Algerian Democratic and Popular Republic

Ministry of Higher Education and Scientific Research

Setif 1 university - Ferhat Abbas

Faculty of Nature and Life Sciences

Department of Ecology and Environment

COURSE HANDOUT

Bioclimatology

FOR THE USE OF

Bachelor's degree (L3) in Ecology and Environment

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Course: Bioclimatology

Credits: 4
Coefficient: 2

Course Objectives

This module aims to introduce students to **bioclimatology** (including meteorological aspects) and to the **dynamics of ecological systems**.
It provides students with a **synthetic overview of ecological diversity** and emphasizes the study of processes, their inherent dynamics, interactions between ecosystem components, and the abiotic factors controlling these interactions.

Recommended Prerequisites

Biostatistics, computer science, and mathematics

COURSE CONTENT

INTRODUCTION

Definition, Bibliography

1. General Climatology

- Meteorology, climatology, and the relationship between the two sciences
- Weather and types of weather

2. Climatological Data

- Data sources, data processing, and their applications
- Satellite images (Meteosat)

Surface measurements:

- Rainfall
- Temperature
- Atmospheric pressure
- Relative humidity
- Sunshine duration
- Cloudiness

- Wind

Upper-air measurements:

- Atmospheric pressure
- Wind
- Temperature

3. Mechanisms of General Circulation of Wind Systems

- Trade winds
- Westerlies
- Polar winds

4. Air Structure and Layer Dynamics

- Troposphere
- Stratosphere
- Ionosphere

5. Thermal Balance at the Earth's Surface

- Net radiation at the Earth's surface
- Geographical variations of radiation balance
- Energy balances
- Specific issues related to CO_2, greenhouse effect, and atmospheric (and terrestrial) ozone

6. Physical Climate Classification

- Based on temperature
- Based on temperature and rainfall

7. Aridity

- Different aridity indices
- Their evolution
- Arid regions in the world, Africa, and the Maghreb

8. Hydrology

- Surface hydrology
- Groundwater hydrology
- Water balance
- Specific issues in forests
- Specific issues in steppes
- Specific issues in the Sahara

9. Water Balance

- Actual evapotranspiration
- Potential evapotranspiration

Methods:

- Measurement methods
- Calculation methods (ETP, ETR)

10. Methods for Characterizing the Mediterranean Climate

- Emberger method
- Derived methods

11. Use of Bioclimatic Syntheses in Applied Ecology

- Concept of scales
- Aridity and anthropogenic degradation

12. Vegetation–Climate Relationships

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SUMMARY

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CHAPTER V | ARIDITY

CHAPTER VI | EVAPOTRANSPIRATION

CHAPTER VII | THE MEDITERRANEAN CLIMATE

CHAPTER VIII | ADAPTATION OF PLANTS AND ANIMALS TO CLIMATIC CONDITIONS

Introduction

Bioclimatology has emerged today as an essential discipline for understanding the complex relationships that unite climate and living organisms. At a time when climate change is disrupting ecological balances and threatening the sustainability of natural resources, this science occupies a strategic position in the analysis of interactions between atmospheric factors and biological systems. Unlike a purely descriptive approach to climate, bioclimatology focuses on how climatic parameters such as temperature, precipitation, humidity, solar radiation, or wind directly or indirectly influence the functioning, distribution, and adaptation of living organisms, whether plants, animals, or humans.

This discipline lies at the intersection of several scientific fields, including meteorology, ecology, physiology, agronomy, and geography. It does not limit itself to the study of large-scale global climate trends but also addresses local and regional scales, where climate shapes the daily life of living beings and conditions their survival. For instance, in agriculture, bioclimatology helps determine the optimal distribution of crops, identify critical growth periods, and anticipate risks associated with droughts, frosts, or heatwaves. Similarly, in human health, it contributes to analyzing the impact of climate variations on the spread of certain diseases, on thermal comfort, and on the vulnerability of populations.

Beyond its practical applications, bioclimatology also provides a fundamental perspective on how ecosystems are formed and transformed under the influence of climatic conditions. Desert zones, tropical forests, savannas, and polar regions are all expressions of the intimate relationship between climate and the biosphere.

Bioclimatology in Algeria examines the interactions between climate and living organisms across a marked north–south gradient, ranging from the humid Mediterranean regions in the north to the arid Sahara in the south. This diversity shapes distinct ecosystems, including forests, steppes, and desert environments, each with specific plant and animal adaptations. However, global climate change is increasingly disrupting these systems, with rising temperatures, decreasing and irregular rainfall, and more frequent extreme events such as droughts and wildfires. These changes are accelerating desertification, degrading natural vegetation, and threatening biodiversity and agricultural productivity. As a result, understanding bioclimatic relationships is essential for developing effective adaptation strategies, such as sustainable water management, drought-resistant crops, and ecosystem conservation, to ensure environmental resilience in Algeria.

In the current context marked by the acceleration of global warming, the study of bioclimatology takes on an even more crucial dimension. It no longer limits itself to scientific observation but is embedded in a forward-looking and applied approach: modeling future scenarios, anticipating ecological and socio-economic impacts, and proposing adaptation strategies. Bioclimatology has therefore become an indispensable tool to support ecological transition, ensure food security, and preserve biodiversity in a rapidly changing world.

Chapter I: General Climatology and Biological Classification of Climates

I.1- General Climatology

I.1.1 Meteorology and Climatology

The words *meteorology* (or *weather*), *climate*, and *climatology* have, for the non-specialist, common definitions that are more restrictive than those used by scientists. It is generally these everyday definitions that appear first in dictionaries and encyclopedias. Scientific definitions are broader, since the study of atmospheric phenomena necessarily leads to consideration of many other environments beyond the atmosphere itself.

- **Meteorology in the common sense**

"Meteorology is the study of atmospheric phenomena and their laws, particularly with a view to weather forecasting" (*Petit Larousse*). An equivalent English-language dictionary gives a very similar definition: "Meteorology: science of the weather; study of the earth's atmosphere and its change." As indicated in the *Dictionnaire culturel des sciences* (Éditions du Seuil), the common meaning tends to conflate meteorology with weather forecasting, especially of the "sensible weather" that governs our immediate human impressions. This definition rarely extends beyond the atmospheric environment, except to note its most direct consequences for humans (frozen soils, floods, etc.).

- **Meteorology in the scientific sense**

"Meteorology is the science of the atmosphere." This concise definition is provided by *Encyclopedia Universalis*, which adds: "More precisely, it studies the physical processes that determine its evolution and explains the phenomena observed primarily in its lowest layer." Since the atmosphere is an open system, meteorology (the science of the atmosphere) must consider many interactive processes with environments connected to the atmosphere: the ocean, the cryosphere, the biosphere, continental surfaces, outer space, etc. To study the relevant physical processes, meteorology must analyze them across all timescales. .(Etienne,2007)

- **Climate and Climatology in the common sense**

The word *climate* comes from the Greek *klima* (inclination), in reference to the tilt of the Earth's axis, which causes climate to vary with latitude.

"Climate is the set of meteorological phenomena that characterize the average state of the atmosphere and its evolution in a given place" (*Petit Larousse*). An equivalent English dictionary states: "Climate: weather conditions of a place or an area" and "Climatology: science of climate." In the most restrictive sense, climate is thus seen as a subset of meteorology, in which only average characteristics (over at least a month) or longer temporal scales (from a month to millions of years) are retained. This is expressed in the *Dictionnaire culturel des sciences* as follows (though it introduces the more complex notion of the "butterfly effect"): "Climate is what remains of weather once stripped of its whims, which no one can predict beyond the horizon imposed by the butterfly effect." For a long time, meteorologists viewed "climatology" in this restricted sense: compiling and studying statistics on the elements of climate.

- **Climate and Climatology in the scientific sense**

More generally, climatology is defined as "the science that provides a systematic description and explanation of the distribution of climates" (*Encyclopedia Universalis*). Today, one might add that climatology seeks not only to explain the geographic distribution of climates but also their evolution over decades and centuries—especially since the slow warming of the planet has become evident. To account for this long-term evolution, some have introduced the concept of "dynamic climatology."

The study of past climate has involved an enormous effort of reconstruction by historians, glaciologists, sedimentologists, and others, producing extensive documentation. On decadal to centennial scales, atmospheric evolution is largely driven by that of the oceans (frozen or not), continental surfaces (ice-covered or not), and the entire biosphere. It also depends, to a lesser extent, on astronomical factors such as solar radiation changes or variations in Earth's orbital geometry. To study, understand, and predict climate evolution (often with the aid of numerical modeling), scientists must therefore address many physical processes external to the atmosphere. These include processes affecting the broader "climate system": for example, the deep ocean and hydrology (lakes, rivers, glaciers, and deep continental water reserves).

For a meteorologist forecasting the weather over a few days, it is not necessary to study these external environments in detail, since they evolve much more slowly than the atmosphere itself. They can thus be represented very simply in operational models. For example, in weather prediction models, the ocean state is assumed to be constant (including sea surface temperature, which directly drives ocean-atmosphere energy exchange). On land, most variables are also fixed in such models (vegetation, glacier extent, soil conditions, etc.), with notable exceptions such as surface temperature and humidity—which can vary considerably on a daily basis—and snow cover thickness.

As a result, the physical processes of interest to the meteorologist are often more limited than those of interest to the climatologist. The "meteorological system" (focused on short-term forecasting) can therefore be seen as a subset of the "climate system"—the opposite of the common notion that views climate as a subset of meteorology. .(Etienne,2007)

- **In the language of mathematicians and modelers**

For modelers, simulations of weather (or meteorological phenomena) differ from simulations of climate evolution mainly through "initial conditions" and "boundary conditions." The state of the atmosphere at a given moment is taken as the initial condition for a numerical model that calculates its evolution over time, producing a weather forecast. Such models necessarily extend slightly beyond the atmosphere, since they must simulate the evolution of

surface temperature and humidity on land variables that can change rapidly, often faster than atmospheric temperatures themselves. This belongs to the domain of weather forecasting and meteorology.
In these models, most external environments—such as ocean state, vegetation, and soil composition are fixed as boundary conditions. In a purely meteorological simulation, boundary conditions remain constant.

It is well known that weather forecasts lose meaning beyond about ten days, since the atmosphere, as a chaotic physical system, quickly “forgets” its initial conditions. At that point, boundary conditions become dominant, determining the mean statistical state of the atmosphere its climate. This is the domain of climate modeling and climatology. Fundamentally, there is no difference between a weather forecast model and a climate simulation model, even if their implementation differs in practice. The same physical laws and equations govern both. The difference lies in treatment: in weather models, many system variables are boundary conditions held fixed, whereas in climate models, the same variables become part of the evolving initial conditions within an extended climate system.(Cano and al.,2022)

I.1.2. Climatology and Bioclimatology

Climatology focuses on the study of a relatively recent past of climatic data, covering a period of about 30 years according to the standards of the World Meteorological Organization (WMO). For the past 150 years, archives have recorded meteorological data, making it possible to trace the evolution of different climatic parameters in a given location. These historical studies are of great importance in governmental planning programs, while civil protection agencies and even insurance companies regularly rely on climatological statistics.

The observed changes in climate mainly attributed to the greenhouse effect—are essential for anticipating phenomena that have a direct impact on fauna, flora, and human populations: desertification, sea level rise, flooding, drought, and fires linked to extreme climatic events. Biometeorology or bioclimatology is a science that studies the interactions between atmospheric phenomena and living beings. Bioclimatology examines the effects of weather variations on plants and animals, and more specifically, the behavior of plants and animals.

Bioclimatology reveals the close relationship between living beings and physical factors (climate), which is evidently strongly linked to and connected with agriculture and vegetation ecosystems, as the concepts of bioclimate and bioclimatic belt (thermotype and ombrotype) are essential for planning crops. It is important to bear in mind that the aim is to achieve maximum yields in terms of quantity and quality with the lowest environmental and economic cost, which is ultimately what both growers and society demand. This cannot be done without taking into account bioclimatology as a critical science for agricultural planning. The use of bioindicators and bioclimatic indices must therefore be incorporated into agricultural management, and this requires obtaining a bioclimatic interpretation of the territory as an essential framework in which to establish the crop. Once the bioclimate has been determined for each ecosystem and crop, a landscape analysis must be conducted in concordance with the bioclimate of the territory. This will contribute to achieving successful reforestation that will act as a CO2 sink and potentially mitigate climate change, always assuming that there is a parallel reduction in CO2 emissions and a change in energy policies. (Cano and al.,2022)

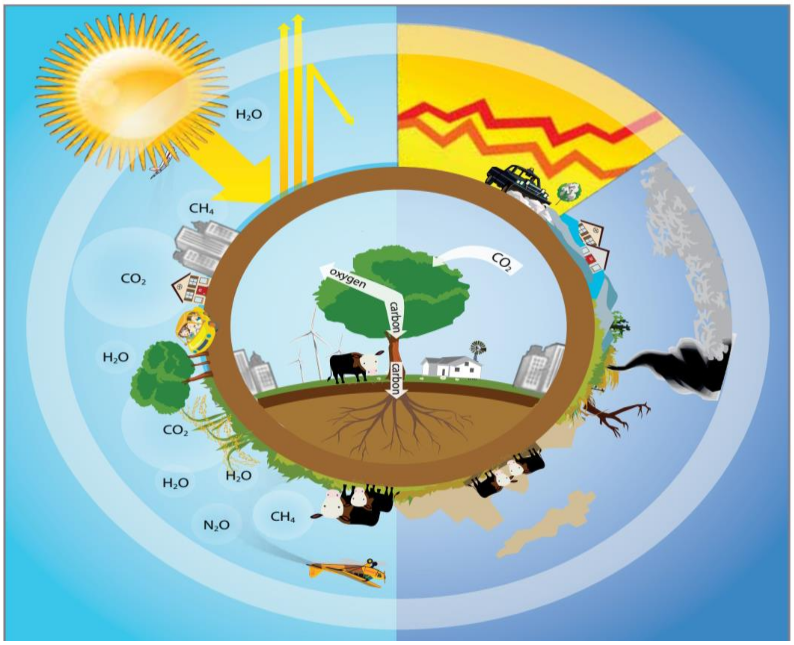
I.1.3. Weather and climate

"Climate is what you expect whereas weather is what you get."

