mentioned already, clouds can increase albedo (a negative feedback), but also warming (a positive feedback).

4.10.3 Wildfires (caused by natural factors such as lightning)

Wildfires are unplanned, unwanted land fires, including unauthorised human-induced fires. Wildfires are common in some parts of the world. They occur on every continent except Antarctica. They happen most frequently in hot areas with extended periods of drought.

The costs of wildfires, in terms of risks to human life and health, property damage and economies, are devastating, and they are only likely to increase unless we better address the risks of wildfires and reduce our activities that lead to further climate change.

Natural causes of wildfires are lightning, spontaneous heating and volcanic eruptions.

- Lightning is the single biggest natural cause of wildfires. Most fires started by lightning are small and burn out quickly but if the conditions are right then fires started by lightning can spread very rapidly. About 8 million lightning strikes hit the Earth every day!
- Spontaneous heating is where material becomes heated to the point at which it catches fire without a spark. This is common where lots of leaves and branches have fallen to the ground and not been cleared away - the flow of air is restricted and may lead to fire.
- Volcanic eruptions give out red hot lava and ash which can start wildfires.

Objectives

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

a) describe how volcanic eruptions, Earth albedos and wildfires cause climate change; and,

b) distinguish the natural from man-made causes of wildfires.

Activity 2 (Group discussion) (20 minutes)

- Discuss any three natural causes of wildfires

In text question (s) (20 minutes)

How do albedo and wildfires cause climate change?

Summary

This session has described how internal drivers – volcanic eruptions, tremors, plate tectonics; Earth's albedo; and, wildfires caused by natural factors such as lightning, contribute to climate change. The next session present the anthropological drivers of climate change.

4.11 Anthropogenic drivers of climate change

The anthropogenic drivers of climate change are human activities that lead to or contribute to climate change. This session introduces learners to some activities that cause climate change. They include:

(i) land use changes from forest to other land uses such as agriculture;

(ii) deforestation and forest degradation;

(iii) extensive use of inorganic fertilizer;

(iv) animal husbandry;

(v) paddy rice cultivation;

(vi) transportation;

(vii) conversion of wetlands to other land uses; and,

(viii) industrial emissions.

Objectives

By the end of this session the learner will be able to:

a) Describe how land use changes from forest to other land uses such as agriculture;

b) Describe how deforestation and forest degradation affects climate;

c) Analyse the impact of extensive use of inorganic fertilizers on climate;

d) Explain how animal husbandry affects climate change;

e) Describe how paddy rice cultivation influences dynamics of climate; and,

f) Asses the impact of transportation systems on climate.

Activity 1 (discussion) (30 minutes)

Learners should:

- list five human activities that cause climate change;
- identify the impacts of these activities on man and the environment; and,
- suggest means of reducing the impacts of these activities.

4.11.1 Land use changes from forest to other land uses such as agriculture

Land-use change is one type of human activity that is causing changes in Earth's climate. The IPCC estimates that land-use change (e.g. conversion of forest into agricultural land) contributes a net 1.6 ± 0.8 Gt carbon per year to the atmosphere. Land-use changes have led to changes in the amount of sunlight reflected from the ground back into space. The scale of these changes is estimated to be about one-fifth of the effect on the global climate due to changes in emissions of GHGs.

About half of the land-use changes in the United States are estimated to have occurred during the industrial era, much of it due to replacement of forests by agricultural cropping and grazing lands. The largest effect of deforestation is estimated to be at high latitudes where the albedo of snow-covered land, previously forested, has increased. This is because snow on trees reflects only about half of the sunlight falling on it, whereas snow-covered open ground reflects about two-thirds. Overall, the increased albedo over Eurasian and North American agricultural regions has had a cooling effect.

Other significant changes in the land surface resulting from human activities include tropical deforestation, which changes evapotranspiration rates (the amount of water vapour put into the atmosphere through evaporation and transpiration from trees), desertification, which increases surface albedo, and general effects of agriculture on soil moisture characteristics. All of these processes need to be included in climate models.

4.11.2 Deforestation and forest degradation

Deforestation is the conversion of forest to another land use or the long-term reduction of the tree canopy cover, including conversion of natural forest to tree plantations, agriculture, pasture, water reservoirs and urban areas, but excluding timber production areas managed to ensure the forest regenerates after logging.

Forest degradation happens when changes within the forest negatively affect the structure or function of the stand or site, and thereby lower the capacity to supply products and/or ecosystem services. Forest degradation creates less resilient and less productive forests and, in some countries, it can be nearly as harmful as deforestation. Forest degradation often begins the slippery slope to deforestation: large canopy gaps can dry out rainforests leaving them vulnerable to fire; abandoned logging roads provide access to settlers; and authorities are often more willing to grant conversion permits in heavily logged forests.

The effects of deforestation and forest degradation are:

- **Reduced biodiversity**: deforestation and forest degradation can cause wildlife to decline. When forest cover is removed, wildlife is deprived of habitat and becomes more vulnerable to hunting. Considering that about 80% of the world's documented species can be found in tropical rainforests, deforestation poses a serious threat to the Earth's biodiversity.
- **Release of greenhouse gas emissions**: forests are the largest terrestrial store of carbon and deforestation is the third-largest source of GHG emissions after coal and oil. Deforestation causes 15% of global GHG emissions. Of these, CO_2 emissions represent c. one-third of total CO_2 emissions released by human causes.
- **Disrupted water cycles**: As a result of deforestation, trees no longer evaporate groundwater, which can cause the local climate to be much drier.
- **Increased soil erosion**: Deforestation accelerates rates of soil erosion, by increasing runoff and reducing the protection of the soil from tree litter.
- **Disrupted livelihoods**: Millions of people rely directly on forests, through shifting cultivation, hunting and gathering, and by harvesting forest products such as rubber. Deforestation continues to create severe social problems, sometimes leading to violent conflict.

4.11.3 Extensive use of organic fertilizer

Fertilizers consist of substances and chemicals like methane, CO_2, ammonia, and nitrogen, the emission of which has contributed to quantity of greenhouse gases present in the environment. This in turn is leading to global warming and weather changes. In fact, nitrous oxide, is the third most significant greenhouse gas, after CO_2 and methane.

4.11.4 Animal husbandry

Climate change has direct effects on livestock productivity as well as indirectly through changes on the availability of fodder and pastures. It determines the type of livestock most adapted to different agro-ecological zones and therefore the animals that are able to sustain rural communities. Climate change is expected to affect livestock at the species level. Emissions throughout the livestock commodity-chains, contribute to 9% of the total anthropogenic CO_2 emission, 37% of methane and 65% of nitrous oxide. Technical options available for mitigating emissions of the sector include:

(i) restoring organic carbon and carbon sequestration through agro-forestry;

(ii) improve livestock diets;

(iii) better manure management; and,

(iv) careful nutrient management.

The use of biogas technology is a way to reduce emissions from mature management while increasing farm profit, and providing environmental benefits.

4.11.5 Paddy rice cultivation

Rice has important implications for food security because it makes up c. one third of the caloric intake of third world populations. Yet, the challenge for rice production is twofold: coping with population growth while also facing climate change.

Unforeseen changes associated with global warming in temperature, CO_2 and rainfall are expected to impact rice production. Studies have shown that increased temperature, due to climate change, adversely affect rice crop physiology ultimately decreasing crop yields and grain quality. Because CO_2 is an essential component in photosynthesis, increased atmospheric concentration of CO_2 is expected to increase plant growth and rice yields.

Uncertainty associated with projected precipitation spatial and temporal patterns caused by climate change, makes it difficult to anticipate the full effect of intensified frequency of floods and severe droughts. It is important to note that in regions with more radiation rice production results in higher grain yields. Overall, scholars believe that climate change has a beneficial effect on rice grain yield. The effects of CO_2 increase has been found to be nullified by the effects of increase in temperature. However, multiple sources of bias make estimates of climate change impact on rice production uncertain. The magnitude of the bias is estimated to range between 1 to 32 %.

4.11.6 Transportation

The CO_2 emissions in the transport sector are about 30% in the case of developed countries and about 23% in the case of the total man-made CO_2 emissions worldwide. There is widespread agreement to reduce CO_2 emissions from transport by a minimum of 50% latest by 2050.

The transportation sector is one of the largest sources of U.S. greenhouse gas (GHG) emissions. In 2013, it represented c. 27 % of total emissions. Between 1990 and 2013, GHG emissions in the transportation sector in the US increased more in absolute terms than in other sectors (i.e. electricity generation, industry, agriculture, residential or commercial).

At a number of international conferences, transport ministers have addressed the need for CO_2 abatement and improved fuel efficiency in the transport sector, mainly through:

(i) innovative vehicle technologies, advanced engine management systems and efficient vehicle powertrains;

(ii) the use of sustainable biofuels, not only of the first generation (vegetable oil, biodiesel, bio-alcohols and biogas from sugar plants, crops or animal fats etc.), but also of the second (biofuels from biomass, non-food crops including wood) and third generations (biodegradable fuels from algae);

(iii) an improved transport infrastructure together with Intelligent Transport Systems (ITS) to avoid traffic congestion and to foster the use of intermodal transport (road, rail and waterways);

(iv) consumer information (campaigns for eco-driving, use of public transport and modal transport etc.); and,

(v) legal instruments (such as tax incentives for low carbon products and processes, taxation of CO_2 intensive products and processes, etc.).

4.11.7 Conversion of wetlands to other use

Conversion of wetlands for commercial development, drainage schemes, extraction of minerals and peat, overfishing, tourism, siltation, pesticide discharges from agriculture, toxic pollutants from industrial waste, and the construction of dams and dikes, often to improve flood protection, are major threats to wetlands everywhere.

A major threat is the draining of wetlands for commercial development, including tourism facilities, or agricultural land. Unwise use of freshwater to feed these developments poses a further threat. In too many places, the amount of water taken from nature's underground aquifers is far outstripping their ability to replenish themselves. The result is that as the water level drops, millions of trees and plants are dying because they are deprived of their life-sustaining supplies.

Hundreds of thousands of hectares of wetlands have been drained for agriculture. Globally, agriculture accounts for 65% of the total water withdrawal on Earth. Agriculture and other industries such as paper making are often very wasteful and inefficient with water.

Summary

This session has described how anthropogenic activities – changes from forest to other land uses such as agriculture; deforestation and forest degradation; extensive use of inorganic fertilizer; animal husbandry; paddy rice cultivation; and conversion of wetlands to other land uses – contribute to climate change. The next session looks at the risks and hazards of climate change.

Exercise question (s) (20 minutes)

1) What is the difference between deforestation and forest degradation?
2) How does intensive use of fertilizer cause climate change?
3) What can be done to reduce the impacts of agriculture on climate?

Case study 10. Impacts of anthropogenic activities on wetlands

Invasive species

Alien invasive species have had severe impacts on local aquatic flora and fauna, and can upset the natural balance of an ecosystem. For example, the introduction of Nile perch to Lake Victoria has pushed many of the lake's native cichlid species to extinction.

Pollution

Pollution in wetlands is a growing concern, affecting drinking water sources and biological diversity. Drainage and run-off from fertilized crops and pesticides used in industry introduce nitrogen and phosphorous nutrients and other toxins like mercury to water sources. These chemicals can affect the health and reproduction of species, posing a serious threat to biological diversity.

Climate change

Increases in temperature are causing polar ice to melt and sea levels to rise. This in turn is leading to shallow wetlands being swamped and some species of mangrove trees being submerged and drowned. At the same time, other wetlands - estuaries, floodplains and marshes - are being destroyed through drought.

Dams

Worldwide there are now over 40,000 dams which alter the natural flow of water and impact on existing ecosystems. Whilst there is much debate about the need for dams to be built, WWF argues that development should be as sustainable as possible to ensure minimum negative impact on biodiversity.

Source: WWF (2015)

4.12 Climate change related hazards

A changing climate leads to changes in the frequency, intensity, spatial extent, duration, and timing of weather and climate extremes, and can result in unprecedented events. Weather or climate events, even if not extreme in a statistical sense, can still lead to extreme conditions or impacts, either by crossing a critical threshold in a social, ecological, or physical system, or by occurring simultaneously with other events. Some climate extremes (e.g. droughts, floods) may be the result of an accumulation of weather or climate events that are, individually, not extreme themselves.

This session presents some risks and hazards associated with climate change.

Objectives

By the end of this session, the learners explain the the effect of climate change on:

a) flooding;

b) drought;

c) crop failure;

d) loss of biodiversity; and,

e) human health.

Activity 1 (Discussion) (20 minutes)

Learners should discuss the trend of flooding, drought, crop failure and human diseases in their home countries.

4.12.1 Flooding

A flood is “the overflowing of the normal confines of a stream or other body of water, or the accumulation of water over areas that are not normally submerged. Floods include river (fluvial), flash, urban, pluvial, sewer, coastal, and glacial lake outburst floods”. The main causes of floods are intense and/or long-lasting precipitation, snow/ice melt, a combination of these causes, dam break (e.g. glacial lakes), reduced conveyance due to ice jams or landslides, or by a local intense storm.