Weather and climate are closely related to each other but they are not synonymous to each other.

The confusion comes from weather and climate being intimately connected to each other, and this confusion is often highlighted in discussions about our changing climate. Weather and climate are not independent. The averages of daily weather are used to monitor climate. Changes in climate lead to changes in weather patterns including extremes. An easy way to remember the difference is that climate is what you expect, like a hot summer, and weather is what you get, like a cool day in August.

Our communities and farms are affected by shortterm weather events. Their long-term sustainability is affected by climate and climate variability attributed to natural processes and human activities. Figure 1 depicts how weather and climate are intertwined. Over time, the weather forms the climate and influences the environment (soil, hydrology, plants, and animals), and economic viability of our human systems.



The sun is the major source of energy for the planet. The atmosphere moderates the solar influence by moderating temperature.

Greenhouse gases, such as water vapor, carbon dioxide, methane, and nitrous oxide, absorb energy and trap it in the atmosphere. Activities such as urbanization, energy consumption, land use change, and agriculture influence the environment.

Extreme weather events, such as heat waves, droughts, tornadoes, torrential rains, and heavy snowfall, are a natural part of the Earth's climate. Nonetheless, extreme weather and climate events have significant effects on our lives and on the environment.

Carbon dioxide is constantly being exchanged among the atmosphere, ocean, and land as it is both produced and absorbed by many microorganisms, plants, and animals.

Figure 1. Communities and farms are affected by short-term weather events. Their long-term sustainability is affected by climate (long-term weather variation or expected weather) and climate variability driven by natural and human processes.(Tomlinson and al.,2013)

I.1.3.1. Weather, Types of Weather

A. Definition of Weather

Weather is a specific state characteristic of a given place and is of limited duration (day, month), such as a sunny day or a rainy month. In other words, weather is concrete and directly observable by humans through measurable atmospheric parameters such as temperature, heat, humidity, atmospheric pressure, winds, precipitation, etc. The values of these parameters combine in various ways to define the existing weather conditions.

A season corresponds to a division of the year according to atmospheric conditions that imply a certain constancy.
In each season, a type of weather may dominate:
(a) **Rainy season** (rainy weather, clouds, high humidity).
(b) **Dry season** (dry weather, few clouds, sunshine, heat).

(c) **Thermal seasons** (summer, autumn, winter, spring with their specific characteristics).

In temperate countries, the seasons are determined by **thermal variations**: they are called **thermal seasons**, that is, linked to temperatures. In contrast, in tropical countries, the seasons are determined by **rainfall variations**: they are called **rainfall seasons**, that is, linked to precipitation.

In general, when speaking of weather and climate, we consider the combination of several factors: temperature (T°), pressure (P), humidity, wind, etc. These are the **states of the atmosphere**. Weather, however, is a **temporary combination**, while climate represents the **sum of stable combinations** established over a long period.

B. types of weather

is defined by the present and momentary state of the atmosphere (wind direction and strength, temperature, cloud cover, rainfall, etc.). It is determined by the movement of air masses across the globe, the relative position of continents and seas, and local conditions such as relief, vegetation, and hydrography, which can alter wind direction or rainfall.

Therefore, the analysis of all these elements in a given location, and the chronological classification of the different types of weather thus studied, make it possible to reconstruct, in an accurate and vivid way, the evolution of the climate over a month, a season, or a year.

There are different types of weather depending on the atmospheric conditions:

- **Sunny weather** – clear sky, lots of sunlight.
- **Cloudy weather** – sky covered with clouds.
- **Rainy weather** – water droplets fall from clouds.

- **Stormy weather** – strong winds, rain, thunder, or lightning.
- **Snowy weather** – frozen precipitation falls as snow.
- **Windy weather** – strong air movements.
- **Foggy weather** – low visibility due to condensed water vapor near the ground.

C.Relationship Between Causes and Weather Types

Each type of weather results from a combination of the causes listed above:

- **Sunny:** high pressure + descending dry air.
- **Rainy:** low pressure + rising humid air.
- **Stormy:** collision of warm and cold air masses.
- **Snowy:** cold temperature + moisture.
- **Windy:** strong pressure gradient.
- **Foggy:** cooling air near the surface to the dew point.

D.Causes of Weather

Weather refers to the short-term state of the atmosphere at a particular place and time. It is mainly caused by several interacting natural factors.

- **Uneven Heating of the Earth's Surface**

The Sun heats the Earth unevenly — the equator receives more direct solar radiation than the poles.This temperature imbalance creates differences in **air density** and **pressure**, which drive air movements.

- Warm air is lighter and rises.
- Cold air is heavier and sinks.
  These vertical and horizontal movements form wind patterns and circulation cells.

- **Air pressure**

Air pressure is the weight of the atmosphere pressing down on the Earth's surface.

- High-pressure systems: air sinks, skies are usually clear and dry.
- Low-pressure systems: air rises, cools, and condenses, leading to clouds and precipitation.

- **Humidity and water vapor**

Water evaporates from oceans, lakes, and soils, entering the atmosphere as water vapor. When this humid air cools, it condenses into tiny droplets, forming clouds and eventually precipitation.

- **Wind and Air Movement**

Winds result from differences in air pressure. Air moves from high-pressure areas to low-pressure areas.
These movements transport heat and moisture, changing local weather conditions.

- **Air Masses and Fronts**

An **air mass** is a large body of air with uniform temperature and humidity.
When two air masses meet, they form a **front**:

- **Cold front** → thunderstorms, rain, drop in temperature.
- **Warm front** → light rain, gradual warming.
- **Stationary front** → long-lasting cloudy or rainy weather.

- **Geographical and Seasonal Factors**

Several environmental factors modify weather patterns:

- **Topography (mountains, valleys)** affects air flow and rainfall (orographic effect).
- **Oceans** moderate temperature and increase humidity.
- **Latitude** determines solar angle and intensity.
- **Seasons** (caused by Earth's tilt) create cyclic changes in temperature and precipitation.

- **Long-term Influences (Climate Change)**

Although weather is short-term, long-term climate changes (like global warming) influence the **frequency** and **intensity** of extreme events — storms, droughts, heat waves, etc.

E.Examples of weather types

The frequencies of similar combinations over a limited period constitute what is called **"weather types."**
The study of weather types aims to define the interactions between climatic elements and their combined influences. Thus, it helps to properly explain climatic issues by considering the overall states of the atmospheric environment.The concept of weather type is understood on a **regional scale**.When studying weather types, it is essential to define the **air masses** as well as the **centers of action** that operate and are closely linked to these weather types.
For this purpose, we will examine the **air masses** that occasionally affect our region, as well as the **centers of action** related to these weather types.

- **Air masses**

The formation of an air mass is a **geographical process** in which the effects of latitude, continentality, and topography combine. It requires a **homogeneous environment**; therefore, air masses do not form in regions of contact between sea and land, nor in mid-latitudes where the atmosphere is constantly disturbed. Consequently, **northern Algeria**, located at the junction between the **Mediterranean Sea** and the **African continent**, does not represent a region favorable to the formation of air masses. On the contrary, it is a **zone of passage and transformation**, receiving the incursions of **foreign air masses** formed in other, more or less distant, regions. These air masses are presented in Table.1.

Table1. **types of air masses**

Air masses	Region of origin	Seasons of occurrence
Tropical continental warm	Sahara	All four seasons
Tropical maritime warm	Atlantic Ocean	All four seasons
Polar continental cold	Central Europe	Winter
Polar maritime cold	Atlantic Ocean	Winter
Cool Mediterranean air	Outside the Mediterranean, but modified by it	Summer – Winter

We can therefore distinguish **five types of air masses** that affect and are directly related to the weather types influencing **northern Algeria**.

1. Cold air masses

• Cold maritime polar air (Pmk):

This air mass originates over the **northern Atlantic Ocean**. It enters the **Mediterranean**, then reaches **Algeria** via the **south of France** or the **east of Spain**, thus arriving from directions between **NW and N**. Its wind blows strongly and sometimes in gusts. It is most frequent during **winter**.

As it crosses the Mediterranean, being much **colder than the sea surface**, it causes a **drop in temperature** and **moderate to strong atmospheric instability**, often resulting in **showers**. The clouds accompanying this air mass are of the following types: **Cirrus, Cumulus,**

Altocumulus, Stratocumulus, or **Nimbus**, producing **showery precipitation**, sometimes accompanied by **hail** or **snow** at high altitudes.

This air becomes **more humid** when it travels a long distance over the Mediterranean before reaching Algeria.

In **summer**, the Pmk **warms** as it passes over the **Iberian Peninsula** or **Western Europe**, and upon crossing the Mediterranean, it becomes **warmer than the sea surface**, resulting in **clear and stable weather**.

• Cold continental polar air (Pck):

This polar air mass generally moves in a **cyclonic direction**, like the maritime air mass, but it is characterized by its **source region** located in **northeastern Europe**. It reaches **Algeria** from **N or NE directions**, after crossing the **central Mediterranean basin**.

In **winter**, at its origin, this air mass is **dry, cold, and stable**. It **slightly warms** as it crosses the Mediterranean and, more importantly, **absorbs moisture**, becoming loaded with **water vapor**. As a result, it **loses its stability** and becomes **unstable** due to **surface warming** and **increased humidity**.
Cumulus and **Cumulonimbus** clouds develop, leading to **sudden showers**.

In summer, the continental polar air mass, which is more frequent than Pmk, is characterized by its stability and fair weather.

2. Warm Air Masses

Warm air masses are always of either maritime or continental origin. Their sources are located near the Azores or the great Sahara.

• Warm Maritime Air Masses (Tmw):

These air masses originate near the Azores and the Canary Islands in the Atlantic Ocean, around the 30th parallel. They enter the Mediterranean through Gibraltar and reach Algeria from directions ranging between south and southwest.

Originally, they are humid and stable, but they may lose some of their stability during their movement. Their winds blow regularly in both direction and strength at low altitudes. In general, these masses are characterized by clouds arranged in horizontal layers, taking the form of *stratus*, *stratocumulus*, and *cirrostratus*.

They occur infrequently in eastern Algeria; however, in the western regions and especially over the Moroccan Atlas, they are very frequent.

In winter, they come into contact with the polar air already present over the Mediterranean, creating disturbances over the western regions. These disturbances then move eastward, sometimes accompanied by showers.

In summer, the Mediterranean Sea is warmer than the neighboring Atlantic regions. As a result, air moves from the Atlantic toward the Mediterranean basin. This air warms from below and generally produces *cumulus* clouds that are not sufficiently developed to cause rainfall.

- **Warm Continental Tropical Air Masses (Tcw)**

These air masses normally form over the central and eastern Sahara. They produce air characterized by high temperature and dryness. They come from directions between south and southeast and generate winds known as the *sirocco*.

In winter, the continental tropical air is warm and stable due to the lack of relative and specific humidity, even though the temperature gradient is quite strong. It forms the warm sector of Saharan and Mediterranean disturbances. The accompanying clouds are rare and of the *altocumulus lenticularis* type. When there is sufficient humidity at higher altitudes, these clouds can develop vertically and produce rain or stormy showers. Occasionally, this air may contain very fine sand suspended up to high altitudes.

In summer, the hot Saharan air is extremely dry and causes sandstorms whose influence extends beyond the Sahara region and can reach the northern edges of the Mediterranean.

Obviously, this air does not produce any precipitation over our region, but once it has crossed the Mediterranean, where it absorbs some humidity, it brings rainfall to the northern coasts of Italy or France. This air generates the most harmful winds for Algeria.

3. Mediterranean Air Masses

The limited surface area of the Mediterranean Sea and its position between the African and European continents do not provide ideal conditions for the formation and generation of air masses. However, when a polar air mass remains over this sea for a sufficiently long period, it gradually loses its original polar characteristics and acquires the properties of warm, humid tropical air. Thus, the Mediterranean air mass is a **modified air mass**.

The conditions favorable for the formation of this air mass are closely linked to an **anticyclonic situation** over the Mediterranean Sea.

The winds associated with this air mass reach Algeria from the **north and northeast** directions.

In **winter**, when Mediterranean air is lifted by cold air invasions, orographic effects, or the diurnal heating of the land, it produces **local showers**.

In **summer**, Mediterranean air is more frequent; it can produce **fog along the coasts** and strengthens the **sea breeze**, which can be felt tens of kilometers inland. Its **specific and absolute humidity** are high; its **temperature** is lower than that of the ground during the day and higher at night.

In general, Mediterranean air masses circulate in an **anticyclonic direction**, which means they are characterized by **low activity** and rarely extend beyond the Tellian Atlas mountain ranges. As a result, their influence is concentrated in the **coastal regions**, where they are most often associated with **fair weather**.

- **Fronts**

The concept of air masses implies the **discontinuity** that arises from the meeting of two or more air masses of different origins, ages, or trajectories. These **zones of separation** are called **"fronts."** Most often, these fronts are **short-lived**, but they can persist permanently in certain regions (for example, the **polar front** over Western Europe).

The analysis of **synoptic charts of Algeria** over a long period has made it possible to identify the following **semi-permanent fronts**:

• **The Afro-Mediterranean front** separates Saharan air from Mediterranean air; it coincides with the Atlas mountain range.

• **The Atlantic-Mediterranean front** separates Atlantic air from Mediterranean air.

Most of these semi-permanent fronts are particularly noticeable in **winter**, between the **thermal anticyclone** that forms over the Algerian high plateaus—where tropical air flows outward—and the **polar air** originating from the **Azores anticyclone**.

The regions where the same arrangements of **isobaric lines** are constantly formed are called **centers of action**. There are **centers of action at low altitudes** and **centers of action at high altitudes**. In each of these categories, we distinguish:

- **Cyclonic centers** (negative centers)
- **Anticyclonic centers** (positive centers)

Example of a positive center: The **Azores Anticyclone**, a permanent high-pressure zone that extends over the central Atlantic in the region of the Azores Islands. It is one of the sources of **westerly winds** that reach North Africa.

Example of a negative center: The **Mediterranean Sea** during winter and spring, when its water surfaces become warmer than the surrounding continents.

The **centers of action at high altitude** are due to the **zonal circulation of the atmosphere**.

The **weather types in Algeria** depend closely on the processes that occur at high altitude. The **temperate circulation** always governs the weather in Algeria.

An examination of **synoptic charts from the B.Q.E.M.** shows that each configuration of **isobaric systems** corresponds to a well-defined atmospheric state, known as a **"weather type."**

Thus, the **weather types** are simply combinations of atmospheric elements acting as a whole. There are **cyclonic weather types** and **anticyclonic weather types**.

The table below (Table.2) presents the **main weather types in Algeria.**

Table 2: Types of winter and summer weather according to HALIMI (1980) in Algeria

Semester	**Regimes**	**Weather Types**	**Characteristics**
Winter	**Anticyclones**	1)North-East 2)South 3) West	Calm and cold Dry and warm Humid
Winter	**Cyclones**	1) Tyrrhenian depression 2) Westerly current 3) South-West current	Bad and very cold weather Rainy and humid Unstable and humid weather
Summer	**Anticyclones**	Mediterranean	Mild and fair weather
Summer	**Cyclones**	Southern current and Sirocco	Very hot and overcast

I.1.3.2. Climate

"Climate is what you expect, weather is what you get" (e.g., Geographical Association and London Geographical Institute, 1902; Lorenz, unpublished). Or: "Climate is the statistics of weather". Public discourse and scientific literature frequently use versions of these colloquial sayings. It is easy to agree with such statements as climate and weather have meaning for most people. Everybody experiences weather and most have, likely, a grasp on the notion of different climates. This is despite that the concepts of 'climate' and 'weather' developed over centuries in different cultural contexts (Barnes, 2003).

The references mentioned above all use variations of the colloquial saying and may refer to different aspects of climate. Nevertheless most people will understand the intentions already without a more thorough definition. Indeed, some may see the question of how to best or correctly define 'climate' as purely academic or philosophic. However, climate is a topic of policies, and discussions on policy benefit from clarity of the topic. Werndl (2015) points to the problems that may arise from a lack of clarity in talking about climate. Depending on their definition of 'climate', correspondents may come to differing conclusions about the seriousness of climatic changes. The thing called 'climate' in a conversation even may not be climate at all. On the other hand, we use the term 'climate' in various contexts that refer to different temporal and/or spatial scales. 'Climate' has colloquial, scientific, philosophical, and political meanings. Already in this introduction, the use of ‘climate’ and climate may confuse. One refers to the word and the concept, the other to its realisation.

A. Definitions of climate

In this everyday sense, a definition of ‘climate’ has to account for scientific and policy purposes but also for individual views. It should allow for classical climate classification and modern perspectives and the development from the former to the latter (Heymann, 2009). It is important to distinguish between the template definition of ‘climate’, which represents the concept, and the instances of climate, that people deal with. The colloquial formulation represents the concept validly but springs from individuals’ views of their specific instances. Generally, public discussions mostly deal with specific instances. Therefore one needs to rigorously specify the instance of current interest. Naturally one turns to the International Panel on Climate Change (IPCC) for a definition of ‘climate’.

Their fifth Assessment Report (IPCC, 2013) takes the view that “Climate in a narrow sense is usually defined as the average weather, or more rigorously, as the statistical description in terms of the mean and variability of relevant quantities over a period of time ranging from months to thousands or millions of years.

The classical period for averaging these variables is 30 years, as defined by the World Meteorological Organization. The relevant quantities are most often surface variables such as temperature, precipitation and wind. Climate in a wider sense is the state, including a statistical description, of the climate system.”

Climate in both senses are instances of a common template. The American Meteorological Society (AMS) (2016) describes climate in a similar way (last modified in the year 2012) as “the slowly varying aspects of the atmosphere–hydrosphere–land surface system. It is typically characterized in terms of suitable averages of the climate system over periods of a month or more, taking into consideration the variability in time of these averaged quantities. . . ” As a sidenote concerning the observable climate, Lovejoy and colleagues suggest to replace the dichotomy in terms of temporal variability between weather and climate with a weather-macroweather-climate trichotomy (Lovejoy et al., 2013). The expected state is the macroweather and climate is its evolution at longer timescales. Combining this with the AMS definition, AMS-climate becomes Lovejoy-macroweather, and Lovejoy-climate is the AMS’s “variability in time of these averaged quantities”.

Many authors presented their views on the concept of ‘climate’. Todorov noted in 1986 a lack of “agreement among climatologists on the definition of the term climate” (Todorov, 1986). A similar notion motivated Bryson’s essay on climatology (Bryson, 1997). He distinguishes between Climate (upper-case) and climate (lower-case). In his definition Climate is “the thermodynamic/hydrodynamic status of the global boundary conditions that determine the concurrent array of weather patterns.” Lower-case climate is “the statistical characteristics of the weather assemblage at various places, or “typical weather” ”. Lower-case climate agrees with the common dictum. The opening of Von Storch and Zwiers (2001) emphasizes the origins of climatology by stating “Climatology was originally a sub-discipline of geography, and description of the climate consisted primarily of estimates of its mean state and estimates of its variability about that state. The paradigm of climate research evolved towards an understanding of the dynamics of climate statistics plays an important role in this new paradigm.” According to them, ‘climate’ is a description of the climate system in terms of statistics as also the IPCC writes (IPCC, 2013). The descriptive climatology and the physical and chemical concepts of the atmospheric sciences may provide different perpectives for a definition.

In turn, Werndl (2015) and Frigg et *al.* (2015) arrive at preferred definitions which state that ‘climate’ is the distribution of climate variables “over time for regimes of varying external conditions”. This is similar to Bryson’s view (Bryson, 1997). These authors and further colleagues still conclude in Bradley et al. (forthcoming) that “defining climate is nontrivial and there 10 is no generally accepted or uncontroversial definition of climate”.

B. The Climate system

Regarding instances of climate on our planet, variables of interest are part of the climate system or more comprehensively of the earth system. They are relevant and specific for the instance of interest at its location and on its time-scales. They describe a state which extends beyond atmospheric processes of purely meteorological interest. Summarising descriptions of the data give us the statistics of weather, e.g., the distributions of these variables. Our knowledge about these is uncertain. Compartments of Earth’s climate system are the atmosphere, the hydrosphere, the cryosphere, the biosphere, the lithosphere (IPCC, 2013). A description of the system’s behavior may have to employ thermodynamics and fluid dynamics but also electromagnetism, rheology, and plasma physics besides statistics.

Then, ‘climate’ is a description of part of a system. It involves potentially multiple elements or just a single property of the system in question. It may include elements of any individual compartment of the system or all together as long as they are relevant. Other parts and their variations may be seen as extrinsic of the climate but interact with it. Such external influences and external boundary conditions are climate forcings. In certain instances, we may consider them internal, or they may originate from internal processes. ‘Climate’ depends on extrinsic influences, which are also varying in time (and potentially in space). The ‘typical weather’ (Bryson, 1997) or the possible weather for a certain location depends on the behavior of the system’s compartments and external factors. Each compartment may depend on different external conditions but ideally it should be a common set for all.

Dependent on the specific temporal and spatial scales, the geographic specifics of the location or its surroundings differ. The climate depends on its own geographic properties and its surroundings. For example, the distribution of land, ocean, and ice-sheets conditioned a different climate for the location of the city of Hamburg in Germany 10,000 and 20,000 years ago than today's configuration. Changes in land cover or land use alter the climate.

The definition of 'climate' has to allow for such influencing factors. For specific instances such factors may be considered intrinsic parts of the climate although some may indeed be external. For example volcanic eruptions may change the composition of the atmosphere and thus change the expectations. Processes at the surface may change the atmospheric composition. Additional 'forcings' are changes in the path on which the celestial body of interest travels around its star or variations in the composition and power of the radiation from the star or cosmic rays reaching the celestial body.

The human sphere also influences the climate system on Earth. Climate variability and climate change describe the variations of the climate. Changes are usually considered slow and refer to detectable differences between climate statistics due to processes which we often but not necessarily may consider external to the climate system. Climate variability are faster variations within the reference time-frame which are usually thought to be intrinsic to the system and do not change the full multivariate distribution. That is, climate as the full probability distribution of certain properties in question is a distribution over the temporal variations at one or more locations dependent on extrinsic influences that are also varying and that influence the climate's evolution.(Bothe,2018)

The climate is an estimate for a specific time-frame. It varies in time and can change over time with the time-frame. If I change the specific period of interest I obtain another instance of climate. Both distributions may be virtually identical or I may be able to detect that the probability of a certain event has clearly changed between both periods. Time-periods may overlap. It is important to allow for gradual changes. If statistics differ over a time period of interest from the distribution over a reference period, one speaks of change. Regarding climate forcings, climate variability, and climate change, a slight excursion is in place.

Werndl (2015) and Frigg et *al*. (2015) express concerns considering the robustness of classical views on climate to sudden shocks to the system. These authors define 'climate' and changes to it over different 'regimes' of external conditions. This regime view accounts for the desired property of a definition that we can undoubtedly identify different climates. However, climate changes transiently, and defining 'climate' and its change for regimes excludes the possibility of gradual changes. The regime view appears to only consider climate states in equilibrium. Furthermore, it is dubious, how observers can define the instance of climate directly after a sudden forcing shock.

Processes internal to an instance of the climate system result generally only in variability of an instance of climate. Processes external to the instance of the system can change our instance of climate. However, external influences may not result in identifiable changes, while certain internal processes may change the instance of climate under consideration. For the sake of defining 'climate', it may be necessary to include the external forcings in the instance of climate or at least consider any instance only with an associated instance of forcings. Both groups of properties vary gradually.

The climate system includes an interconnected group of subsystems, or spheres: the atmosphere, the hydrosphere, the cryosphere, the biosphere, and the lithosphere (sometimes also called the geosphere).

- The compositions, structures, and circulation processes of the subsystems, as well as the interactions between subsystems, are factors that affect how Earth's climate system responds to external climate forcings over different timescales and spatial scales. These and other characteristics and internal processes of each subsystem affect the storage or transfer of energy, water, and carbon in the climate system.

- The lower two layers of the atmosphere—the troposphere and the stratosphere—are most directly involved in Earth's climate system. Carbon dioxide and water vapor as greenhouse gases, and in the carbon and water cycles, affect the habitability of the planet and climate variability. Aerosols and greenhouse gases affect the energy balance and therefore global temperatures. Atmospheric circulation redistributes heat, drives large-scale precipitation patterns, and is a primary factor influencing surface ocean circulation.

- The hydrosphere is dominated by the global ocean, which is a major player in the transfer and storage of heat, carbon and other nutrients, and oxygen within the Earth system. Physical and chemical properties of sea water, especially temperature, salinity, and dissolved gases, affect the ocean's structure, circulation, and habitability for marine life. The currents of the surface ocean and deep ocean redistribute heat across the planet and influence the acidity and oxygenation of the deep ocean. High-latitude ocean regions are particularly sensitive areas that affect overturning circulation of the entire ocean.