Floods are affected by various characteristics of precipitation, such as intensity, duration, amount, timing and phase (rain or snow). They are also affected by drainage basin conditions such as water levels in rivers, presence of snow and ice, soil character and status (frozen or not, soil moisture content and vertical distribution), rate and timing of snow/ice melt, urbanization, and the existence of dikes, dams and reservoirs. Along coastal areas, flooding may be associated with storm surge events.

A change in the climate physically changes many of the factors affecting floods (e.g., precipitation, snow cover, soil moisture content, sea level, glacial lake conditions, and vegetation) and may consequently change the characteristics of floods. Literature on the impact of climate change on pluvial floods (e.g. flash floods and urban floods) is scarce.

In summary, there is limited to medium evidence available to the IPCC to assess climate-driven changes in the magnitude and frequency of floods at a regional scale because the available instrumental records of floods at gauge stations are limited in space and time, and because of confounding effects of changes in land use and engineering.

Furthermore, there is little agreement in this evidence, and thus overall low confidence at the global scale regarding even the sign of these changes. There is low confidence (due to limited evidence) that anthropogenic climate change has affected the magnitude or frequency of floods, though it has detectably influenced several components of the hydrological cycle, e.g. precipitation and snowmelt (medium confidence to high confidence), which may impact flood trends.

Projected precipitation and temperature changes imply possible changes in floods, although overall there is low confidence in projections of changes in fluvial floods. Confidence is low due to limited evidence and because the causes of regional changes are complex, although there are exceptions to this statement. There is medium confidence (based on physical reasoning) that projected increases in heavy rainfall would contribute to increases in rain-generated local flooding, in some catchments or regions. Earlier spring peak flows in snowmelt- and glacier-fed rivers are likely, but there is low confidence in their magnitude.

4.12.2 Drought

Drought is generally “a period of abnormally dry weather long enough to cause a serious hydrological imbalance”. While lack of precipitation (i.e. meteorological drought) is often the primary cause of drought, increased potential evapotranspiration induced by enhanced radiation, wind speed or vapour pressure deficit (itself linked to temperature and relative humidity), as well as pre-conditioning (soil moisture pre-event; lake, snow, and/or ground-water storage) can contribute to the emergence of soil moisture and hydrological drought.

The main drivers for soil moisture or hydrological droughts are reduced precipitation and/or increased evapotranspiration. Although the role of deficits in precipitation is generally considered more prominently in the literature, several drought indicators also explicitly or indirectly consider effects of evapotranspiration. In the context of climate projections, analyses suggest that changes in simulated soil moisture drought are mostly driven by changes in precipitation, with increased evapotranspiration from higher vapor pressure deficit (often linked to increased temperature) and available radiation modulating some of the changes.

Because of the complex definition of droughts, and the lack of soil moisture observations, several indices have been developed to characterise (meteorological, soil moisture, and hydrological) drought. These indicators include land surface, hydrological or climate model simulations (providing estimates of soil moisture or runoff) and indices based on measured meteorological or hydrological variables.

There is medium confidence that since the 1950s some regions of the world have experienced trends toward more intense and longer droughts, in particular in southern Europe and West Africa, but in some regions droughts have become less frequent, less intense, or shorter, e.g. in central North America and North Western Australia. There is medium confidence that anthropogenic influence has contributed to some changes in the drought patterns observed in the second half of the 20th century, based on its attributed impact on precipitation and temperature changes (though temperature can only be indirectly related to drought trends;).

However, there is low confidence in the attribution of changes in droughts at the level of single regions due to inconsistent or insufficient evidence. Post-AR4 studies indicate that there is medium confidence in a projected increase in duration and intensity of droughts in some regions of the world, including southern Europe and the Mediterranean region, central Europe, central North America, Central America and Mexico, northeast Brazil and southern Africa. Elsewhere, there is overall low confidence because of insufficient agreement of projections of drought changes (dependent both on model and dryness index). Definitional issues and lack of data preclude higher confidence than medium in observations of drought changes, while these issues plus the inability of models to include all the factors likely to influence droughts preclude stronger confidence than medium in the projections.

4.12.3 Crop failure

IPCC confirms that in the next few decades climate change will result in crop losses. Its Fourth Assessment Report projected the potential future effects of climate change on agriculture as low to medium confidence. The report concluded that for about a 1 to 3°C global mean temperature increase (by 2100, relative to the 1990–2000 average level) there would be productivity decreases for some cereals in low latitudes, and productivity increases in high latitudes. In the same report, “low confidence” means that a particular finding has about a 2 out of 10 chance of being correct, based on expert judgement. “Medium confidence” has about a 5 out of 10 chance of being correct.

In Africa, IPCC projected that climate variability and change would severely compromise agricultural production and access to food. This projection was assigned “high confidence.”Africa’s geography makes it particularly vulnerable to climate change, and 70 % of the population rely on rain-fed agriculture for their livelihoods. Tanzania’s official report on climate change suggests that the areas that usually get two rainfalls in the year will probably get more, and those that get only one rainy season will get far less. The net result is expected to be that 33% less maize - the country’s staple crop - will be grown.

4.12.4 Loss of biodiversity

There is ample evidence that climate change affects biodiversity. According to the Millennium Ecosystem Assessment, climate change is likely to become one of the most significant drivers of biodiversity loss by the end of the century. Climate change is already forcing biodiversity to adapt either through shifting habitat, changing life cycles, or the development of new physical traits.

Climate change alone is expected to threaten approximately one quarter or more of all species on land with extinction by 2050, surpassing even habitat loss as the biggest threat to life on land. Species in the oceans and in fresh water are also at great risk from climate change, especially those that live in ecosystems like coral reefs that are highly sensitive to warming temperatures, but the full extent of that risk has not yet been calculated.

Climate change is a threat because species have evolved to live within certain temperature ranges. When these are exceeded and a species cannot adapt to new temperatures, or when other species it depends on, e.g. its food supply, cannot adapt, its survival is threatened.

The IPCC has predicted that by 2100, assuming that current trends in burning fossil fuels continue, the surface of the Earth will warm on average by as much as 6° C or more. It is not possible to predict how most species, including our own, and how most ecosystems, will respond to such extreme warming, but the effects are likely to be catastrophic.

Biodiversity can support efforts to reduce the negative effects of climate change. Conserved or restored habitats can remove CO_2 from the atmosphere, thus helping to address climate change by storing carbon (for example, reducing emissions from deforestation and forest degradation). Conserving in-tact ecosystems, such as mangroves, can help reduce the disastrous impacts of climate change such as flooding and storm surges.

4.12.5 Human health

A changing climate impacts human health and wellbeing. The World Health Organisation (WHO) has identified climate change as a critical public health problem. Climate change makes many existing diseases and conditions worse, but it may also help introduce new pests and pathogens into new regions or communities. As the planet warms, oceans expand and the sea level rises, floods and droughts become more frequent and intense, and heat waves and hurricanes become more severe.

The most vulnerable people – children, the elderly, the poor, and those with underlying health conditions – are at increased risk for health effects from climate change. Climate change also stresses health care infrastructure and delivery systems. The number of preventable deaths is projected to rise in developing countries (especially Africa) which have impoverished populations and have already been hit by climate change.

Exercise question (20 minutes)

Write an essay on the impact of climate flooding and drought on crop yield and their relationship with climate change.

Summary

The risks and hazards of climate change has been presented in this session. They include floods, drought, crop failure, forest fires, livestock death, human health, and loss of biodiversity. The next session prescribes some management measures of the anthropogenic drivers of climate change.

4.13 Managing anthropogenic drivers of climate change

This session presents some innovative ways of reducing the impacts of climate change – the use of green technologies and climate smart agriculture.

Objectives

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

a) describe the various anthropogenic drivers of climate change; and,

b) explain how anthropogenic drivers of climate change can be managed.

Activity 1 (Brainstorming) (20 minutes)

Learners should brainstorm on the meaning and impacts of green technologies and climate smart agriculture.

4.13.1 Green technologies

The term “technology” refers to the application of knowledge for practical purposes. The field of “green technology” encompasses a continuously evolving group of methods and materials, from techniques for generating energy to non-toxic cleaning products.

Green technologies can affect biodiversity by reducing emissions and other environmentally harmful outputs that contribute to climate change and habitat pollution. Examples of green technology include: clean energy; green transportation; green building and green chemistry.

Clean energy must come from emissions-free sources. It includes all primary current energy sources except for fossil fuels, the primary source of energy. Fossil fuel burning currently makes up over three quarters of the world’s energy consumption. Renewable energy sources include solar, wind, nuclear, hydroelectric and geothermal sources. Ideally, the world’s energy should come from a combination of these sources, depending on what is available a given area.

Green transportation. Fossil-fuel based transportation is responsible for 23 to 24 percent of global CO_2 emissions. The sector can be split into public and private transportation. Public transportation is normally more efficient because it transports more people for less energy. But, it could be further improved by using cleaner fuels or clean electricity sources. Private vehicles are almost entirely powered by fossil fuels today. To transition to renewable energy sources they will have to be replaced by battery-electric vehicles or plug-in hybrid electric vehicles. Simply increasing the efficiency of private cars can be achieved by reducing the size of the cars and making the engines more efficient for regular driving.

Green building encompasses everything from the choice of building materials to where a building is located.

Green chemistry. The invention, design and application of chemical products and processes to reduce or eliminate the use and generation of hazardous substances.

4.13.2 Climate-smart agriculture

Climate-smart agriculture (CSA) is an approach to address interlinked challenges of food security and climate change that has three objectives:

1) sustainably increasing agricultural productivity, to support equitable increases in farm incomes, food security and development;
2) adapting and building resilience of agricultural and food security systems to climate change at multiple levels; and,
3) reducing greenhouse gas emissions from agriculture (including crops, livestock and fisheries).

CSA considers these three objectives together at different scales - from farm to landscape – at different levels - from local to global - and over short and long time horizons, taking into account national and local specifies and priorities.

Activity 2 (Group Discussion) (20 minutes)

Discuss some practical means to reduce the impact of climate change.

Summary

The potential of technological change/green technology (e.g. climate smart agriculture) to reduce the changing climate has been treated in this session.The next session presents a detailed description of the vulnerability and impacts of climate change.

4.14 The concept and components of vulnerability

This training session introduces the concept and components of vulnerability. It defines key concepts of vulnerability to climate change. It helps to explain the various determinants and components of vulnerability.

Objectives

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

a) describe key concepts of vulnerability to and impact of climate change;

b) explain the various determinants of vulnerability to climate change; and,

c) distinguish components of vulnerability.

Activity 1 (Group discussion) (20 minutes)

Critically examine the concept of vulnerability in the context of your country.

4.14.1 Definitions of key concepts

IPCC defines vulnerability as the extent to which a natural or social system is susceptible to sustaining damage from climate change, and is a function of the magnitude of climate change, the sensitivity of the system to changes in climate and the ability to adapt the system to such changes. Hence, a highly vulnerable system is one that is highly sensitive to modest changes in climate and one for which the ability to adapt is severely constrained. The concept encompasses hunger vulnerability which refers to the presence of factors that place people at risk of becoming food insecure or malnourished. This could be as a result of increased weather extremes and temporal/spatial shifts which makes it difficult for farmers in the tropics and subtropics to increase agricultural productivity. Due to differences between countries, regions, economic sectors and social groups, vulnerability to climate change impacts will be unevenly distributed. It is known that the poor (countries and people) are likely to be hardest hit by climate change and would have difficulty responding to it owing to the level of economic development and institutions. This makes understanding linkages between social and economic vulnerability to climate change imperative. Again, vulnerability could be understood from the natural hazards perspective - the characteristics of a person or group in terms of their capacity to anticipate, cope with, resist and recover from the impact of a natural hazard. In reviewing discussions on vulnerability. It is evident that the definition of vulnerability, on one hand, is dependent on the adaptation that has taken place and, on the other, that vulnerability is defined in terms of capacity to adapt, and capacity to respond to stress. In the analyses of vulnerability, the use of a political economy framework, the “entitlements approach” developed by Sen (1981) is advocated. This approach assumes that vulnerability is determined by access to resources by individuals or groups and their entitlement to call on these resources.

In text question (10 minutes)

Point out institutional and governance arrangements in your country which is likely to make individuals and groups vulnerable to climate change?