- The cryosphere is composed of the various forms of frozen water (ice) present at, or near, Earth's surface, including ice sheets, mountain glaciers, snow and ice fields, sea ice, and permafrost (frozen ground). The cryosphere affects the climate system in several ways: the size of glaciers and ice sheets affects global sea level; the high reflectivity of snow and ice impacts the planet's energy balance; the volume of water in ice sheets affects the global water cycle; and carbon stored in permafrost affects the carbon cycle and thus global temperatures.

- The geosphere is composed of the nonliving materials that form the "solid Earth": soil, sediment, and rock near the Earth's surface as well as geologic materials in Earth's interior. The composition of the geosphere, as well as tectonic and weathering processes that move the materials through the rock cycle, impacts the climate system over short and long-time periods especially by influencing boundary conditions and the carbon cycle, which in turn affect the energy balance of the planet.

- The biosphere is composed of all living organisms on Earth. The biosphere plays a role in Earth's surface energy budget primarily by affecting albedo and on the carbon cycle through photosynthesis and respiration, which are evident in the seasonal cycles of CO_2 in the atmosphere.(Fig.2)

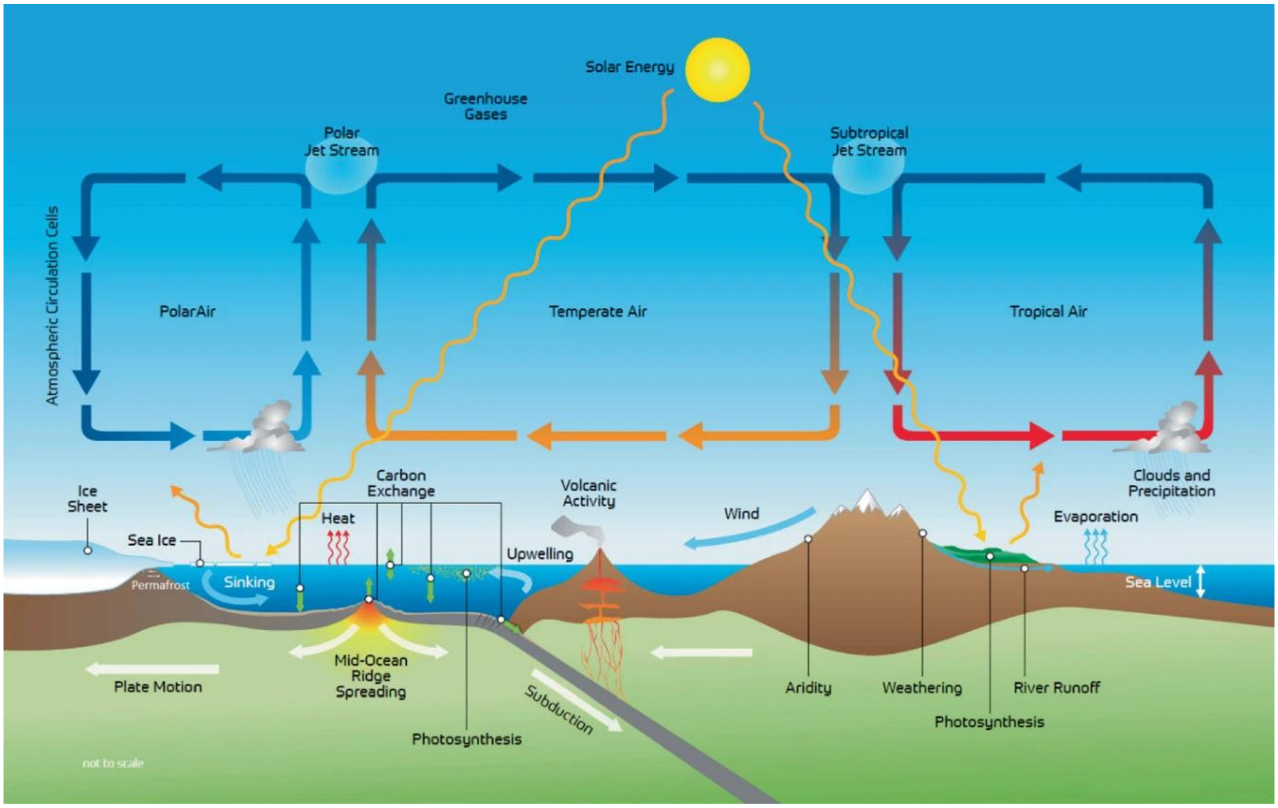


Figure.2. Representation of the Earth's climate system, which includes five subsystems: the atmosphere, hydrosphere, cryosphere, biosphere, and geosphere (sometimes also called the lithosphere). The Earth's climate system also includes processes and interactions among these systems. The cycling of energy, water, and carbon are three processes that are particularly important in Earth's climate system. This representation of the Earth's climate system shows one hemisphere; the equator would be on the right margin of the diagram. Illustration by Geo Prose. From Koppers and Coggon (2020)

C. The scales of climate

In climatology, it is necessary to clearly specify the spatial scale and the temporal scale chosen. The representative values of climatic elements depend on the period and the spatial domain studied.

In climatology, it is customary to define four main spatio-temporal scales, associated with four terms designating climate:

- **The global or planetary scale:** associated with the term *"global climate"*

- **Time scale:** one week and longer.
- **Spatial scale:** from 10,000 kilometers to the entire globe.

To describe processes and phenomena that extend throughout the whole atmosphere, they are referred to as hemispheric-scale or global-scale phenomena. Examples include seasonal changes occurring simultaneously across the globe, the general circulation of the atmosphere, and the exchange of energy by radiation between the Earth and the surrounding space.

- **The large scale or synoptic scale:** associated with the term *"regional climate"*

- **Time scale:** 12 hours to one week.
- **Spatial scale:** 100 to 10,000 kilometers.

Synoptic-scale or large-scale phenomena include, for example, depressions (low-pressure systems) moving along with their frontal systems.

The extent of each regional climate is variable and depends on factors such as topography and proximity to oceanic areas.

- **The medium scale or mesoscale:** associated with the term *"topoclimate"* or *"local climate"*

- **Time scale:** 1 to 12 hours.
- **Spatial scale:** 1 to 100 kilometers.

At this scale, climate is influenced by the geographical arrangement of the relief or topography. Mesoscale processes generate thunderstorms and tornadoes, as well as phenomena such as land and sea breezes and the formation of lenticular clouds over mountain peaks.

The small scale or microscale: associated with the term *"microclimate"*

- **Time scale:** 1 second to 1 hour.
- **Spatial scale:** less than one kilometer.

Phenomena observed at a specific location are small-scale phenomena, such as heating or cooling on a building wall, evaporation above a water body that alters the characteristics of the overlying air mass, cooling beneath a tree during calm daytime conditions, or mechanical turbulence generated by a small grove of trees, among others.

- **The climatic scales in viticulture**

A systemic approach to the assessment of climatic variability at the local scale (a wine region) will imply a consideration of the structure of the main natural components: - atmosphere (clouds, wind…) - topography (slope, altitude…) - water surface (ocean, river…) - vegetation (forests, cultures…) - anthropogenic actions (roads, buildings, human activities…), considering that these components are interdependent (Quénol, 2013). To study climate, scientists consider mainly three scales: - macroclimate at the level of a country-big region - mesoclimate at the level of a vineyard or a group of vineyards - microclimate at the level of a vine (canopy and/or bunch zone) .While trying to understand the climatic effects (i.e. the effect of abiotic factors such as water, light, temperature) on grapevine physiology, berry development-composition/ripening & wine styles, the preferred scale is the microclimate (generally in association with mesoclimate). Climatic & physiological studies required the right sensors, to collect-store the data & to be able to properly analyse-interpret the information. Day and night temperatures matter. A vine is able to transpire overnight (Rogiers et al., 2009; Dayer et al., 2021), & some genes involved in berry ripening are expressed only during nights (Rienth *et al.,* 2014). (Fig.3)

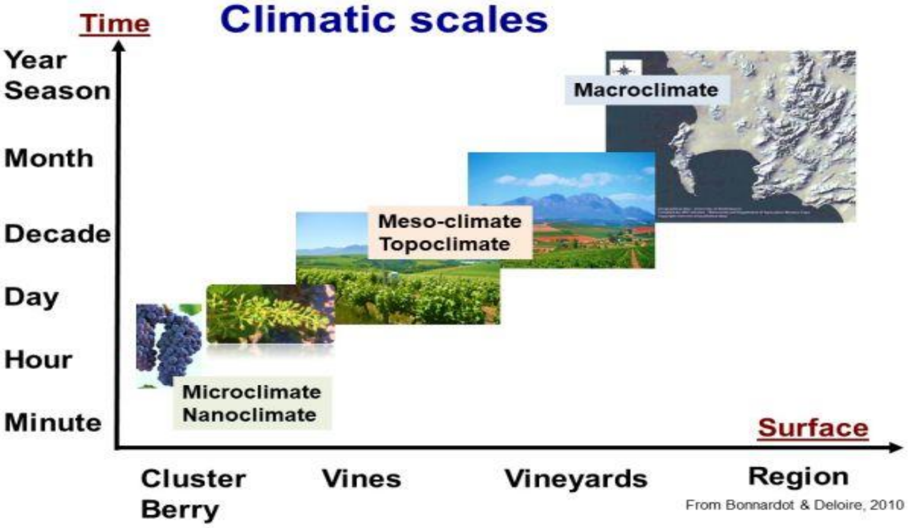


Figure 3. Climatic scales (Bonnardot and deloire.2010)

- **Climate analysis at local scale in the context of climate change**

Since the late 1980s, the international scientific community has been focusing on global climate change and questioning its future impacts at the planetary scale. The various reports of the IPCC (Intergovernmental Panel on Climate Change) have warned the international community about an increase in temperature as well as in the frequency and intensity of climate hazards worldwide [IPCC, 2007]. Although many uncertainties remain regarding the magnitude of climate change and its consequences, improvements in the reliability of General Circulation Models (GCMs), together with the positive correlation between greenhouse gas (GHG) emissions and rising temperatures over recent decades, suggest that global warming will range between 2 and 6 °C (depending on scenarios and models) by 2050–2100 (Pachauri and Reisinger, 2007).

Impacts on humans and territories, at both global and regional scales, estimated from GCMs indicate an increase in climate-related disasters, droughts, and in the frequency and intensity of heat waves, among others. These changes could have serious consequences for ecosystems and societies, particularly in terms of food security, malnutrition, and quality of life. The first results of these research programs were obtained mainly through numerical modeling, based on international collaborations among atmospheric physicists, geophysicists, and environmental scientists. Although climate simulations operate at relatively large scales, significant progress has been made in improving the resolution of model outputs.

As noted by Le Treut [2010], “despite the convergence of models toward largely shared results that appear significant at large scales, two types of uncertainty remain, relating both to the magnitude and to the localization (in time or space) of the expected effects. It is still impossible to answer precise questions such as: what will be the most significant local impacts and how can we protect ourselves against them? Improved forecasting of local climate changes therefore represents a major challenge in order to mitigate and adapt to changes of which a part is unavoidable.”

In the context of climate change, many uncertainties remain regarding the temporal and spatial accuracy of future simulations and, consequently, the adaptation methods to be recommended. Although contemporary global warming is characterized by a more pronounced increase in temperatures over recent decades, the climate has always experienced variations over shorter or longer timescales.

The analysis of local climates at the nature–society interface can help propose adaptation strategies to the current climate and to future climate conditions, based on local climate variability. Fine-scale analysis of the present climate highlights strong climatic variability over small areas. This variability is linked to the influence of local characteristics such as topography or various obstacles shaping the environment. A systemic analysis of local climate that accounts for the nesting of spatial scales makes it possible to observe and model the strong variability of climate at fine scales.

With the aim of studying the impacts of climate change at local scales, whether through measurements or modeling, the scientific approach consists of analyzing the spatial and temporal variability of climate in order to study local climates in relation to the human activities concerned, while providing local-scale data that contribute to improving the spatial resolution of models, particularly through data validation (Quinole, 2013).

The many physical processes in the Earth's climate system span a vast dynamic range, both in space (from 10^{-3} to 10^{7} m) and time (from seconds to millions of years) . Williams et al. (**2017**) provide a census of atmospheric processes, the variability of which range from seconds to decades. In the climate system, we typically deal with the following physical processes and associated scales: turbulent eddies on time scales of a few seconds and length scales of millimeters to centimeters, convective activity on temporal scales of hours and spatial scales of hundreds of meters to a few kilometers, synoptic weather systems varying diurnally on spatial scales of hundreds to thousands of kilometers, large-scale teleconnection patterns with an intraseasonal to interannual temporal variability and spatial scales that can span an entire hemisphere, the coupled atmosphere-ocean system which varies from decadal to centennial time scales and a global spatial scale, and the ice ages that represent global variations on millennial time scales.