4.14.2 Determinants of vulnerability

The vulnerability of ecosystems (e.g. forests) to climate change describes their tendency to be adversely affected, determined by the sensitivity of ecosystem processes to particular elements of climate change and the degree to which the system (including its coupled social elements) can maintain its structure, composition and function in the presence of such change, either by enduring or adapting to it. According to IPCC, vulnerability to climate change is a function of exposure which refers to the inventory of elements in an area in which hazard events may occur. Exposure is not only the extent to which a system is susceptible to significant climatic variations, but also the degree and duration of these variations. The element, or exposure unit, could be an activity, group, region or resource. These elements could be exposed to hazards such as drought, flood, cyclones, and extreme temperatures. A 2010 report from the United Nations Conference on Trade and Development (UNCTAD) found that the frequency and intensity of extreme weather events in the Least Developed Countries (LDCs) have been increasing, with five times as many such incidents occurring during the period 2000-2010 compared to 1970-1979. It also stated that the number of people in the LDCs affected by extreme events has almost doubled (100 million in 1970-1979 to 193 million in 2000-2010). Exposure to climate variation is primarily a function of geography. For example, coastal communities will have higher exposure to sea level rise and cyclones, while communities in semi-arid areas may be most exposed to drought. Mostly, exposure and vulnerability are interchanged to convey the same meaning but they are distinct. For instance, it is possible to be exposed but not vulnerable (e.g. living in a flood prone area but having sufficient means to modify building structure and behaviour to mitigate potential loss). However, to be vulnerable to an extreme event, it is necessary to also be exposed. Exposure results in considerable economic loss and disruption of livelihoods. Because agricultural production in Africa is mostly rain-fed, drought commonly receives the most attention of all the exposures.

Activity 2 (Brainstorming) (20 minutes)

Discuss how the capacities of the poor and minority in communities could be improved to help them adapt to climate vulnerabilities.

The severity of climate impacts not only depend on exposure, but also on the sensitivity of the unit exposed (e.g. an ecosystem, a watershed, an island, a household, a village, a city or a country) and on the capacity to cope or adapt. Sensitivity is the degree to which a given community or ecosystem is affected by climatic stresses. It reflects the degree to which a system is affected, either adversely or beneficially, by climate variability or change. For example, a community dependent on rain-fed agriculture is much more sensitive to changing rainfall patterns than one where mining is the dominant livelihood. Again, the effect could be direct (e.g. a change in crop yield in response to a change in the mean, range or variability of temperature) or indirect (e.g. damages caused by an increase in the frequency of coastal flooding due to sea level rise). Exposure and sensitivity are almost inseparable properties of a system (or community) and are dependent on the interaction between the characteristics of the system and on the attributes of the climate stimulus. The exposure and sensitivity of a system to an environmental change risk (e.g. drought) reflect the likelihood of the system experiencing the particular conditions and the occupance and livelihood characteristics of the system. The occupance characteristics (e.g. settlement location and types, livelihoods, land uses, etc.), reflect broader social, economic, cultural, political and environmental conditions, sometimes called drivers or sources or determinants of exposure and sensitivity. However, it has to be noted that even though a system may be considered as being highly exposed and/or sensitive to climate change, it does not necessarily mean that it is vulnerable. This is because neither exposure nor sensitivity account for the capacity of a system to adapt to climate change (i.e. its adaptive capacity). Vulnerability is the net impact that remains after adaptation is taken into account.

Exercise question (10 minutes)

Should the focus of building adaptive capacity be on the poor and vulnerable in society or poor countries?

Adaptive capacity is defined as the ability of a system (human or natural) to adjust to climate change (variability and extremes) to moderate potential damages, to take advantage of opportunities or to cope with the consequences. It highlights the potential of species and systems to show resistance (ability to resist a change) and resilience (ability to recover from a change) to environmental change. Adaptations to climate change signify how people reduce the adverse effects of climate on their health and well-being, and take advantage of the opportunities that their climatic environment provides. The tendency of systems to adapt is influenced by certain characteristics, called determinants of adaptation. These include sensitivity, vulnerability, resilience, susceptibility and adaptive capacity, among others. Adaptive capacity comprises adjustments in behaviour, resources and technologies. The forces that influence the ability of the system to adapt are the drivers or determinants of adaptive capacity. One of the most important factors shaping the adaptive capacity of individuals, households and communities is their access to and control over natural, human, social, physical and financial resources. It has been found that some socio-economic determinants of adaptive capacity are generic (like education, income and health), whereas other determinants are specific to particular climate-change impacts like floods or droughts (e.g. institutions, knowledge and technology). Determinants are, generally, not independent of each other nor are they mutually exclusive as, for example, economic resources facilitate the implementation of new technologies and may ensure access to training opportunities. LDCs lack many of the key elements of the adaptive capacity to respond to climate change and other environmental crises. There is therefore a need to improve access to resources that could help individuals and groups in responding to threats and exposures (i.e. functioning community networks, access to low-rate loans, accessible services like health care and sanitation, irrigation systems and water storage, etc.). Adaptations vary not only with respect to their climatic stimuli but also with respect to other, non-climate conditions, sometimes called intervening conditions, which serve to influence the sensitivity of systems and the nature of their adjustments. For example, a series of droughts may have similar impacts on crop yields in two regions, but differing economic and institutional arrangements in the two regions may well result in quite different impacts on farmers and hence in different adaptive responses, both in the short and long terms. Adaptive capacity is accepted as a desirable property of a system for reducing vulnerability. The more a system has, the greater the likelihood that the system is able to adjust and, thus, becomes less vulnerable to climate change and variability.

Activity 3 (Small group discussion) (20 minutes)

Taking any of the following; social, cultural, economic or political, discuss how changes in these in our communities could help build climate change resilience.

Other determinants of vulnerability are capacity and resilience. Capacity refers to the resources and assets people possess to resist, cope with and recover from disaster shocks. It encompasses the ability to either use and access needed resources and thus goes beyond the sole availability of these resources. Capacities are often rooted in resources which are endogenous to the community and which rely on traditional knowledge, indigenous skills and technologies and solidarity networks. The manner in which people and organisations use existing resources to achieve various beneficial ends during unusual, abnormal and adverse conditions of a disaster phenomenon or process is termed coping strategies. Capacity is an important element in most conceptual frameworks of climate change vulnerability and risk. Improving capacity is often identified as the target of policies and projects based on the notion that strengthening capacity will eventually lead to reduced risk.

This could be looked at in two ways; coping and adaptation. Coping is typically used to refer to ex post actions (refers to the ability to react to and reduce the adverse effects of experienced hazards), while adaptation is normally associated with ex ante actions (transforming structure, functioning, or organization to better survive hazards). Presence of capacity suggests that impacts will be less extreme and/or the recovery time will be shorter. One could thus infer that vulnerability is a result of a lack of capacity. Vulnerability is the opposite of capacity, so that increasing capacity means reducing vulnerability, and high vulnerability means low capacity. Resilience on the other hand is the ability of a system (human or natural) to resist, absorb and recover from the effects of hazards in a timely and efficient manner, preserving or restoring its essential basic structures, functions and identity. A resilient community is well-placed to manage hazards, to minimise their effects and/or to quickly recover from negative impacts, resulting in a similar or improved state compared to before the hazard occurred. In most African regions, achieving resilience may require changes (social, cultural, economic or political). There are strong linkages between resilience and adaptive capacity. Resilience also varies greatly for different groups within a community and, as such, reducing vulnerability and building resilience requires increasing participation of local communities.

4.14.3 Components of vulnerability

The definition of IPCC specifically highlights three components of vulnerability in the climate change context: exposure, sensitivity and adaptive capacity (figure 29). It implies that a system is vulnerable if it is *exposed* (the degree of climate variability and change that a country, community, individual or ecosystem experiences) and *sensitive* (an assessment of the impact climate factors have on a country, community, individual or ecosystem) to the effects of climate change and, at the same, time has only limited *capacity to adapt* (ability of a country, community, individual or ecosystem to manage the negative impacts and take advantage of any opportunities that arise). A system is less vulnerable if it is less exposed, less sensitive or has a strong adaptive capacity. These components are multi-dimensional and differential. That is, they vary across physical space and among and within social groups. They are also scale-dependent; with regard to space and units of analysis such as individual, household, region, or system.

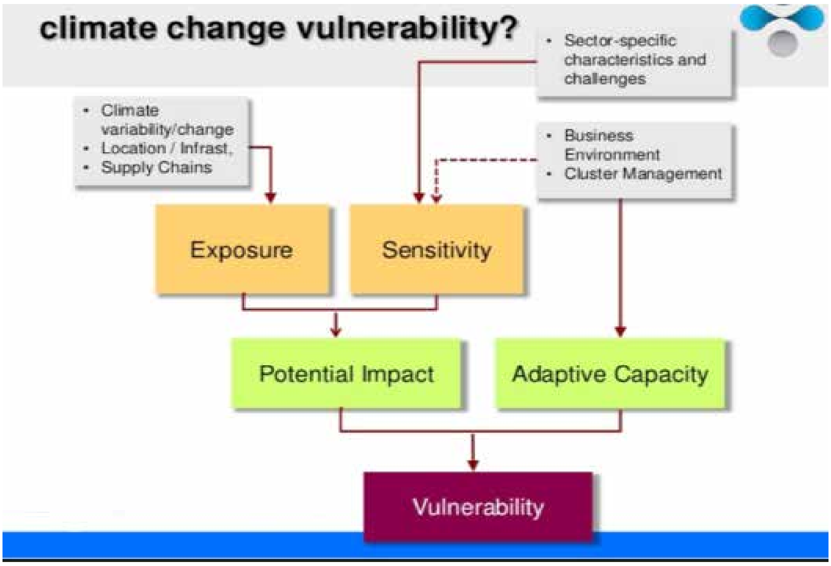


Figure 29. Determinants of vulnerabilities.

Source: Schoen, 2015

Summary

In this session, we have learnt about the concept and components of vulnerability. The session has explained how exposure, sensitivity, adaptive capacity and other determinants influences how an ecosystem (e.g. forest) or societies are impacted by climate change. In the next session, we shall look at approaches to climate change vulnerability assessment.

4.15 Approaches to vulnerability assessment

This session takes a look at approaches to vulnerability assessment and how outcomes could influence policy actions.

Objectives

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

a) describe the principles useful for climate vulnerability assessment; and,

b) describe the expected policy actions for climate change.

Activity 1 (Brainstorming) (20 minutes)

Identify an article or report on climate vulnerability assessment. Based on the findings, suggest policies or remedial actions.

Assessing vulnerability to climate change is important for defining the risks posed and providing information for identifying measures to adapt to impacts. The diversity of concepts of vulnerability has resulted in a variety of methodological approaches and tools that have evolved to assess it. Vulnerability assessments can, for example, vary with respect to the methodological approach (e.g. experimental, modelling, meta-analysis, survey-based), integration of natural and social science, policy focus, time horizon (short to long term), spatial scale (farm, local, national, regional, global level), consideration of uncertainties, and the degree of stakeholder involvement. Generally, methods applied for assessing vulnerability focuses on use of indicators, modelling approaches and stakeholders. In operationalizing indicators, a set of composite or proxy signs are employed. Based on the three components of vulnerability (exposure, sensitivity and adaptive capacity), appropriate indices are developed to aid in their assessment. The indicators used for the components include both biophysical (primarily for exposure and sensitivity) and socio-economic (mainly for adaptive capacity) sources. However, it should be noted that vulnerability is a relative measure rather than something that can be expressed in absolute terms. Since vulnerability is context specific, it is quite a challenge to come up with standardized indicators. As such, developing indicators should be carried out at the local level where vulnerable people, regions or sectors can be narrowly defined.

Activity 2 (Small group discussion) (20 minutes)

Considering an ecosystem, develop indicators to be used in assessing its vulnerability. Develop another set which could be used to assess the vulnerability of communities living close to the ecosystem under consideration.

Another approach to vulnerability assessment is building empirical models. This is done when observations are available about a phenomenon (e.g. forest fires) and possible explanatory variables (e.g. climate or human activities). This aids in establishing a relationship between an observed impact and explanatory variables and can be used for testing the effects of changes (e.g. climate change or adaptation practices) on the phenomenon. Models can be built with simple statistical approaches or more elaborated methods, such as meta-analysis (combining the quantitative findings of different studies) and data mining (sorting through large datasets and picking out relevant information). Examples of forest ecosystems models for vulnerability assessment include bioclimatic models (assessing the impacts of climate change on species or ecosystems), biogeochemical models (studying effects on the functioning of ecosystems, especially fluxes of carbon, water and energy), equilibrium models and dynamic models (the most advanced ecosystem models). In general, statistical approaches have the advantage that they require less data than simulation issues.

The application of vulnerability assessment methods requires the involvement of stake-holders. Participatory methods are applied to obtain first-hand documentation of vulnerability owing to social conditions and physical stimuli from the perspectives of community members. Likewise, when quantitative data are not available, expert opinions of stakeholders offer alternative sources of information. *Cognitive mapping* (or concept mapping or mental model is a structured process that enables participants to produce a map of the concepts or ideas behind a topic of discussion and to describe how these ideas are interrelated), *expert judgement* (eliciting informed opinions from people knowledgeable in the field), *brainstorming*, *interviews* or *surveys* are useful methods for involving stake-holders in vulnerability analysis. Most importantly, vulnerable groups must be adequately involved in the processes of developing assessment criteria and designing and implementing plans to mitigate problems and strengthen adaptive capacity. Other approaches employed in vulnerability assessment are natural hazards research, food security research and poverty analysis and sustainable livelihoods research. A vulnerability assessment must recognize and inform about the uncertainties inherent in the assessment. Uncertainties range from the lack of understanding of the studied systems (e.g. lack of knowledge about the behaviour of a social system facing climate change) to the lack of certainties about the external conditions (e.g. climate or socio-economic scenarios). To deal with this, uncertainty analysis must be conducted.

Exercise (10 minutes)

Why is it necessary to conduct climate change vulnerability assessments?

Summary

In this session, we have learnt about approaches to vulnerability assessment. The session discussed some models and methods to help assess how susceptible ecosystems and people are to climate change. Approaches to solicit for solutions were also highlighted. The next session looks at the nature and variability of vulnerability.

4.16 The nature and variability of vulnerability

This training session deals with the nature and variability of vulnerability. It focuses on biophysical, socio-economic and livelihood vulnerability to climate change.

Objectives

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

a) analyse the impact of climate change on natural and built environments; and,

b) evaluate the cross-cutting issues (institutional and governance) pertinent to climate change vulnerability.

4.16.1 Biophysical vulnerability

Ecosystems are of fundamental importance to environmental function and to sustainability, and they provide many goods and services critical to individuals and societies. Changes in climate have the potential to affect ecological systems, the mix of species that they contain, and their ability to provide the wide range of benefits on which societies rely. Recent research has revealed the world's most and least vulnerable regions to climate change. The most endangered regions include southern and southeast Asia, western and central Europe, eastern South America and southern Australia. The least vulnerable areas, in terms of both climate impacts and degradation, include southern South America, the Middle East, northern Australia, and south-western Africa. Climate change alters the biophysical and biogeochemical processes of ecosystems. With the advent of climate change, the species compositions of forests are likely to change. In some regions entire forest types may disappear leading to the establishment of new ecosystems. Major alterations in other ecosystem types may result in altered rainfall amount and seasonality, increased evapo-transpiration and mean temperature increase, exacerbating ecosystem degradation (land-cover change, pollution).This phenomenon leads to the triggering of more disasters whilst reducing natures' and peoples' capacities to withstand impacts of climate change and disasters.

Changes in climatic conditions have implications on the physical components of aquatic and terrestrial environments. Biological vulnerability culminates in the altering of species phenology, community structure and diversity, physiological intolerance to new environments, changes in species interactions, altering of food webs and mutual associations (e.g. pollination) and the migration of species. Changing regional and local climates could alter landforms, drainage patterns, aquifers recharge, soil characteristics and disturbance regimes (e.g. fires, pests, and diseases), which would more favour some species than others. Changes in the landscape or topography might lead to loss of certain keystone species, resulting in less diversity in flora and fauna. The effect of climate change on soil moisture is expected to vary not only with the degree of change but also with soil characteristics. The water-holding capacity of the soil will affect possible changes in soil moisture deficits (the lower the capacity, the greater the sensitivity to changes). Changes in water logging or cracking of soils could potentially damage existing ecosystems or give rise to new ones as edaphic factors are important in defining the habitats of individual species.

Activity 1 (Group discussion) (20 minutes)

Discuss the implications of edaphic vulnerability on climate change mitigation strategies such as reforestation.

4.16.2 Socio-economic and livelihood vulnerability

Climate change is expected to have an impact on built environments. Prolonged high temperatures may lead to road deterioration and railway buckling. Airports, coastal roads and railways become vulnerable to sea level rise. In nations that rely chiefly on hydro-generated power, climate change might mean a reduction in water levels in dams or additional cost in maintaining dams due to constant overflow. When it comes to human settlement, people living on arid or semi-arid lands, steep hillsides, in low-lying coastal areas, in water-limited or flood-prone areas, or on small islands, are particularly vulnerable to climate change. In some instances, new building materials or technologies may be required. Impacts on human settlements from climate change may be indirect, as well as direct. However, many of the impacts on human settlements from climate change are likely to be experienced indirectly through effects on other sectors. As a result, individuals living in marginal areas may be forced to migrate to urban areas if the marginal lands become less productive under new climate conditions. Management of pollution, sanitation, waste disposal, water supply and public health, as well as provision of adequate infrastructure in urban areas, could become more difficult and costly under changed climate conditions.

In text question (10 minutes)

Analyse the effect of climate change on migration, change in building materials, consumption in energy, and waste management

Climate change could adversely affect most socio-economic sectors. Considering the forest sector, climate change leaves tropical forests and rangelands vulnerable to loss of biodiversity, rapid deterioration in land cover and destruction of catchments and aquifers. This implies a loss in forest ecosystems goods and services on which a lot of African nations and individuals are dependent. Because agriculture on the continent is mostly rain-fed, there is a need to keep our forest intact so as to improve rainfall cycles. With respect to agriculture, increases in temperature and the frequency of droughts and floods are likely to affect crop production, which could increase the number of people at risk from hunger and increased levels of displacement and migration. Changes in climate will interact with stresses that result from actions to increase agricultural production costs, affecting crop yields and productivity in different ways, depending on the types of agricultural practices and systems. The main direct effects will be through changes in factors like precipitation and time and length of growing seasons. The fisheries sector could suffer risk from diminishing nursery areas and extensive inshore and coastal pollution, extreme warming and cooling of water bodies (El Niño and El Nina phenomena). Water availability is an essential component of welfare and productivity. Changes in climate could exacerbate periodic and chronic shortfalls in water, particularly in arid and semi-arid areas of the world. Developing countries are highly vulnerable to climate change because many are located in arid and semi-arid regions, and most derive their water resources from single-point systems such as bore holes or isolated reservoirs. Climate change could increase the cost of water for both domestic and commercial use which could deepen the vulnerability of poor people.

In terms of energy, increasing human population and temperature extremes requires devices for heating or cooling which places more demand on energy consumption. Currently, most energy generation today contributes to climate change. Projected changes are likely to alter the health status of millions of people, through increased deaths, disease and injury due to heat waves, urban air pollution, floods, storms, fires and droughts. Increased malnutrition in some areas will increase vulnerability to resurgent vector-borne and infectious diseases, such as dengue, malaria, hantavirus and cholera. One of Africa's fastest-growing industries is tourism. Tourism is hinged on wildlife, nature reserves, coastal resorts and an abundant water supply for recreation. The potential impact of climate change on this sector in the form of drought would devastate wildlife and reduce the attractiveness of some nature reserves, thereby reducing income accrued from tourism. Coastal resorts would also become prone to floods. Generally, climate change has repercussions on the resources or raw materials needed by people to engage in their livelihood activities.

Activity 2 (Small group discussion) (20 minutes)

Identify some forest-based livelihoods. Discuss the ramifications of potential raw materials shortage on the standard of living of fringe communities and SFM.

Exercise question (10 minutes)

Thinking through some of the natural resource policies in your country, assess some of the provisions that impede the capacity of people to adapt?

Socio-economic and livelihood vulnerability in Africa and most of the world is the result of multiple stresses and low adaptive capacities, arising from poverty, marginalization, inequality, weak institutions, and complex disasters and associated conflicts. Different groups and places within countries differ in their susceptibility to climate vulnerability and the divisions between rich and poor translate into differentials in people's ability to adjust.

Overcoming the constraints of climate change vulnerability requires technological advances, institutional arrangements, availability of financing, empowering women and poor in society as well as information exchange. There is a need to review institutional and governance arrangements which make it less favourable for people to adapt.

Adjusting to shortages and/or implementing adaptation measures will impose a heavy burden on national economies. There is a need to consider economic policies and conditions (e.g. taxes, subsidies and regulations) that shape private decision making, development strategies and resource-use patterns. For example, water is subsidized in many countries which encourages over-use (wastage) and discourages conservation. In such a scenario, a range of approaches, including strengthening legal and institutional frameworks, removing pre-existing market distortions (e.g. subsidies), correcting market failures (e.g. failure to reflect environmental damage or resource depletion in prices or inadequate economic valuation of biodiversity), and promoting public participation and education are essential.

Summary

In this session, we have learnt about the nature and variability of vulnerability. The session has explained how ecosystems and socio-economic factors are impacted by climate change. In the next session, we shall look at climate change risks, disaster management and reduction.

4.17 Climate change risks and disaster management and reduction

This training session introduces climate change risks, disaster management and reduction. It defines concepts in risk and disaster management, explains weather factors that contribute to disasters and discusses strategies for reducing climate change disaster risks.

Objectives

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

a) explain the key concepts in risk and disaster management;

b) describe the extent to which weather factors contribute to climate change risks and disasters; and,

c) explore strategies for reducing climate change disaster risks.

Activity 1 (Brainstorming) (20 minutes)

What roles could stakeholders, especially the media play in climate change risks, disaster management and reduction?

4.17.1 Definitions of concepts in risk and disaster management

Climate change risk is resulting from climate vulnerability which affects natural and human systems. The risk could be in the form of continuous increase in temperature, extreme weather events, crop failure, polar cap melting, changes in ecosystems or diseases. Climate change and disaster risk management are closely linked. Disaster connotes alterations in the normal functioning of a community or a society due to hazardous physical events interacting with vulnerable social conditions, leading to widespread adverse human, material, economic or environmental effects that require immediate emergency response (may require external support for recovery). The hazardous events referred to in the definition of disaster may be of natural, socio-natural (originating in the human degradation or transformation of the environment), or purely anthropogenic origins. The occurrence of disaster is always preceded by the existence of specific physical and social conditions that is generally referred to as disaster risk (likelihood of disaster occurrence over a specified time period).To better understand the concept of disaster risk it is important to consider the notions of hazard, vulnerability and exposure. Because of the negative impacts of disasters, there is a need to put measures in place to either prevent or ameliorate the effects. Disaster risk management is the action taken to reduce the risks and adverse impacts of natural hazards, through systematic efforts to analyse and manage the causes of disasters, including avoiding hazards, reducing social and economic vulnerability to hazards, and improving preparedness for adverse events (Figure 30). It involves processes for designing, implementing and evaluating strategies, policies and measures to improve understanding of disaster risks, foster disaster risk reduction and transfer, and promote continuous improvement in disaster preparedness, response and recovery practices. The explicit purposes are to increase human security, well-being, quality of life and sustainable development. Disaster risk management is applied at differing levels and intensities. In other words, it is not restricted to a 'manual' for the management of the risk or disasters associated with extreme events, but rather includes the conceptual framework that describes and anticipates intervention in the overall and diverse patterns, scales, and levels of interaction of exposure, hazard, and vulnerability that can lead to disaster.

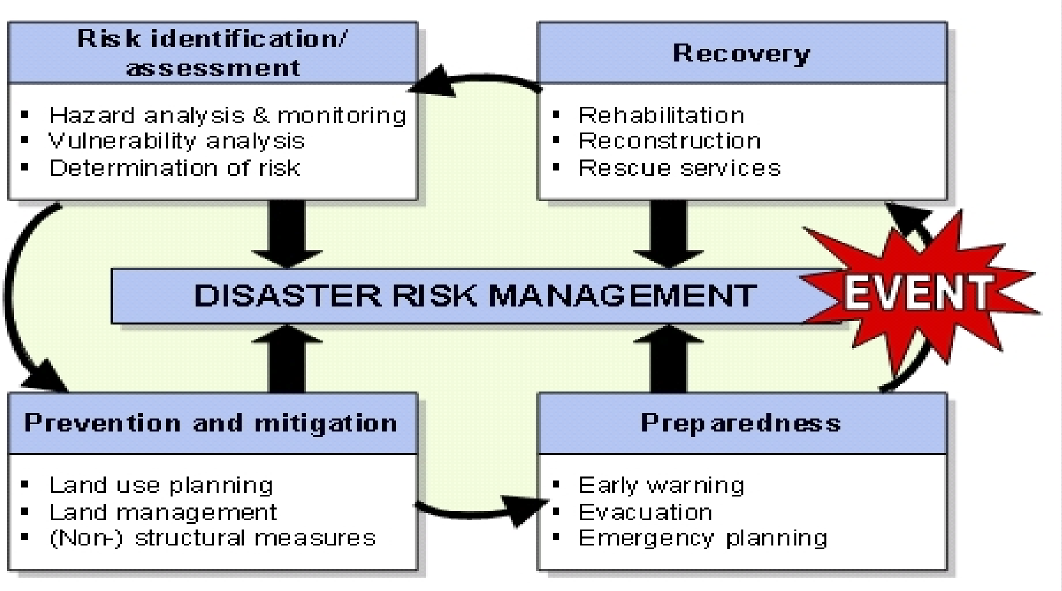


Figure 30. Disaster risk management

In text question (10 minutes)

To what extent are African nations prepared for climate change disaster management and reduction?