The main four components of the climate system (atmosphere, ocean, land, and cryosphere) tend to operate on different time scales that interact nonlinearly with each other creating a plethora of interesting effects and feedbacks (Williams *et al*., **2017**).

Fig 4, illustrates the relationship between **spatial scales** (horizontal axis) and **time scales** (vertical axis) of atmospheric processes. It shows how different meteorological and climatic phenomena occur at different sizes and durations.

- **Horizontal axis (Spatial Scales):**
  Ranges from **microscale** (very small, up to a few meters) to **global scale** (thousands of kilometers).
- **Vertical axis (Time Scales):**
  Ranges from **seconds and minutes** to **centuries and millennia**.

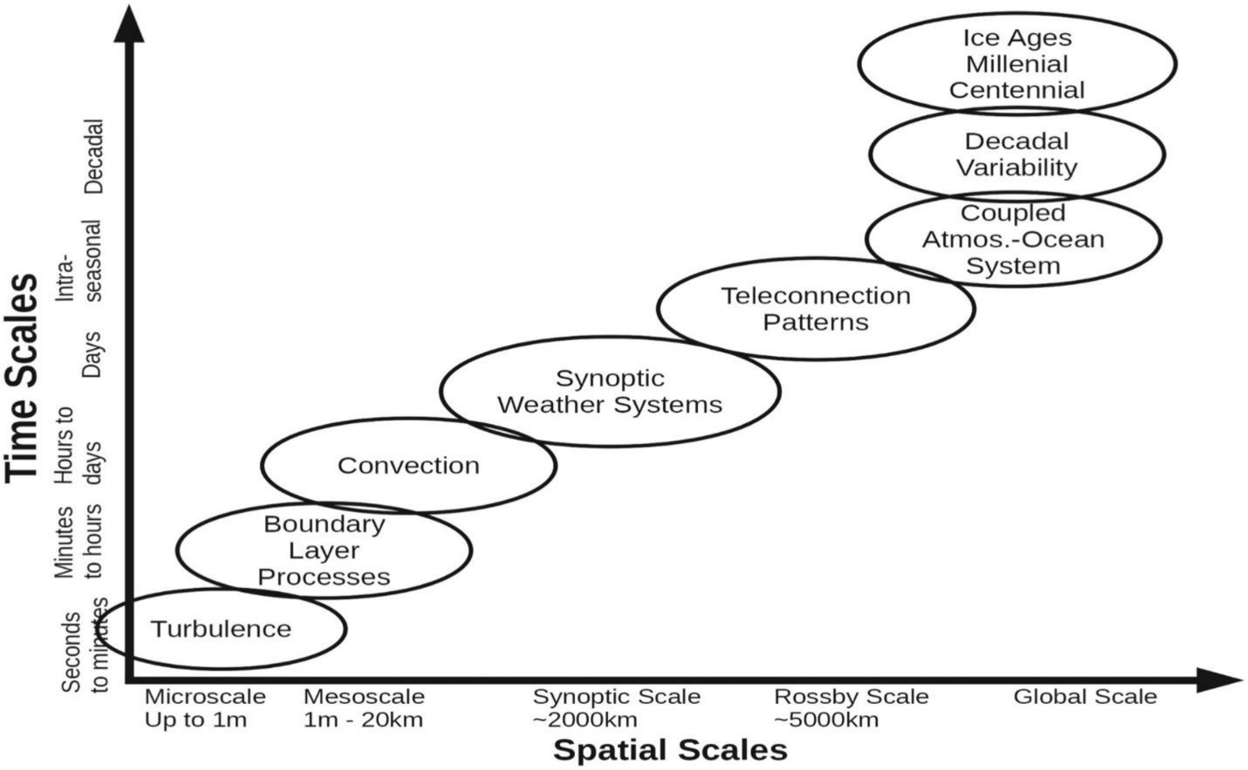


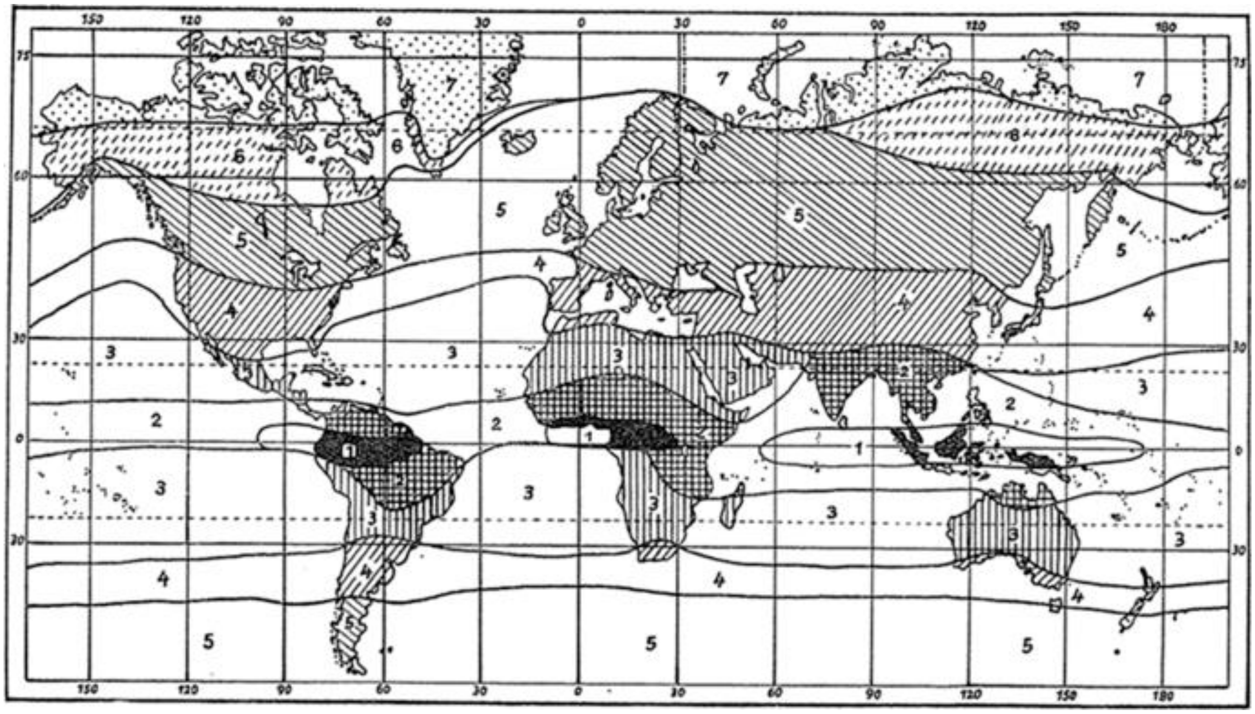
Figure.4. global variations on millennial time scales (Fortak 1982).

D.Types of climate and climate zones

Different parts of the globe have different climates. In northern countries, when people look out of the window during winter and see snow everywhere, they are keen to go on holiday to tropical countries, where one can enjoy hot weather and swim in the warm sea all year round.

Since ancient times, scientists have divided Earth into climate zones depending on the height of the sun above the horizon and the length of the day. The word ‘climate’ comes from the Greek language, in which it refers to the angle of inclination of the sun. Differences in the climate are primarily because the sun’s heat is distributed unevenly over the Earth’s surface. Proximity to the sea, atmospheric circulation, patterns of precipitation and other so- called ‘climate-forming factors’ also have a major role in determining climate, and they, in turn, depend much on geographical latitude and on the height above sea level.

Areas with similar climates are like broad stripes encircling the globe. They are what scientists call ‘climate zones’ and they turn colder the further away they are from the equator (Fig. 5).



Alisov’s seven climatic zones (Alisov 1954). 1: Equatorial zone, 2: Subequatorial zone, 3: Tropical zone, 4: Subtropical zone, 5: Polar zone, 6: Subarctic zone, 7: Arctic/Antarctic zone

Figure 5. The Earth’s climates (Boris Alisov's 1954. Shimabukuro et al; 2023)

➢ Climate zones

The most well-known classification of climates was introduced by a German Russian climatologist Wladimir Köppen in 1884. He divided the climates into five main types: **A** – Tropical, **B** – Dry, **C** – Temperate, **D** – Continental, **E** – Polar and Alpine.

Another system of climate classification, commonly used in Eastern Europe, was created in the 1950s by the Russian scientist Boris Alisov (Fig.5). It defines four main climate zones in each hemisphere and three transitional zones.

The main climate zones are **equatorial, tropical, temperate, and polar (Arctic in the Northern Hemisphere and Antarctic in the Southern Hemisphere)**. They are the main climate zones since each is dominated throughout the year by the same air masses.

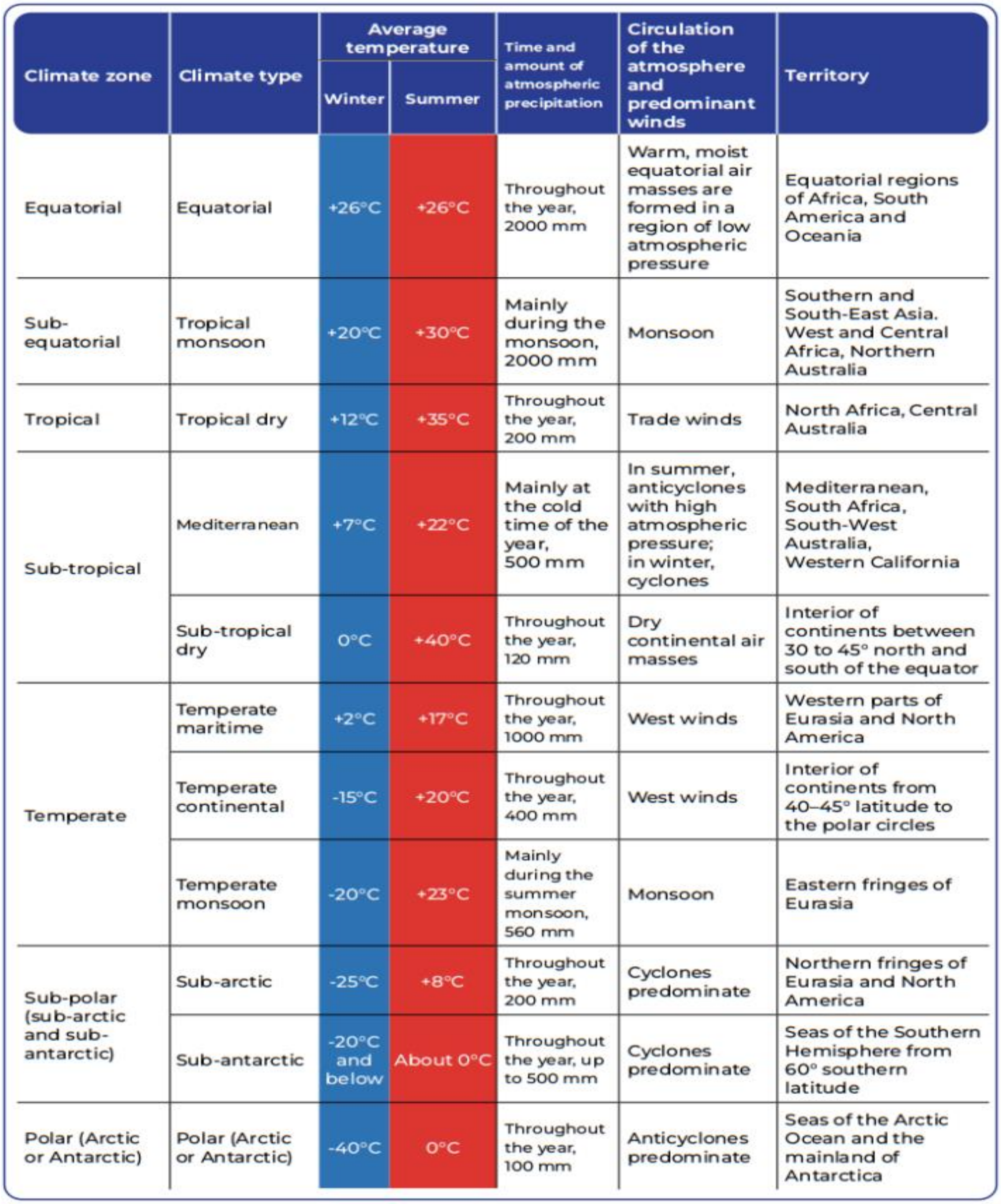
Between the main climate zones are the transitional zones: **sub-equatorial, sub-tropical and sub-polar (sub-Arctic in the Northern Hemisphere, and sub-Antarctic in the Southern Hemisphere)**. All the names of transitional climate zones have the prefix 'sub', which in Latin means 'under'.

The air masses in transitional climate zones change with the seasons, entering them from neighbouring zones at various times of the year. For example, in a sub-tropical climate the summer is hot, like in the tropics, but the winter is cool, since the tropical air mass is displaced by an air mass from the temperate zone.

Some climate zones contain specific climate regions with a **continental, maritime or monsoon** climate (See Table 3).