As part of disaster risk management, early warning systems are crucial. These are a set of capacities needed to generate and disseminate timely and meaningful warning information to enable individuals, communities and organizations threatened by a hazard to prepare and to act appropriately and in sufficient time to reduce the possibility of harm or loss. Effective mass media channels (e.g. radios, television) are necessary.

Climate change extreme events like weather related disasters, as well as slow changes, such as rising sea levels, threaten sustainable development and resilience, impair socio-economic development and reinforce cycles of poverty across the globe. Because the risks often fall more heavily on those least able to reduce or recover from them, the most vulnerable people and countries need particular assistance. The impacts of climate change can set back development by increasing not only the incidence, but also the severity of poverty. Climate impacts undermine resilience and the capacity to recover and absorb losses from these events, especially that of poorer countries and their citizens, by reducing their agricultural productivity, weakening water and food security, increasing the incidence of diseases, threatening existing infrastructure, economic productivity and value chains.

Activity 2 (Brainstorming) (20 minutes)

- In what ways could climate resilience be strengthened through risk insurance in African economies?
- Discuss ways African governments could get their citizenry to partake in climate insurance schemes.

The absence of economic safety nets which could cushion the adverse impact of these disasters remains a serious concern. Increasing the resilience of societies and the most vulnerable to climate change requires some risk insurance. Such insurance is a vital instrument within a comprehensive climate risk management system, spanning a continuum of prevention, risk reduction, risk retention and risk transfer. Climate risk insurance can play numerous roles at individual, community, country, regional (international) and global levels in providing security against the loss of assets, livelihoods and even lives, e.g.: ensuring reliable and dignified post disaster relief; setting incentives for prevention; providing certainty for weather affected public and private investments; and, easing disaster related poverty and spurring economic development. Insurance related solutions facilitate the assessment of loss and damage potential as a prerequisite for identifying needs and policy priorities. Insurance helps to provide timely and reliable finance to cover loss and damage, in particular compared to other ad hoc post disaster financing options, such as aid, loans and family assistance. Insurance clients can access timely payouts to purchase food and get back on their feet while avoiding poverty traps. Payouts can help governments to avoid fiscal deficits and costly post disaster loans, and to take prompt action, for example to assist poor people who are most affected by disasters. Against this background, climate risk insurance markets have been stimulated for effective and smart use of insurance related schemes for people and assets at risk in developing countries. In one such response, the Munich Climate Insurance Initiative (MCII) has been set up to research, design and implement insurance solutions and also monitor their effects.

In text question (10 minutes)

Are financial institutions in Africa ready to offer climate insurance schemes? What alternatives can the institutions put in place to offer this opportunity?

4.17.2 Weather factors in climate change risks and disasters

Weather is the set of meteorological conditions (wind, rain, snow, sunshine, temperature, etc.) at a particular time and place. The type, frequency and intensity of some weather events are expected to change as Earth's climate changes. Severe weather conditions pose risks to ecosystems and life. Climate change could affect storm formation by decreasing the temperature difference between the poles and the equator. That temperature difference fuels the mid-latitude storms which affect the Earth's most populated regions. Warmer temperatures could increase the amount of water vapour that enters the atmosphere. The result is a hotter, more humid environment. As temperatures continue to rise, more and more water vapour could evaporate into the atmosphere, and water vapour is fuel for storms. A warmer, wetter atmosphere could also cause hurricanes and tropical storms to become more intense, lasting longer, unleashing stronger winds, and causing more damage especially to coastal ecosystems and communities. Again, as a result of warmer temperatures, glaciers and ice caps will melt causing sea levels to rise. The warming and cooling effects of weather culminate in the El Niño and El Nina phenomenon.

Another weather variable is rainfall. Heavy rainfall can lead to a number of hazards, most of which are floods or hazards resulting from floods. Plants and crops in agricultural areas can be destroyed by the force of raging water. Soil erosion can occur as well, exposing risks of landslide as well as reducing the fertility of agricultural lands. Flooding can also spread and produce waterborne and insect-borne diseases (malaria, cholera, typhoid, common cold etc.). Changes in timing and reliability of rainy seasons are another effect of climate change which poses disaster risk. Drought - a prolonged period of dry weather - is another form of severe weather. Droughts have a variety of effects. They cause crops to fail, severely deplete water resources and also significantly increase the risk of wildfires.

Heat waves - prolonged periods with excessive heat – also contribute to disasters. They are extremely dangerous to humans and animals. More frequent and intense extreme heat events can increase illnesses and deaths, especially among vulnerable populations, and damage some crops.

A more common weather factor to West African countries is harmattan. The harmattan (north-easterly trade wind) season is characterized by cold, dry, dust-laden wind, and also wide fluctuations in temperatures between day and night. The harmattan brings desert-like weather conditions, lowering humidity, dispelling cloud cover, preventing rain formation and sometimes creates big clouds of dust which can result in dust storms or sandstorms. The season increases fire risk, causes severe crop damage, nose bleeding, skin conditions and respiratory diseases (aggravation of asthma). Interaction of harmattan with monsoon winds can cause tornadoes.

Exercise question (10 minutes)

Which African countries were present at the world conference on disaster reduction in Kobe?

Dust storm - an unusual form of windstorm that is characterized by large quantities of sand and dust particles carried by moving air - is another disaster factor. They develop during periods of droughts, or over arid and semi-arid regions. Dust storms have numerous hazards and are capable of causing deaths. For example, visibility may be reduced dramatically, so risks of vehicle and aircraft crashes increase. Additionally, the particulates may reduce oxygen intake by the lungs, potentially resulting in suffocation. Damage can also be inflicted upon the eyes due to abrasion. Water bodies may be polluted by settling dust and sand, killing aquatic organisms. Decrease in sunlight can affect plant growth.

4.17.3 Strategies for reducing climate change disaster risks

Disaster risk reduction can be defined as "action taken to reduce the risk of disasters and the adverse impacts of natural hazards, through systematic efforts to analyse and manage the causes of disasters, including through avoidance of hazards, reduced social and economic vulnerability to hazards, and improved preparedness for adverse events". In January 2005, as an outcome of the World Conference on Disaster Reduction (in Kobe, Japan, involving 168 countries), the international community working on DRR (Disaster Risk Reduction) adopted the Hyogo Framework for Action (HFA).

The HFA is the key instrument for implementing disaster risk reduction, adopted by the UN member states. The plan is the key global instrument for guiding the implementation of DRR within all levels of society. Its overarching goal is to build resilience of nations and communities to disasters, by achieving substantive reduction of disaster losses by 2015 in lives, and in the social, economic, and environmental assets of communities and countries. The HFA offers five areas of priorities for action, guiding principles and practical means for achieving disaster resilience for vulnerable communities in the context of sustainable development. Since the adoption of the HFA, many global, regional, national and local efforts have addressed disaster risk reduction more systematically. Much however, remains to be done. Many regional bodies have formulated strategies at regional scale for disaster risk reduction in line with the HFA: the Andean region, Central America, the Caribbean, Asia, Pacific, Africa and Europe. The priorities for action are presented below.

- **Ensure that disaster risk reduction is a national and local priority with a strong institutional basis for implementation**

Strong national and local commitments are required to save lives and livelihoods threatened by natural hazards. Natural hazards must be taken into account in public and private sector decision-making in the same way that environmental and social impact assessments are currently required. Countries must therefore have policies, laws and organizational arrangements, as well as plans, programmes and projects, to integrate disaster risk reduction. They must also allocate sufficient resources to support and maintain them, including: creating effective, multi-sector national platforms to provide policy guidance and coordinate activities; integrating disaster risk reduction into development policies and planning, such as Poverty Reduction Strategies; and, ensuring community participation.

- **Identify, assess and monitor disaster risks and enhance early warning**

To reduce vulnerability to natural hazards, countries and communities must know the risks they face, and take actions based on that knowledge. Understanding risk requires investment in scientific, technical and institutional capabilities to observe, record, research, analyse, forecast, model and map natural hazards. Tools need to be developed and disseminated. Statistical information about disaster events, risk maps, disaster vulnerability and risk indicators are essential. Countries need to use this knowledge to develop effective early warning systems, appropriately adapted to the unique circumstances of the people at risk. Early warning is widely accepted as a crucial component of disaster risk reduction. When effective early warning systems provide information about a hazard to a vulnerable population, and plans are in place to take action, thousands of lives can be saved.

- **Use knowledge, innovation and education to build a culture of safety and resilience at all levels**

Disasters can be reduced substantially if people are well informed about measures they can take to reduce vulnerability and are motivated to act. Key activities to increase awareness of disaster prevention include: providing relevant information on disaster risks and means of protection, especially for citizens in high-risk areas; strengthening networks and promoting dialogue and cooperation among disaster experts, technical and scientific specialists, planners and other stakeholders; including disaster risk reduction subject matter in formal and informal education and training activities; developing or strengthening community-based disaster risk management programmes; and working with the media in disaster risk reduction awareness activities. Local knowledge is critical for disaster reduction.

- **Reduce the underlying risk factors**

Vulnerability to natural hazards is increased in many ways, for example: locating communities in hazard-prone areas, such as flood plains; destroying forests and wetlands, thereby harming the capacity of the environment to withstand hazards; building public facilities and housing unable to withstand the impacts of hazards; and, not having social and financial safety mechanisms in place. Countries can build resilience to disasters by investing in simple, well-known measures to reduce risk and vulnerability. Disasters can be reduced by applying relevant building standards to protect critical infrastructure, such as schools, hospitals and homes. Vulnerable buildings can be retrofitted to a higher degree of safety. Protecting precious ecosystems, such as coral reefs and mangrove forests, allow them to act as natural storm barriers. Effective insurance and micro-finance initiatives can help to transfer risks and provide additional resources.

- **Strengthen disaster preparedness for effective response at all levels**

Being prepared, including conducting risk assessments, before investing in development at all levels of society will enable people to become more resilient to natural hazards. It involves the development and regular testing of contingency plans; establishment of emergency funds to support preparedness, response and recovery activities; developing coordinated regional approaches for effective disaster response; and, continuous dialogue between agencies, planners, policy-makers and development organizations. Regular disaster preparedness exercises, including evacuation drills, also are key to ensuring rapid and effective disaster response. Natural hazards cannot be prevented, but it is possible to reduce their impacts by reducing the vulnerability of people and their livelihoods.

In text questions (10 minutes)

1) What is the level of awareness of local communities on HFA?
2) To what extent has the capacity of communities been built enough to carry out climate disaster risk reduction?

4.17.4 Who is responsible for implementing disaster risk reduction and the Hyogo Framework?

Collaboration and cooperation are crucial to disaster risk reduction. States, regional organizations and institutions, and international organizations all have a role to play. Civil society, including volunteers and community-based organizations, the scientific community, the media, and the private sector, are all vital stakeholders. States are responsible for developing national coordination mechanisms, conducting baseline assessments on the status of risk reduction, publishing and updating summaries of national programmes, reviewing national progress towards achieving the objectives and priorities of the HFA, working to implement relevant international legal instruments and integrating disaster risk reduction with climate change strategies. Regional organizations are responsible for promoting regional programmes for disaster risk reduction, undertaking and publishing regional and sub-regional baseline assessments, coordinating reviews on progress toward implementing the HFA in the region, establishing regional collaborative centres and supporting the development of regional early warning mechanisms. International organizations are responsible for encouraging the integration of disaster risk reduction into humanitarian and sustainable development programmes and frameworks, strengthening the capacity of the UN system to assist disaster-prone countries with disaster risk reduction initiatives, supporting data collection and forecasting, information exchange, and early warning systems, supporting States' own efforts with coordinated international assistance and strengthening disaster management training and capacity building. The ISDR (International Strategy for Disaster Reduction) system is responsible for developing a matrix of roles and initiatives related to the HFA, facilitating the coordination of actions at the international and regional levels, developing indicators of progress to assist states in tracking their progress towards implementation the HFA, supporting national platforms and coordination mechanisms, stimulating the exchange of best practices and lessons learned and preparing reviews on progress toward achieving the HFA.

The UN General Assembly Resolution 66/199 requested UNISDR to facilitate the development of a post-2015 framework for disaster risk reduction. As the HFA (2005-2015) ended, it became important to outline an approach and shape the discussions on an international framework for disaster risk reduction and resilience. Subsequently, the Sendai Framework for Disaster Risk Reduction 2015-2030 has been adopted by UN Member States (March 2015).The Sendai Framework contains seven targets and four priorities for action. The *targets* are:

1) substantially reduce global disaster mortality by 2030, aiming to lower average per 100,000 global mortality between 2020-2030 compared to 2005-2015;
2) substantially reduce the number of affected people globally by 2030, aiming to lower the average global figure per 100,000 between 2020-2030 compared to 2005-2015;

3) reduce direct disaster economic loss in relation to global gross domestic product (GDP) by 2030;
4) substantially reduce disaster damage to critical infrastructure and disruption of basic services, among them health and educational facilities, including through developing their resilience by 2030;
5) substantially increase the number of countries with national and local disaster risk reduction strategies by 2020;
6) substantially enhance international cooperation to developing countries through adequate and sustainable support to complement national actions for implementation of this framework by 2030; and,
7) substantially increase the availability of and access to multi-hazard early warning systems and disaster risk information and assessments to people by 2030.

The *priorities* are:

priority 1: understanding disaster risk;

priority 2: strengthening disaster risk governance to manage disaster risk;

priority 3: investing in disaster risk reduction for resilience; and,

priority 4: enhancing disaster preparedness for effective response and to build back better in recovery, rehabilitation and reconstruction.

4.17.5 Disaster risk reduction and the UNFCCC process

UNFCCC parties have recognized that existing knowledge and capacities for coping with extreme weather events must be harnessed to adapt to climate change. The Bali Action Plan's directions for adaptation call for the consideration of risk management and risk reduction strategies, including risk sharing and transfer mechanisms such as insurance. Many of the general principles and requirements for adaptation that are listed in the Bali Action Plan are highly relevant to reducing disaster risk, particularly vulnerability assessments, capacity-building and response strategies, as well as integration of actions into sectorial and national planning. In the climate change domain, robust capacity building can take the form of specific training at community level up to technical assistance for target ministries or government institutions. They include building individual and institutional capacity for analysis, impact prediction and vulnerability assessment (such as weather data collection and analysis), monitoring and observation, risk assessment, cost-benefit analysis of alternative development options. The establishment of knowledge banks to disseminate information and provide training for action on climate change is essential. Such information is necessary for decision making, improving analytical capacity, knowledge management, disseminating activities and implementing pilot projects.

Increasing support to accelerate the transfer of environmentally sound technologies for both adaptation and mitigation is also a focus of the UNFCCC process for disaster risk reduction. In many cases people will adapt to climate change simply by changing their behaviour, by moving to a different location or by changing their occupation. But often they will employ different forms of technology, whether "hard" forms, such as new irrigation systems or drought-resistant seeds, or "soft" technologies, such as insurance schemes or crop rotation patterns or combination of hard and soft, as with early warning systems that combine hard measuring devices with soft knowledge and skills that can raise awareness and stimulate appropriate action. Societies can also take advantage of technologies such as Earth observation systems that can provide more accurate weather forecasts.

Approaches and strategies undertaken under the UNFCCC in reduction of climate change disaster risks are summarised as follows:

- **Develop national coordination mechanisms to link disaster risk reduction and adaptation.**

This can be done through convening inter-departmental and national consultation meetings with personnel from the fields of disaster risk reduction, climate change and development, formally cross-linking the national platform for disaster risk reduction and the national climate change team, and encouraging systematic dialogue and information exchange between climate change and disaster reduction bodies, focal points and experts.

- **Conduct a baseline assessment on the status of disaster risk reduction and adaptation efforts.**

This involves efforts by countries to collect and summarise national risk information, including socio-economic data concerning vulnerability and institutional capacities, together with reviews of relevant existing policies, particularly development strategies and sector plans, HFA implementation, adaptation programmes, and risk transfer mechanisms.

- **Prepare adaptation plans drawing on the HFA.**

Based on the assessment of needs and gaps, this task could include the joint development of a disaster reduction plan and an adaptation plan. It should capitalize on National Adaptation Plans of Action where present and other adaptation initiatives, and should use the concepts and language of the HFA where appropriate, ideally with action on all five of the HFA priorities, to ensure a comprehensive, integrated and systematic approach to adaptation.

Recognising that climate change is affecting vulnerable communities now and mostly, the following strategies should be reflected in developing and implementimg national disaster risk reduction strategies and programmes:

- prioritize adaptation efforts in communities where vulnerabilities are highest and where the need for safety and resilience is the greatest;
- build expected climate change related trends into risk and vulnerability assessment based on current climate variability to craft effective short, medium and long-term strategies to strengthen response capacities and preparedness, reduce risks and promote effective adaptation;
- fully integrate adaptation into long term national and local sustainable development and poverty reduction strategies;

- prioritize the strengthening of existing capacities among local authorities, civil society organizations and the private sector to lay the foundations for robust management of climate risk and rapid scaling up of adaptation through community-based risk reduction and effective local governance;
- develop robust resource mobilisation mechanisms for adaptation that encourage the climate-proofing of development programmes, promote the integration into development planning of dedicated climate change adaptation measures, and ensure the flow of both financial and technical support to local actors; and,
- leverage the opportunities in disaster prevention and response, through improved early warning systems, contingency planning and integrated response, to promote effective community-based adaptation and risk reduction and to strengthen domestic systems for managing international disaster cooperation.

In text question (10 minutes)

How many countries in Africa have successfully developed and implemented national climate change disaster risk reduction strategies and programmes?

Summary

In this session, we have learnt about climate change risks and disaster management and reduction. The session defined concepts in risk and disaster management, highlighted some weather factors that contribute to disasters as well as key strategies for reducing climate change disaster risks.

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Chapter 5: Climate Change Data Management

5.0 Chapter overview

Climate change data provide evidence on climate change and its impacts, as well as vulnerability to climate change and facilitate the development of early warning systems. Thus, access to high quality and timely data is central to understanding the basic science of climate change. Assessing impacts of and vulnerability to climate change and subsequently working out adaptation needs also requires good quality data. This chapter introduces learners to different sources of climatic and climate related data, exposes them to data collection methods, tools and instrumentation, analysis and interpretation, development of climate hazards early warning systems, and information dissemination.

Learning outcomes

By the end of this chapter, the learners will be able to:

- distinguish sources of climatic and climate related data
- apply appropriate methods for collecting climate data
- synthesize climate data into meaningful information, and,
- develop climate hazards early warning systems.

5.1 Definition of climate data

Objectives

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

a) define the concept of climate data;
b) explain how climate data is obtained; and,
c) analyse the uses of climate data in disaster reduction.

Activity 1 (Brainstorming) (20 minutes)

What do we mean by the term climate data?

Climate data is defined as a time series of measurements of sufficient length, consistency and continuity to determine climate variability and change. Climate variability refers to variations in the mean state of climate on all spatial and temporal scales beyond that of individual weather events. Variability may be due to natural internal processes within the climate system (internal variability), or to variations in natural or anthropogenic external forcing (external variability). Data produced from meteorological and climatological networks and various research projects represent a valuable and often unique resource, acquired with substantial expenditure of time, money and effort. The most useful types of climate data are temperature, mean pressure, relative humidity, mean visibility, average dew point, wind direction, wind speed, mean sea level pressure, occurrence of snow, thunderstorm and fog. The issue of global climate change is stretching the requirements for climate data and data management systems. However, the main interest in the use of observed climatological data statistics is not to simply describe the data, but to make inferences from it that are helpful to users of climatological information. Statistics is the tool used to bridge the gap between raw data and useful information. Climate data can be categorised as:

- ***historical information***: data on past conditions and trends can be used for mapping hazards, assessing trends, identifying relationships with historical impacts (e.g. disease outbreaks and food insecurity), and providing a reference against which to compare current and anticipated conditions; historical data can also be used for identifying the seasonality of climate, which can, for example, be important information for under-standing the monthly distribution shifts of disease-carrying vectors, or identifying likely cropping cycles;
- ***current information:*** data on current and recent conditions can be useful for indicating whether potentially impactful weather and climate events, such as severe storms, have recently occurred, or are underway, such as droughts; and,
- ***prospective information:*** forecasts, projections and scenarios are useful in anticipating climate hazards, for planning humanitarian operations, and for longer-term recovery and development planning.

Climate data is generated by a number of global, regional and national stakeholders. At the local and national levels it is typically the responsibility of national meteorological services. Generating data requires functioning, well-maintained and well-distributed physical infra-structure (e.g. weather stations), as well as capacities within meteorological services for analyzing climate data. Whether the public can access climate data depends on the policies of the stakeholders involved in funding, producing, processing and storing the data. While many datasets are available free online, access may still be limited by national policies governing data sharing. The government is not the sole source of local and national climate data and information in a country. Information generated by the meteorological service can be complemented by additional data from universities or the private sector.

Activity 2 (Group discussion) (20 minutes)

Consider meteorological stations in Africa. Do they possess the requisite equipment and capacity to generate reliable climate data?

Summary

In this session, we have learnt about the definitions of climate data and their relevance for disaster reduction. In the next session, we take a look at types of climate data

5.2 Types of climate data

This session looks at the various types of climate data.

Objectives

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

a) differentiate between quantitative and qualitative climate data; and,

b) describe the primary and secondary sources of climate data.

5.2.1 Quantitative and qualitative data

There are two general types of climate data. *Quantitative* climate data are measures of values or counts and are expressed as numbers. They are basically numeric variables. Technologies and instruments have been developed to measure most weather variables. Atmospheric conditions can be measured with instruments and equipment to provide information for weather forecasts and to study the weather and climate. These equipments are calibrated to enable accurate reading of the scale or intensity of the weather variable. For example, thermometers are used for measuring air and sea surface temperature, barometers for measuring atmospheric pressure, hygrometers for measuring humidity (in %), anemometers for measuring wind speed, pyranometers for measuring solar radiation, rain gauges for measuring liquid precipitation (in mm/day), snow gauges are used for solid precipitation, tensiometers and irrometers are used to monitor soil moisture. For other weather variables, like draught, special tools have been designed to measure them. The instruments have gauges which are able to translate weather variables into figures which can then be subjected to statistical scrutiny.

Qualitative climate data on the other hand are categorical measurement expressed not in terms of numbers, but rather by means of verbal description. In simple terms, data can be observed but not measured. This type of data is useful where measuring equipment are lacking and, as a result, the judgement or perception of people become indispensible. This is also useful for less literate populations. For example, to measure drought under such circumstances, an index (abnormally wet, average and abnormally dry) could be built to collect the data. To measure temperature, respondents could use phrases such as hot or extremely hot to depict the intensity. Quantitative climate data define whereas qualitative climate data describe. Quantitative and qualitative data provide different outcomes, and are often used together to get a full picture of the climate data.

In text question (10 Minutes)

What are the likely factors that can affect the quality of qualitative climate data?

5.2.2 Primary and secondary data

Climate data can be primary or secondary. *Primary* climate data are data observed or collected directly from first-hand experience. Such data are collected directly from a source for a specific purpose. The source could be from a weather station, satellite data or by the use of any weather instrument to measure weather variables. Getting a narrative of past climate trends and current changes from those who have lived in their area for an extended period in the absence of measuring equipment qualify as primary data.

Secondary climate data are published data or data collected in the past by another party. It involves consulting records of historical weather or climate variables (e.g. temperatures and rainfall measures) which may be useful for prediction, modelling, simulation or decision-making in the absence of primary-generated data. Secondary climate data are available online, at national meteorological stations or WMO (World Meteorological Organization).

Summary

In this session, we have learnt about the types of climate data. Differences between quantitative and qualitative, primary and secondary data have been expounded. The next session takes a look at sources of climate data.

5.3 Sources of climate data

This training session talks about sources of climate data. The session focuses on various places where climate data can be obtained.

Objectives

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

Describe various sources where climate data can be obtained.

Activity 1 (Small group discussion) (20 minutes)

Describe sources of climate data. Categorise these sources as to whether they provide historical, current or prospective data.

5.3.1 Indigenous knowledge systems

Indigenous communities have long been recognised as being particularly vulnerable to the impacts of climate change due to the close connection between their livelihoods, culture, spirituality and social systems and their environment. At the same time, however, this deep and long-established relationship with the natural environment affords many indigenous peoples with knowledge that they have long used to adapt to environmental change, and are now using to respond to the impacts of climate change. Over time, indigenous people, through observations, have accumulated experience-based knowledge and ideas on changing weather or climate variables such as high temperatures, intense erratic rainfall, rise in sea level, extended periods of drought. Where access to other forms of scientific knowledge are inaccessible or incomplete, weather or climate information from people who have lived in those areas for long periods are crucial.

5.3.2 Country and regional meteorological stations

Various countries have meteorological service stations set up to collect, process, archive, analyse and disseminate findings or meteorological information to end users. There are also meteorological stations set up at regional level under the national stations to address climate data issues at the local level. These meteorological services have weather stations with instruments and equipments for measuring atmospheric conditions to provide information for weather forecasts and to study the weather and climate on a daily basis.

Activity 2 (Group discussion) (20 minutes)

Consider your national/regional meteorological station. What are the key challenges facing their operations? How can these challenges be addressed?