The seasons in the southern and northern hemispheres are directly opposite: from December to February, when it is winter in the Northern Hemisphere, the Southern Hemisphere is in the midst of summer, and when the Northern Hemisphere is at its coldest, the Southern Hemisphere is at its hottest.

Table 3: Climates of Earth (by Boris Alisov 1954. Shimabukuro et al; 2023)



Climate zone	Climate type	Average temperature		Time and amount of atmospheric precipitation	Circulation of the atmosphere and predominant winds	Territory
		Winter	Summer			
Equatorial	Equatorial	+26°C	+26°C	Throughout the year, 2000 mm	Warm, moist equatorial air masses are formed in a region of low atmospheric pressure	Equatorial regions of Africa, South America and Oceania
Sub-equatorial	Tropical monsoon	+20°C	+30°C	Mainly during the monsoon, 2000 mm	Monsoon	Southern and South-East Asia. West and Central Africa, Northern Australia
Tropical	Tropical dry	+12°C	+35°C	Throughout the year, 200 mm	Trade winds	North Africa, Central Australia
Sub-tropical	Mediterranean	+7°C	+22°C	Mainly at the cold time of the year, 500 mm	In summer, anticyclones with high atmospheric pressure; in winter, cyclones	Mediterranean, South Africa, South-West Australia, Western California
	Sub-tropical dry	0°C	+40°C	Throughout the year, 120 mm	Dry continental air masses	Interior of continents between 30 to 45° north and south of the equator
Temperate	Temperate maritime	+2°C	+17°C	Throughout the year, 1000 mm	West winds	Western parts of Eurasia and North America
	Temperate continental	-15°C	+20°C	Throughout the year, 400 mm	West winds	Interior of continents from 40–45° latitude to the polar circles
	Temperate monsoon	-20°C	+23°C	Mainly during the summer monsoon, 560 mm	Monsoon	Eastern fringes of Eurasia
Sub-polar (sub-arctic and sub-antarctic)	Sub-arctic	-25°C	+8°C	Throughout the year, 200 mm	Cyclones predominate	Northern fringes of Eurasia and North America
	Sub-antarctic	-20°C and below	About 0°C	Throughout the year, up to 500 mm	Cyclones predominate	Seas of the Southern Hemisphere from 60° southern latitude
Polar (Arctic or Antarctic)	Polar (Arctic or Antarctic)	-40°C	0°C	Throughout the year, 100 mm	Anticyclones predominate	Seas of the Arctic Ocean and the mainland of Antarctica

- **A brief description of different climates**

Equatorial climate

An equatorial climate is marked by hot and moist equatorial air masses. Air temperature is constant (+24–28°C) and there is much rain throughout the year (from 1500 to 5000 mm). Rain falls faster than water can evaporate from the ground, so the soil in an equatorial climate is waterlogged and covered by a dense and high rainforest. An equatorial climate is found in northern parts of South America, the coast of the Gulf of Guinea, in the Congo River basin and the headwaters of the Nile in Africa, over the greater part of the Indonesian archipelago and the adjacent parts of the Indian and Pacific Oceans in Asia.

Sub-equatorial climate

A sub-equatorial climate is marked by a rainy season in the summer, followed by a cool and dry season in the winter. Rainfall in a sub-equatorial climate is very uneven throughout the year. For example, Conakry (the capital of Guinea) receives just 15 mm of rain from December-March, but 3920 mm from June-September. This type of climate is found in some parts of the Indian Ocean, the western Pacific Ocean, as well as in South Asia and the tropical regions of Africa and South America.

Tropical climate

A tropical climate is dominated by anticyclones with high pressure, giving clear weather nearly all the year round. There are two seasons: warm and cold. Temperatures can vary from

+20°C on the coast to +50°C in the interior. The temperature can also vary greatly within a single day: on a summer afternoon the air heats up to +40–45°C but cools down at night to +10–15°C. Deserts are often found in tropical climates, and the largest is the Sahara Desert in Africa. Deciduous forests (forests that lose their leaves in the winter) and savannas are common in wetter regions. Mexico, North and South Africa, Central Australia and the Arabian Peninsula have a tropical climate.

Sub-tropical climate

A sub-tropical climate is found in regions between tropical and temperate latitudes, from about 30° to 45° north and south of the equator. They are marked by hot, tropical summers and cool winters. The average temperature in summer is above +22°C and in winter above -3°C, but the arrival of air from polar regions in wintertime may cause temperatures to drop to -10 to -15°C, and occasionally even as low as -25°C. This type of climate is typical for the Mediterranean, South Africa, Southwestern Australia and Northwestern California.

Temperate climate

A temperate climate is found in so-called temperate latitudes (from 40°–45° north and south of the equator as far as the polar circles). In the northern hemisphere more than half of the temperate zone is occupied by land rather than the sea. But 98% of the temperate zone in the southern hemisphere consists of ocean. A temperate climate is marked by frequent and severe weather changes due to cyclones. A temperate climate is characterized by four seasons, of which one is cold (winter), one is warm (summer) and the other two (spring and autumn) are transitional. The average temperature in the coldest month is usually below 0°C, and in the warmest month it is above +15°C. The ground is covered with snow in the winter. Prevailing westerly winds bring rain and snow throughout the year, with rainfall and snowfall varying from 1,000 mm in coastal areas to 100 mm deep inland.

Sub-polar (sub-Arctic, sub-Antarctic) climate

A sub-Arctic climate is found between Arctic and temperate climate zones in the northern hemisphere. This climate is marked by air masses at moderate temperature in the summer and cold air masses from the Arctic in the winter. The summers are short and chilly, with air temperature in July rarely above +15°C by day and dropping to 0°–+3°C at night, and frosty nights likely through the summer. In winter the temperature by day and night is -35°–45°C. The landscape in a sub-Arctic climate consists of tundra and forest tundra, the soil is marked by permafrost, and there are few plants and animals. The north of Russia and Canada, Alaska (USA), South Greenland and the far north of Europe have a sub- Arctic climate.

A sub-Antarctic climate is found in the southern hemisphere between the temperate and Antarctic zones. The greater part of the sub-Antarctic zone consists of ocean, with annual rain and snowfall up to 500 mm.

Polar (Arctic, Antarctic) climate

A polar climate is found to the north of 70° latitude in the northern hemisphere (Arctic climate) and to the south of 65° latitude in the southern hemisphere (Antarctic climate). Polar air masses are dominant all year round. The sun does not appear above the horizon for several months (this period is called the ‘polar night’) and during some other months it does not set beyond the horizon (‘midnight sun’ or ‘polar day’). Snow and ice reflect more heat than they absorb, so the air is very cold, and the snow never melts. Atmospheric pressure is high all year-round (anticyclone), so winds are weak and there are almost no clouds. There is very little snowfall, the air is full of small icy needles and a water haze often occurs in the summer. The average temperature in summer is below 0°C, and between -20°C and -40°C in winter. (Raschka and Mirjalili;2020).

Chapter II | Climatological Data

II.1. Meteorological Observations

In Algeria, the implementation of meteorological observations is a task assigned to the National Meteorological Office (ONM), which operates under the authority of the Ministry of Transport. Resulting from the restructuring of ENEMA, the ONM was created by Ordinance No. 75-25 of April 29, 1975, as an administrative public institution, and later transformed into a public industrial and commercial enterprise (EPIC) with scientific and technical purposes by Decree No. 98-258 of August 25, 1998. Its main missions consist of:

- Acquiring, processing, utilizing, and disseminating national and international meteorological data.
- Forecasting weather developments across the national territory and issuing warning notices to the public and various users (such as farmers).
- Conducting climatological studies, providing meteorological assistance, as well as monitoring climate change.

To ensure continuous monitoring of the atmosphere, the National Meteorological Office has established and operates a network of meteorological observation stations covering the country's different climatic regions. This network includes: 77 surface observation stations, 12 upper-air stations, 3 additional structures dedicated to research and special observations located in Tiaret, Ksar Chellala, and Tamanrasset, 5 meteorological radars, and over 400 climatological posts. In terms of anti-locust operations, the ONM also has a regional meteorological monitoring center in Tamanrasset, with 40 monitoring stations located in this southern province and 80 others spread across the national territory.

In addition to the consultation services it provides, the ONM maintains a database containing all climatic parameters on a national scale with variable time steps: hourly, daily, monthly, yearly, etc. This climatological database, with records dating back nearly 150 years and covering the entire country, is widely used by public and semi-public service users, national and international researchers, students, consulting firms, and various experts.

The information disseminated by meteorological services concerns three main areas (Soltner, 1999):

- The regular recording of meteorological observations, taken several times per day. These records provide useful information for farmers regarding past and recent weather conditions (in the past weeks or months), particularly with respect to rainfall, evaporation, and temperature.

- Weather forecasting, whether short-term (12 to 48 hours), medium-term (2 to 10 days), or long-term (from 1 to several months).

The description of the local climate is based on long-term established measurements, including: average temperatures, rainfall, evaporation, wind direction, duration of sunshine, number of frost days, etc. In addition to the National Meteorological Office, the National Agency for Water Resources (ANRH) operates a network of meteorological observation stations located within various hydraulic infrastructures across the country, mainly dams. There are also other institutions, including certain pilot farms, which are equipped with basic meteorological observation tools that vary depending on the type of crops: fruit trees, vineyards, horticulture, market gardening, cereals, etc.

The main historical data sources are:

The publication by Seltzer (1946), which provided the first synthesis of Algeria's climate for the period 1913–1938.

The works of Dubief (1959–1963), which offer similar advantages to Seltzer's results for stations in the northern Sahara.

The agroclimatic atlas (Ahdali, 1978), prepared for Arab countries, three volumes of which are dedicated to Algeria.

Finally, the climatological atlas published by the National Meteorological Office (ONM), which presents two main advantages:

It includes, for 48 professional stations, several meteorological parameters (rainfall, temperature, humidity, wind, atmospheric pressure, radiation, etc.).

It uses recent data.

To determine the climate of a station, a data series of at least 25 to 30 years is required, according to the standards of the World Meteorological Organization (WMO).

II.2. Measuring Instruments

II.2.1 Climatic Measurements in Conventional Stations

Ground-level measurements of meteorological variables such as temperature or humidity may yield different results depending on the environment surrounding the measuring instruments. For example, a thermometer that is not protected from sunlight will give incorrect values. To avoid such measurement errors, instruments are placed inside a meteorological shelter (Fig. 6), the Stevenson Screen (named after its inventor in 1864).

This shelter is a wooden box designed to minimize heat transfer, installed at 1.5 m above the ground. Its walls are made of white slatted panels to reflect solar radiation while allowing air to flow through. The slats ensure adequate air circulation, and the white color reflects sunlight, preventing the shelter from heating up and thus avoiding biased data.

Currently, atmospheric parameters are measured under strict conditions at varying time intervals (from seconds to daily). These physical atmospheric criteria mainly include measurements of temperature, precipitation, sunshine duration, air humidity, and wind.

Figure 6. Abri météorologique de STEVENSON

II.2.2. Automatic Measuring Station

This type of meteorological station is specifically designed to be installed in natural environments or in areas that are difficult to access. These stations are equipped with a **photovoltaic system (solar panel)** that provides the energy required for the operation of the

station. The main climatic parameters are measured and recorded in accordance with **WMO standards**, such as temperature, relative humidity, wind speed and direction, precipitation, as well as solar radiation and ultraviolet radiation.

The station is also capable of calculating several **agro-climatic parameters**, such as **ETP (potential evapotranspiration)**, **dew point**, etc.

The data collected by the meteorological station are initially stored locally; then, a simple phone call via the **GSM network** or a **satellite transfer** allows the retrieval of all data and their storage in a computer (Fig. 7).

Figure 7. Station météo autonome avec transmission par GSM DATA

II.2.3. Surface Measurements

II.2.3.1. Precipitation

Precipitation is known as all forms of water that reach the earth from the atmosphere. It is also defined as the process where water vapor condenses in the atmosphere to form water droplets that fall to the Earth in the form of rain, sleet, snow, hail, etc. Precipitation is the primary source of fresh water supply. There is a great variation of precipitation in space and time. In most parts of Ethiopia, atmospheric moisture (or weather system) causes good precipitation during the months of May up to September and nearly dry weather during the remaining periods. Some of the precipitation that might get intercepted while reaching the ground by trees and buildings and evaporates back is called the initial loss. The other part meets requirements like depression storage and infiltrates into the ground. The excess rainfall flows in streams to large water bodies. Factors like soil-type, vegetation, geology and topography of the area largely determine the quantity of rainfall excess available as stream flow from the precipitable water. Nearly one-fourth of the total precipitation that falls on land reaches large water bodies as direct runoff. The balance three-fourths of water returns back to the atmosphere at different times as evaporation.

A.Causes and Forms of Precipitation

a.Causes of Precipitation

For the formation of clouds and subsequent precipitation, it is necessary that the moist air masses cool to form condensation. This is accomplished by adiabatic cooling of moist air through a process of being lifted to higher altitudes. Some of the terms and processes connected with the weather systems associated with precipitation are given below;

1.Front:is the interface between two distinct air masses. Under certain favorable conditions, when a warm air mass and cold air mass meet, the warmer air mass is lifted over the colder one with the formation of a front. The ascending warmer air cools adiabatically with the consequent formation of clouds and precipitation.

2.Cyclone: is a large low-pressure region with circular wind motion. Two types of cyclones are recognized: tropical cyclones and extratropical cyclones.

- ✓ **Tropical Cyclone**

A tropical cyclone, also called cyclone in India, hurricane in USA and typhoon in South-East Asia, is a wind system with an intensely strong depression with mean sea level (MSL) pressures sometimes below 915 millibars. The normal areal extent of a cyclone is about 100-200 km in diameter. The isobars are closely spaced and the winds are anticlockwise in the northern hemisphere. The center of the storm, called the eye, which may extend to about 10-50 km in diameter, will be relatively quiet. However, right outside the eye, very strong winds/reaching to as much as 200 kmph exist. The wind speed gradually decreases towards the outer edge. The pressure also increases outwards (Fig. 8). The rainfall will normally be heavy in the entire area occupied by the cyclone.

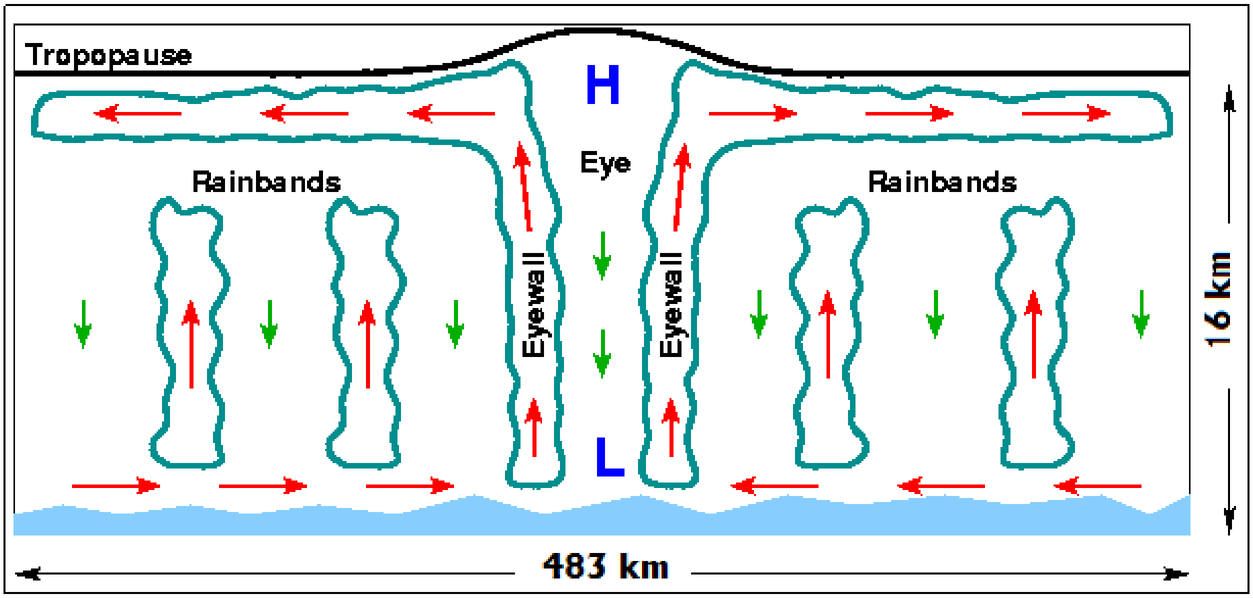


Figure. 8 Schematic section of a tropical cyclone

A schematic of radial and vertical wind fields at low and upper levels can be seen in the diagram above (stage#3). The radial inflow and vertical velocity components at low levels are driven by friction in the boundary layer. These components supply the rainbands and eyewall with warm moist air. The radial outflow and vertical velocity at upper levels are driven by the ascending features from below and the pressure gradient associated with the upper- level anticyclone. The ascending features of vertical velocity are driven by low-level convergence and local buoyancy. The descending features of the vertical wind field are driven by mass balance and convergence aloft.

✓ Extratropical Cyclone

These are cyclones formed in locations outside the tropical zone. Associated with a frontal system, they possess a strong counter- clockwise wind circulation in the northern hemisphere. The magnitude of precipitation and wind velocities are relatively lower than those of a tropical cyclone. However, the duration of precipitation is usually longer and the areal extent also is larger. (Fig.9)

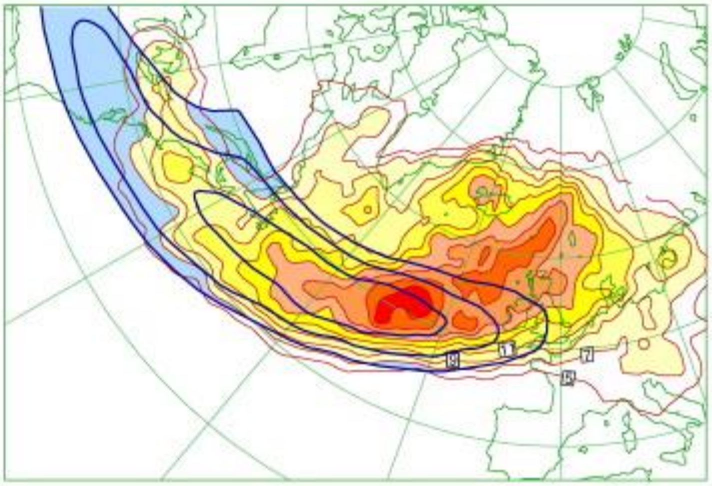


Figure 9. Map showing the density of extratropical cyclones trajectories derived from automatic tracking in the February 1997 6-hourly analyses (thin contours and shading, contour interval: two tracks per grid point). The field overlaid is the monthly mean 300 hpa wind velocity (heavy contours, interval 5 m s^{-1} from 40 m s^{-1}). (Adapted from Baehr Ch, Pouponneau B, Ayrault F, Joly A (1999)

- ✓ **Anticyclones**: These are regions of high pressure, usually of large areal extent. The weather is usually calm at the centre. Anticyclones cause clockwise wind circulations in the northern hemisphere. Winds are of moderate speed, and at the outer edges, cloudy and precipitation conditions exist.

b.Types of Precipitation

- ✓ **Convective Precipitation**:In this type of precipitation, a packet of air which is warmer than the surrounding air due to localised heating rises because of its lesser density. Air from cooler surroundings flows to take up its place, thus setting up a convective cell. The warm air continues to rise, undergoes cooling and results in precipitation. Depending upon the moisture, thermal and other conditions, light showers to thunderstorms can be expected in convective precipitation. Usually, the areal extent of such rains is small, being limited to a diameter of about 10 km.(Figs.10,11)

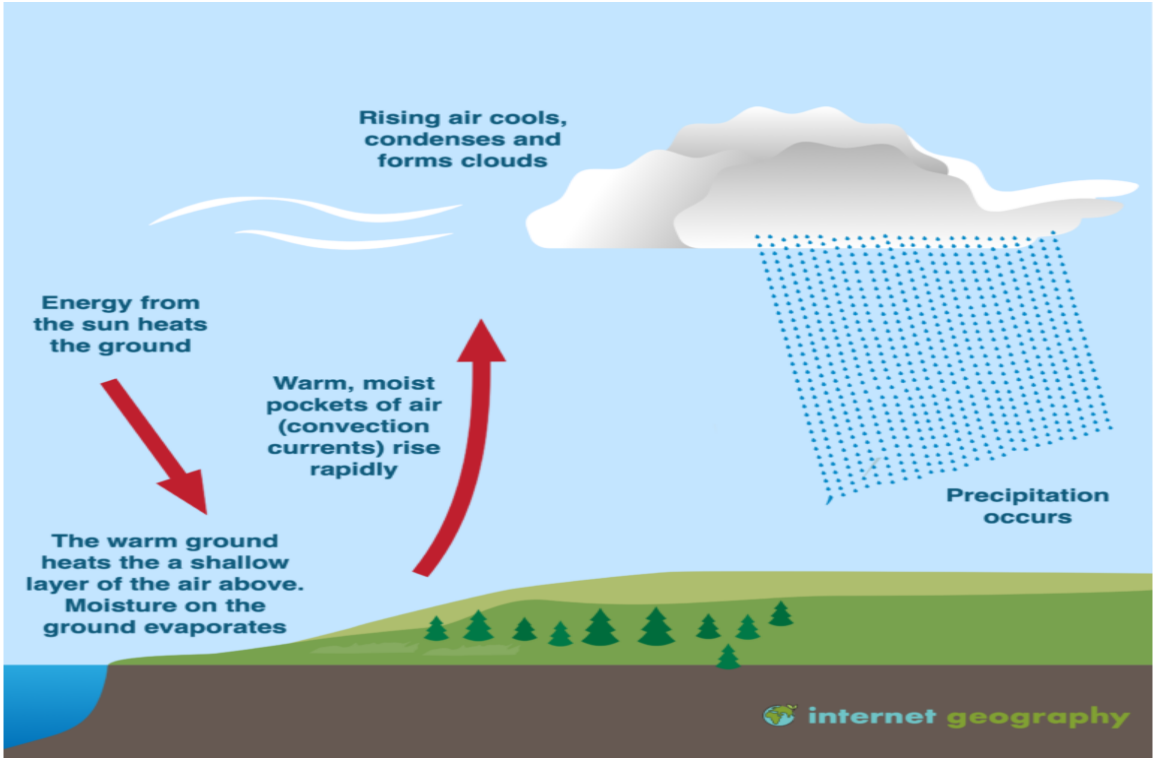


Figure:10. Convectional rainfall

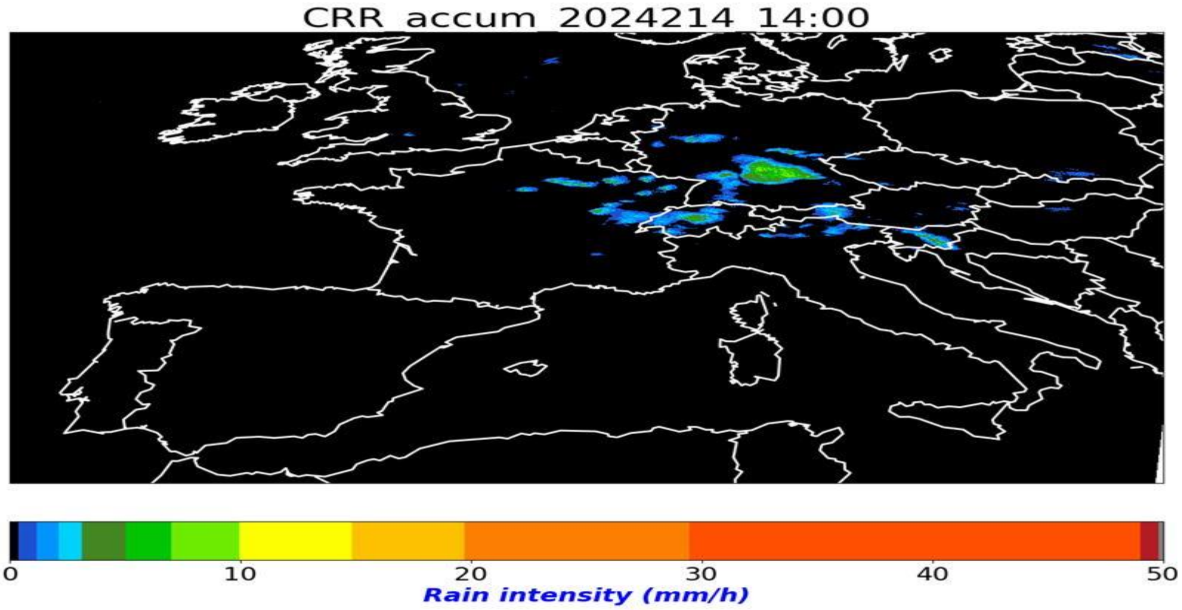


Figure 11. CRR hourly accumulations output corresponding to 1st of August, 2024, at 14:00Z Algorithm Theoretical Basis Document for ”Convective Rainfall Rate” (v1.1.1), 2025

- ✓ **Orographic Precipitation**:The moist air masses may get lifted up to higher altitudes due to the presence of mountain barriers and consequently undergo cooling, condensation and precipitation. Such a precipitation is known as orographic precipitation. Thus, in mountain ranges, the windward slopes have heavy precipitation and the leeward slopes have light rainfall.