5.3.3 World Meteorological Organization (WMO)

The World Meteorological Organization (WMO) is a specialized agency of the UN. It is the UN system's authoritative voice on the state and behaviour of the Earth's atmosphere, its interaction with the oceans, the climate it produces and the resulting distribution of water resources. As weather, climate and the water cycle know no national boundaries, international cooperation at a global scale is essential for the development of meteorology and operational hydrology as well as to reap the benefits from their application. WMO provides the framework for such international cooperation. WMO facilitates the free and unrestricted exchange of data and information, products and services in real or near-real time on matters relating to safety and security of society, economic welfare and the protection of the environment. Observation systems collect meteorological, climatological, hydrological and marine and oceanographic data from more than 15 satellites, 100 moored buoys, 600 drifting buoys, 3 000 aircraft, 7 300 ships and some 10 000 land-based stations. Powerful computers use mathematical models based on physical laws to produce charts, digital products, weather and air-quality forecasts, climate predictions, risk assessments and early warning services. Meteorological satellites broadcast real-time weather information several times a day to more than 1 000 locations. WMO data provide the basis for better understanding the climatology of severe weather and extreme events such as tropical cyclones, El Niño, floods, heat waves, cold waves, droughts and other natural hazards, contributing to saving both lives and property, and improving our understanding and monitoring of the climate system and environment. WMO has drawn attention to issues of major concern, such as ozone layer depletion, global warming, climate change and diminishing water resources.

5.3.4 National Aeronautics and Space Administration (NASA)

Earth-orbiting satellites and other technological advances have enabled scientists to collect many different types of information about our planet and its climate on a global scale. This body of data, collected over many years, reveals the signals of a changing climate. The National Aeronautics and Space Administration (NASA) conducts research on climate science, enhancing the ability of the international scientific community to advance global integrated Earth system science using space-based observations. The agency’s research encompasses solar activity, sea level rise, the temperature of the atmosphere and the oceans, the state of the ozone layer, air pollution, and changes in sea ice and land ice. NASA has 17 space missions collecting climate data. NASA’s Earth Observing System’s, weather instruments and the amount of data they have collected over the years makes them a good source for obtaining climate data.

5.3.5 African Centre for Meteorological Application and Data (ACMAD)

ACMAD is the weather and climate centre with African continental competence. It was created in 1987 by the Conference of Ministers of the United Nations Economic Commission for Africa (UNECA) and WMO. ACMAD has been operational in Niamey since 1992. It is composed of the 53 countries of the African continent. ACMAD’s mission is the provision of meteorological, climate and environment data and products for sustainable socio-economic development in Africa. It is tasked to promote and develop the applications of meteorological data and information so as to enhance the economic and social development of member states, assist in the investigation and mitigation of the effects of weather phenomena, improve the knowledge of the anomalies of the weather and climate resources of member states and foster the proper conservation of the natural resources of member states. ACMAD carries out its mission through capacity-building for the 53 National Meteorological Services (NMSs) of its member states, in weather prediction, climate monitoring (extreme events), transfer of technology (telecommunications, computing and rural communication) and in research.

In text question (10 minutes)

To what extent are the activities of ACMAD well publicized?

5.3.6 IGAD Climate Prediction and Application Centre (ICPAC)

In an effort to minimize the negative impacts of extreme climate events, WMO and UNDP established the regional Drought Monitoring Centre (DMC) in Nairobi and a sub-centre in Harare covering 24 countries across the eastern and southern African sub-region. The participating countries of ICPAC are Burundi, Djibouti, Eritrea, Ethiopia, Kenya, Rwanda, Somalia, Sudan, Uganda and Tanzania. ICPAC's main objective is to contribute to climate monitoring and prediction services for early warning and mitigation of the adverse impacts of extreme climate events on various socio-economic sectors in the region, such as agricultural production and food security, water resources, energy and health. The early warning products enable users to put mechanisms in place for coping with extreme climate and weather related risks in the Greater Horn of Africa. Some of the key functions of the centre include development and archiving of regional and national quality-controlled climate databanks, data processing including development of basic climatological statistics, timely acquisition of near real-time climate and remotely sensed data, monitoring space-time evolutions of weather and climate extremes over the region, generation of climate prediction and early warning products, delineation of risk zones of extreme climate related events, climate change monitoring, detection and attribution.

Activity 3 (Group discussion) (20 minutes)

- Juxtapose the purpose and activities of ACMAD and ICPAC.
- Can one make the inference that ICPAC addresses some lapses in ACMAD, complement the activities of ACMAD or the ICPAC regions have special climate needs?

5.3.7 Other sources of climate data

Another source of climate data is the National Oceanic and Atmospheric Administration (NOAA). NOAA uses data from its satellites, along with those of its partners, to generate weather forecast each day. It operates on three types of satellite systems; those that orbit around Earth (polar-orbiting), those that stay focused on one region of Earth (geostationary) and a deep space satellite, located one million miles from Earth. NOAA's Climate Data Online (CDO) provides free access to an archive of global historical weather and climate data in addition to station history information. These data include quality controlled daily, monthly, seasonal and yearly measurements of temperature, precipitation, wind and degree days as well as radar data and 30-year climate normals. There are a host of other online sources of climate data but a few of them demand payment to get access to their data.

Summary

In this session, we have learnt about the various sources of climate data. Most of these sources offer data freely but a few online mediums demand payment. The next session will focus on climate data collection methods.

5.4 Climate data collection methods

This training session centres on climate data collection methods. It will highlight various means through which climate data could be solicited.

Objectives

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

a) describe observation as climate data collection method;
b) describe experimentation as climate data collection method;
c) describe survey as climate data collection method;
d) describe case study as climate data collection method;
e) describe rapid rural appraisal as climate data collection method; and,
f) describe desk study/literature search as climate data collection method.

5.4.1 Direct weather observations

Climate data can be collected by directly observing weather or climatic interactions, processes, or behaviours as they occur. Observation is useful when one is trying to understand an ongoing process or situation. Observing changes in temperature, rainfall or any other weather element in the natural setting can help increase understanding of the event being evaluated. Observational studies attempt to understand cause and effect relationships. However, unlike experiments, the researcher is not able to control the study variables. Observation could be a way of validating data collected by other means.

Activity 1 (Brainstorming) (10 minutes)

What precautions should one take to ensure that data collected through direct observations are accurate?

5.4.2 Experimentation

An experiment is a controlled study in which one attempts to understand cause and effect relationships. A study is controlled in the sense that the researcher determines treatments each variable receives. Generally, one or more variables are manipulated to determine their effect on a dependent variable. Experiments are conducted to be able to predict a phenomenon and to be able to explain some kind of causality. In a climate change scenario, one could set up an experiment involving two communities; one with an intact forest and the other without forest. Then we could observe how weather or climatic factors would interact with the activities and livelihoods of residents in the two communities.

5.4.3 Survey

A survey is a study that obtains data from a subset of a population. Survey research is often used to assess thoughts, opinions and feelings about climate change. Surveys are mostly done using questionnaires. The questionnaire would contain a series of questions to elicit climate information or data from a target group of people. The questionnaire is completed through face-to-face interviews, a telephone call, via a mail or online.

5.4.4 Case study

A case study is an approach that focuses on gaining an in-depth understanding of climate change. This method of study is especially useful for trying to test theoretical models by using them in real world situations. It is a method used to narrow down a very broad field of research into one easily researchable. For example, the manifestation of climate change on forest ecosystems could be studied on the basis of the individual components of the forest (trees, animals). Or it is expected that climate change may heavily impact coastal communities. A case study of a community would help determine why it would be so. Case studies present data that are usually gathered through a variety of means including, but not limited to, interviews, observations, audio and video data and document collection. The goal of collecting data through a variety of means is both to enhance the theory generating capabilities of the case, and to provide additional validity to assertions made.

5.4.5 Rapid Rural Appraisal

RRA was developed in response to the disadvantages of more traditional research methods, including the time taken to produce results, the high cost of formal surveys and the low levels of data reliability due to non-sampling errors. It is a bridge between formal surveys and unstructured research methods such as depth interviews, focus groups and observation studies. RRA is mostly useful where there is relatively low literacy in the studied populations of interest and few trained enumerators. The nature of RRA is such that it holds the promise of overcoming limitations of other data collection procedures. The approach aims at incorporating the knowledge and opinions of rural people in the climate data collection process. Local people are allowed to examine the issue of climate change and proffer solutions on their own. RRA requires multi-disciplinary teams and the use of a suite of visual methods and semi-structured interviews to learn from respondents. This means that people are not just listened to, but also heard and that their voices help shape outcomes. Because respect for local knowledge and experience is paramount, the result is data that reflect local realities, often leading to better supported and longer lasting change.

5.4.6 Desk study/literature search

It involves the summary, collation and/or synthesis of climate data from existing research or publication (e.g. the press, the internet, analytical and statistical reports) rather than from research subjects or experiments. It often helps to identify important information needs that have not been addressed through previous research. They also serve as a baseline for understanding changes resulting from climatic or weather variables. Desk research/ literature search can serve as a stand-alone data collection technique or as the initial stage of a study and a precursor to primary research. There are a lot of climate data from weather stations available online which are useful for making weather and disaster predictions.

In text question (10 minutes)

What are the advantages and disadvantages of conducting a desk study/literature search?

Summary

In this session, we have learnt about climate data collection methods. The appropriate methods for situations have been explained as well as methods for all categories of people. The next session takes a look at tools and instrumentation.

5.5 Tools and instrumentation

This training session takes a look at tools and instrumentation. It highlights the tools for climate data collection and instruments used in the measurement of weather variables.

Objectives

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

a) develop and use the appropriate tool for climate data collection based on the circumstance; and,

b) describe the instruments used in measuring weather or climate variables.

Activity 1 (Group discussion) (20 minutes)

SDiscuss the instruments used to measure weather or climatic factors.

5.5.1 Questionnaires, interview checklist and observation checklist

A questionnaire is a mean of eliciting the feelings, beliefs, experiences, perceptions or attitudes of a sample of individuals. It is a very concise, pre-planned set of questions designed to yield specific information to meet a particular need (e.g. climate data) for research information about a pertinent topic (e.g. climate change or disaster reduction). As a climate data collecting tool, it could be structured or unstructured. The questionnaire can be administered face to face, mailed, filled online or via a telephone call. Questionnaires have the advantage of uniformity of questions. Each respondent receives the same set of questions phrased in exactly the same way. Questionnaires may, therefore, yield data more comparable than information obtained through an interview. If the questions are highly structured and the conditions under which they are answered are controlled, then the questionnaire could become standardized. Questionnaires can be closed or open ended.

The interview checklist is another tool. The purpose of the interview checklist is to explore the views, experiences, beliefs and/or motivations of individuals on specific matters. It provides a deeper understanding of social phenomena than would be obtained from purely quantitative methods. There are three types of interview checklists; structured, semi-structured and unstructured. *Structured* interviews are a list of predetermined questions. They are relatively quick and easy to administer and may be of particular use if clarification on certain questions are required or if there are likely to be literacy or numeracy problems with the respondents. Because of the structured nature, they might prevent the collection of additional data. Conversely, *unstructured* interviews do not reflect any preconceived ideas and are performed with little or no organization. They usually start with simple conversation about the subject matter. Unstructured interviews are usually very time consuming and can be difficult to manage, and to participate in, as the lack of predetermined interview questions provides little guidance on what to talk about. Their use is, therefore, generally only considered where significant depth is required, or where virtually nothing is known about the subject area. *Semi-structured* interviews consist of several key questions that help to define the areas to be explored, but also allows the interviewer or interviewee to diverge in order to pursue an idea or respond in more detail. The flexibility of this approach, particularly compared to structured interviews, also allows for the discovery or elaboration of information that is important for participants but may not have previously been thought of as pertinent by the researcher.

An observation checklist is a list of things that an observer is going to look at when observing a phenomenon or a situation. It gives an observer a structure and framework for observation. Observation overcomes one of the key disadvantages of interviews and questionnaires, i.e. the responses provided may not be accurate. Such inaccuracies occur due to the respondents' lack of awareness on the event, lack of an accurate memory of what happened, deliberate lies to make them appear better than they are and desire to tell the researcher what they think the researcher wants to hear. Observation can be used where it is not possible to collect data using interviews or questionnaires, such as when the study subject or phenomenon is inanimate.

Activity 2 (Small group discussion) (20 minutes)

Select an ecosystem type. Develop a sample observation checklist to study the impact of climate change on the named ecosystem.

Another useful tool is the focus group. A focus group is a group discussion (on climate change in this case) organised for research purposes. This discussion is guided, monitored and recorded by a researcher (as moderator or facilitator).They are used for generating information on collective views, and the meanings that lie behind those views. They are also useful in generating an understanding of participants' experiences and beliefs. Focus groups share many common features with less structured interviews. Participatory research approach tools such as resource mapping, fishbone diagrams are also helpful data collection tools.

Exercise question (10 minutes)

Which other PRA tools could prove useful in collecting climate change data/information?

5.5.2 Equipment

Weather equipment is used to take measurements of various atmospheric parameters at weather stations. They are used to measure temperature, wind, humidity and rainfall, as well as other atmospheric factors which describe the local weather and climate. A rain gauge is an instrument used to measure the amount of liquid precipitation over a certain length of time. In its simplest sense, a rain gauge is tool which collects water which falls from the sky as rain. The depth of the rain can be measured with a ruler. During hurricanes, high winds make liquid measurements in rain gauges impossible. Also, when the temperature approaches freezing (0°C), liquid may freeze around the rain gauge and block the opening. A common type of rain gauge used at weather stations is the heated tipping bucket. This rain gauge melts frozen precipitation around the opening and keeps the precipitation in liquid form when it enters the bucket. As rain enters the funnel, the rain drips into one of the two buckets that are balanced on a pivot below the funnel.

When the bucket tips, it triggers a reed switch which sends data back to the weather station on the amount of precipitation in the bucket. However, the heating element can cause evaporation of small amounts of rain before it gets to the measuring funnel. Also, the tipping bucket can jam or overflow in high-intensity rain like thunderstorms, which can cause errors in the precipitation amount. The hygrometer is another weather measuring instrument for relative humidity. Humidity is the measure of the amount of moisture in the air.

A thermometer measures the air temperature. Most thermometers are closed glass tubes containing liquids such as alcohol or mercury. When air around the tube heats the liquid, the liquid expands and moves up the tube. A scale then shows what the actual temperature is. Most thermometers measure by direct contact with the air, although infrared thermometers use sensors to detect infrared radiation coming off of surfaces and estimate temperature in that manner. The sunshine recorder is a device used for measuring the number of hours of sunshine in a day. A barometer measures air pressure. It tells you whether or not the pressure is rising or falling. A rising barometer means sunny and dry conditions, while a falling barometer means stormy and wet conditions. An aneroid barometer, one of the most common types, uses a sealed can of air to detect changes in atmospheric pressure.

A wind vane is an instrument that determines the direction from which the wind is blowing. An anemometer measures wind speed. Some instruments measure both wind speed and direction. Doppler radar takes measurements of winds in clouds in order to predict severe storms. Tensiometers, watermark sensor or irrometer are used in measuring soil moisture. Weather stations often contain the different weather instruments listed above to collect data. In addition, scientists use weather balloons to collect data from the atmosphere. Research aircraft and satellites also carry instruments to collect data about weather and climate.

Activity 3 (Brainstorming) (20 minutes)

Devise innovative ways to record atmospheric conditions with local materials so as to help individuals and the poor (vulnerable) gather their own climate data.

Summary

In this session, we have learnt about tools and instrumentation. The session has explained tools and instruments for collecting qualitative and quantitative climate data respectfully. These data are essential for disaster reduction strategies. The next session takes a look at data analysis and interpretation.

5.6 Data analysis and interpretation

This training session takes a look at data analysis and interpretation. It highlights tools for climate data analysis, methods for data analysis and data presentation.

Objectives

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

a) utilize climate data analysis tools and softwares;
b) describe climate data analysis methods; and,
c) present and interpret climate data.

5.6.1 Tools for data analysis

Climate Data Analysis Tools are used for the analysis, manipulation and plotting of atmospheric science data. There is no one-size fit all software for carrying out these analyses. All software tools and languages have strengths and weaknesses. For large scale data processing on a variety of data sets in assorted data formats and differing requirements, it is unlikely that a perfect tool or language exits. Often, a combination of tools and languages will be needed. Climate data processing involves three components: (1) file handling; (2) processing (data manipulation and computations); and, (3) graphics (visualization).

There are three different software categories used for climate data processing and visualization: (1) compiled languages (eg. fortran, C, C++); (2) command line operators and viewers (NCO, CDO, ncview, panoply); and, (3) interpreted languages (NCL, GrADS, Ferret, R, Python [CDAT/PyNIO/PyNGL/Numpy/matplotlib] and the commercial products Matlab, R-statistical software, IDL and, to a lesser extent, PV-Wave). Some other tools are Weather and Climate Toolkit (provides simple visualization of data), GIS-Based Map Interface (Climate Data Online) (provides specialized dynamic mapping capabilities for datasets). Calculators and conversion tables help people understand and interpret weather and climate data, including converting temperature between Celsius and Fahrenheit or estimating wind speed. NOAA's Operational Model Archive and Distribution System (NOMADS) Ensemble Probability Tool allows users to query the Global Ensemble Forecast System (GEFS), to describe a set of conditions and determine the probability that those conditions will occur at a given location. There are a number of other web-based sites (e.g. NASA) that provide the capability to visualize and perform limited processing tasks. Common tasks include difference maps, correlations, composites, climate monitoring and deriving climate indices.

Activity 1 (Brainstorming) (20 minutes)

- Identify tools with which local people can easily analyse climate data and make inferences.
- How can their capacities be developed to perform more complex analysis to better make predictions?

5.6.2 Methods of data analysis

By definition, climate is the statistics of weather over an arbitrarily defined time span. The methods used to derive the statistical estimates can be simple or very complex. The most common statistic is the average of some variable (e.g. temperature). However, solely focusing on the average can be misleading. For example, the average temperature may be consistent with previous time spans but the variance may have changed in some significant way. The gradual change of some variable over time is defined as a trend. Given a time series of temperatures, the trend is the rate at which temperature changes over a time period. The trend may be linear or non-linear. A common method for analyzing data that occurs in a series, such as temperature measurements over time, is to look at anomalies, or differences from a pre-defined reference value.

Another method of climate data analysis is hypothesis testing. This approach helps to take decisions from data and also helps to affirm or disprove long held suspicions. Principal component and multivariate correlation analysis are used to find related patterns in noisy climate data. Extreme value analysis (EVA) is used to assess the likelihood of events at the tails of a variable's distribution. EVA, for example, can help show how to quantify 100 years flood with only 30 years of data. In addition to conventional statistics, there are diagnostics which are used to assess the nature of climate variations on differing time scales. The detection, estimation and prediction of trends and associated statistical and physical significance are important aspects of climate analysis. Data analysis guides simplification and understanding of complex processes.

5.6.3 Data presentation

Putting data into a visual format can facilitate additional analysis. One common way of presenting climate data of a region is via a climograph, a graphical representation of the long-term average monthly precipitation and temperature for that location. On climographs, precipitation is traditionally depicted via bars and a line graph is used to present monthly temperature values. Alternatively, atmospheric data can be presented in the form of maps and time series, temperature and precipitation maps, temperature anomalies time series, homogenised time series of in-situ observations and associated metadata. Taylor diagrams are used to portray the results of more complex data and analysis. Climate data presentation is essential for policy purposes, to plan disaster risk reduction and to improve livelihood strategies of the vulnerable.

Exercise question (10 minutes)

In what innovative ways could climate data be presented to enhance understanding among less literate populations?

Summary

In this session, we have learnt about data analysis and interpretation. Various tools and softwares for climate data analysis were mentioned. Methods of data analysis and presentation were also explained. The next session takes a look at data documentation and archiving.

5.7 Data documentation and archiving

This training session takes a look at data documentation and archiving. It talks about climate data storage and data retrieval systems.

Objectives

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

a) describe climate data storage; and,

b) describe climate data retrieval.

Activity 1 (Brainstorming) (15 minutes)

What gadgets are needed to store climate data at the individual and community levels?

5.7.1 Data storage

For thousands of years historians have recorded information about the weather. In the past, however, this information was often based on accounts from others and was not drawn from the historians' personal observations. Such accounts may have been vague, truncated or affected by memory lapses. This type of weather information was embedded within an immense array of other kinds of information, and much of it is contained in national libraries and archives. Specialized national meteorological archives are relatively recent, with the earliest being established during the first half of the twentieth century. Early records in manuscript form were kept in daily, weekly or monthly journals. Notes were made of extreme or catastrophic events such as high or low temperatures, abnormal wind speeds, excessive rainfall or prolonged drought, dates of frost or freezing, hurricanes and tornadoes. Storms, calms, winds, currents, types of cloud and cloudiness were noted in marine logbooks. Freezing and thawing dates of rivers, lakes and seas, as well as the first and last dates of snowfall, were often recorded as an important part of any journal. Specific journals for the collection and retention of climatological information have been established within the last two or three centuries. Until the 1940s, the forms developed, printed and used in various countries were often different, and observations were normally recorded by hand.

Since the 1940s and especially following the establishment of WMO, standardized forms and procedures have gradually become prevalent, and national meteorological archives have been designated as the storage site for these records. With each new improvement or addition to the tools of observation, the number of items or variables entered in journals and logbooks increased and specially prepared formats were developed. Even as formats have changed, regularity, consistency or continuity of the record-keeping, has always been desirable. A good chronological record should be kept current and in sequential order. Methodical careful observations and recording permit easier collection, archiving and use of records. The collection, transmission, processing and storage of operational meteorological data, however, are being dramatically improved by rapid advances in computer technology, and increasingly meteorological archives are being populated with data that have never been recorded on paper. The power and ease of use of computers, the ability to record and transfer information electronically, and the development of international exchange mechanisms, such as internet, have given climatologists new tools to rapidly improve the understanding of climate.

The management of the vast variety of data collected for meteorological or climatological purposes requires a systematic approach that encompasses paper records, microform records and digital records. Achieving this requires the services of a data manager. An important function of the data manager is to estimate data storage requirements, including the estimation of future growth. Account must be taken of the additional information to be included in data records (e.g. data quality flags, original messages, and date and time of record updates), metadata needs, and any redundancy necessary to ensure that databases can be restored. Some data types (such as those from remote-sensing, oceanography with high temporal resolution) require large amounts of storage. Unconventional data (such as soil moisture, phenological observations and vegetation indices) may have storage needs that are different from more traditional observations. Non-digital records should be stored in a way that minimizes their deterioration. They should be stored in a controlled environment to avoid temperature and humidity extremes, insects, pests, fire, flood, accidents or deliberate destruction. An ideal example would be storage in acid-free boxes in air-conditioned, secure storerooms.

In text questions (10 minutes)

1) Do national meteorological services have the capacity and resources to effectively manage climate data?
2) What is metadata?

A maintenance programme should be established to rescue deteriorating documents and particularly the data they contain. The electronic images of the paper records can be stored and retrieved using computer technologies such as optical character recognition software. It is important to remember that no storage medium is permanent, and therefore regular review of archival arrangements should be undertaken. Computer based archives must be securely and regularly backed up with at least one copy stored at a site separate from the main archive.

In summary, climatological data are most useful if they are edited, quality-controlled and stored in a national archive or climate centre and made readily accessible in easy to use forms. A climate data management system (CDMS) is a set of tools and procedures that allows all data relevant to climate studies to be properly stored and managed. The primary goals of database management are to maintain the integrity of the database at all times, and to ensure that the database contains all the data and metadata needed to meet the requirements for which it was established, now and in the future. Database management systems have revolutionized climate data management by allowing efficient storage, access, conversion and updating for many types of data, and by enhancing data security.

5.7.2 Data retrieval systems

It is essential that both the development of climate databases and the implementation of data management practices take into account the needs and capabilities of existing and future data users. While this requirement may seem intuitive, information important for a useful application is sometimes omitted, or data centres commit insufficient resources to checking the quality of data for which users explicitly or implicitly demand high quality. For instance, a database without both current and past weather codes could lead to underestimates of the prevalence of observed phenomena. In all new developments, data managers should attempt to have at least one key data user as part of the project team or to undertake some regular consultative process with user stakeholders to keep abreast of both changes in needs and any issues that user communities may have. An important aspect of any CDMS is the power of the facilities to perform data retrieval and analysis. Graphical user interface retrieval facilities should be provided for most users, and command line facilities should be available for the small number of knowledgeable users who have a need for non-standard retrievals. Users should be able to specify their own retrieval criteria, and the system documentation should be clear and provide as much information as necessary to support the users. Output options should be extensive and include facilities for customizing stations, times and details of output presentations. Access should be given to listings of data, tabular summaries, statistical analyses and graphical presentation.

To prevent loss of, or damage to, the CDMS, there is a need to have security policies. An audit trail is one such security measure. It is a record showing who has accessed a CDMS and what operations he or she has performed during a given period of time. Audit trails are useful for recovering lost transactions. Most accounting systems and CDMS include an audit trail component. There are separate audit trail software products that enable network administrators to monitor use of networks. Password security principles should be applied, including not sharing passwords, not writing them on paper, changing them regularly, and using “strong” passwords with seemingly unrelated letters, numbers and characters. All unnecessary services should be disabled on the database computer, the database must be protected against attacks from viruses and hackers, regular backups must be made. National/regional meteorological stations should make available written climate data records when the demand is placed by stakeholders who cannot access computers.

Activity 2 (Small group discussion) (20 minutes)

If audit trails exist to ensure data integrity in computer storage systems, how can the integrity of manually recorded data be ensured?

Summary

In this session, we have learnt about data documentation and archiving. The appropriate way to store climate data has been learnt. Ways to retrieve climate data whilst ensuring the security and validity of data was discussed.

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