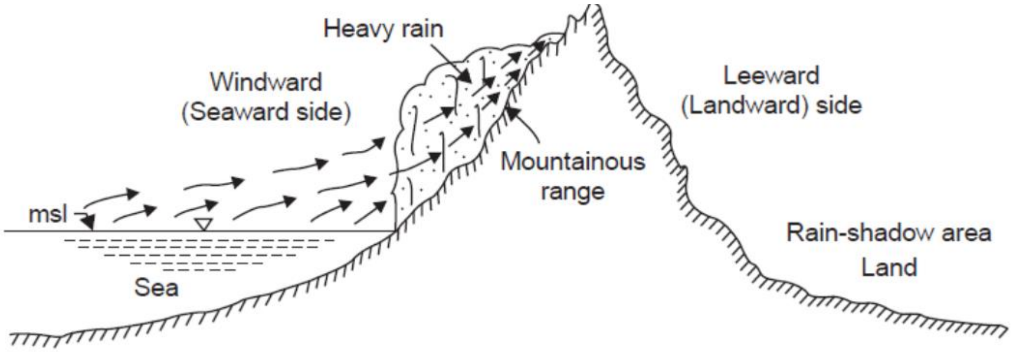


Figure 12. Orographic Precipitation (Jasim Mohammed Al-Rajab, 2021)

- ✓ **Cyclonic**

Cyclonic precipitation occurs when warm, moist air is drawn into a low-pressure cold front. The warm air rises as it is drawn into the low-pressure zone and is subjected to adiabatic cooling. The intensity of the precipitation is determined by the magnitude of the low-pressure system and the presence of a warm and moist air mass. Cyclonic storms tend to be large and have a light- to medium-intensity precipitation rate. Because of their large size, they tend to have a long duration. Most precipitation is the result of cyclonic activity.

Cyclonic Precipitation itself is categorized into two types,

- Frontal Rainfall
- Non-Frontal Rainfall

Frontal and non-frontal precipitation are described below:

- ✓ **Frontal Precipitation**

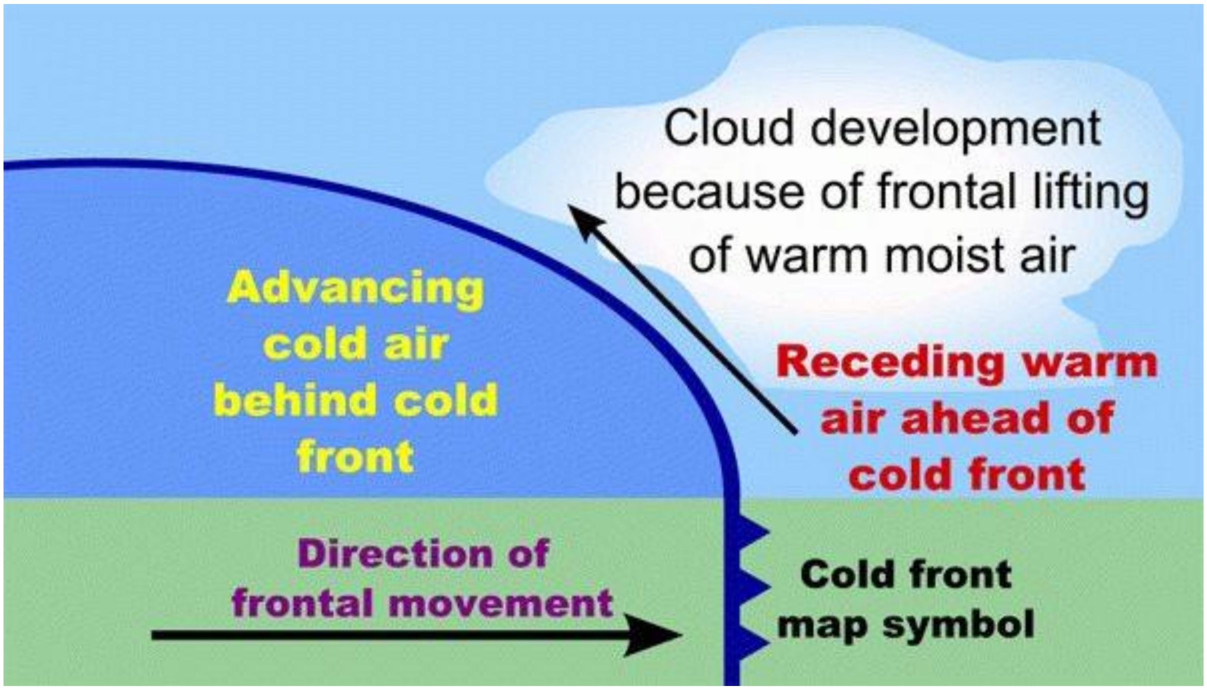


Figure 13. Frontal Precipitation

The collision of two different air masses, due to differences in temperature and densities, results in condensation and precipitation at the contact surface.

This contact surface is named as Frontal Zone, whereas the precipitation occurring in that zone is called Frontal Rainfall.

If cold air drives out warm air then the front is called a Cold Front and if the Warm nature masses of air overlap the superior cold air mass, it can be known as a warm Front. Similarly Stationary Front is the result of both air masses are moving toward an area of low pressure in a simultaneous way.

Intense Precipitation is the result of the Cold Front spread over a shorter area as compared to a warm nature front which covers a larger area but has a low intensity of the precipitation.

- ✓ **Non Frontal Precipitation**

This phenomenon occurs when the moving mass of cold air meets the stationary warm nature of air mass. As a result of which the lighter warm air rises up and reaches the saturation point.

The saturation point of lighter warm air causes precipitation known as Non-Frontal Precipitation. It is a type of Cyclonic Precipitation. This process differs from Frontal Precipitation in some sense hence categorized as a different type of Cyclonic Precipitation.

c.Hydrological cycle

It consists of three major steps viz., Evaporation, condensation and precipitation.

1. Evaporation: The primary source of water vapour in the atmosphere is the moisture evaporated from the Ocean (99%), lands and a small extent from transpiration.

2. Condensation: Warm air raises and water vapour is condensed.

3. Precipitation: The condensed water vapour float through the air in the form of clouds through the barrier of adiabatic cooling. Extensive air masses fall below the dew point. Water particle increase in size until they are too heavy to float and then they fall as rain or snow or other forms of precipitation.

d.Mechanism of Formation of Precipitation

Precipitation occurs when local air becomes saturated with water vapor, and can no longer maintain the level of water vapor in gaseous form. This occurs when less dense moist air cools, usually when an air mass rises through the atmosphere. However, an air mass can also cool without a change in altitude (e.g. through radiative cooling, or ground contact with cold terrain). There are three distinct types of precipitations. (Fig.14)

1. Convectional
2. Cyclonic
3. Orographic

-Mechanism of cooling

Evaporative cooling is a cooling of the air due to latent heat absorption of water molecules. When water evaporates, the evaporation process requires taking heat from the environment in order for the evaporation to occur. With the removal of heat from the air, the air cools. The amount of water that is able to evaporate into a volume of air impacts the cooling. Evaporative cooling can occur until the relative humidity reaches 100% (saturated air). Thus, initially dry and warm air will produce the greatest amount of evaporate cooling when this air is saturated through the evaporation process. This is because dry air can evaporate a greater amount of moisture as compared to less dry air when both are initially at the same temperature and warm air can evaporate a greater amount of moisture as compared to cold air. When air rises, it moves from a zone of dense air on the surface to areas of less dense air in the atmosphere. The rising air thus has less weight above it and the lower pressure allows the air to expand and cool down. The decrease in air temperature that result from expansion of rising air is called Adiabatic Cooling.

-Mechanism of Condensation

Clouds are formed by the condensation of water vapor onto nuclei in a rising mass of moist air. This produces droplets with sizes of the order of several microns. To precipitate, such droplets have to grow to millimeter sizes, either by coagulating together or by freezing and capturing the water evaporating from super-cooled droplets.

-Mechanism of Droplet Growth

According to the microstructure of the cloud is divided into: water clouds, cloud droplets are small water droplets, they rely mainly on collision with each other continue condensation and increases to the rain; ice clouds (composed by small ice crystals): composed of tiny ice crystals. Clouds form when the invisible water vapor in the air condenses into visible water droplets or ice crystals. For this to happen, the parcel of air must be saturated, i.e. unable to hold all the water it contains in vapor form, so it starts to condense into a liquid or solid form.

-Mechanism of Accumulation of Moisture

▪ water undergoes huge expansion during evaporation: 1 g of water equals 1 ml volume in liquid form and 42 l as vapor (at 25oC)

▪ gravity concentrates the atmospheric gases near the surface, the pressure drops to 1/e (= 37%) at about 8 km elevation P/Po = exp(-h/8000m) ----90% of water vapor content is confined to the lower 6 km

▪ absolute humidity (or water vapor mixing ratio): mass of vapor per unit volume of air, in g m-3 at 30oC, air has a svp of 42.43 hPa (hPa = mbar) and can contain up to 30 g m-3 , at 0oC is only 4.5 g m-3

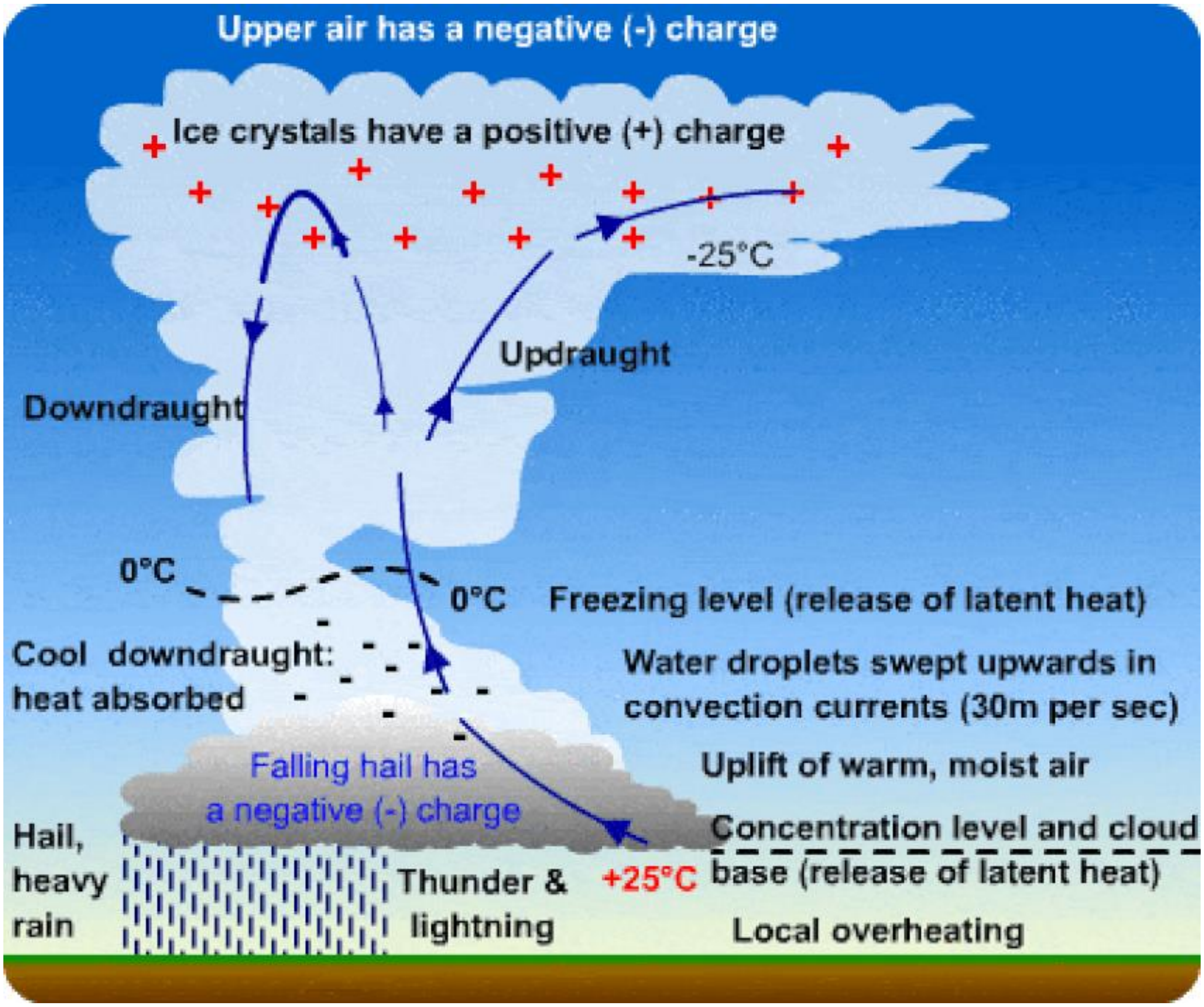


Figure 14. Mechanism of Formation of Precipitation

e. Forms of Precipitations

Any product of atmospheric water must reach the earth surface after condensation. However, fog and frost are not part of precipitation as they are not falling moisture. Some common forms of precipitation explained below are: (i) rain, (ii) snow, (iii) drizzle, (iv) glaze, (v) sleet, (vi) hail and (vii) dew.(Fig.15)

(i)Rain: When precipitation reaches the surface of earth in the form of droplets of water, we call it rain. The size of drops vary from 0.5 mm to 6 mm as drops larger than this size is found to breakup during their fall in the air. Rain is considered as light if intensity of rainfall is up to 2.5 mm/h, moderate from 2.5 to 7.5 mm/h and heavy over 7.5 mm/h.

(ii)Snow:It is precipitation in the form of ice-crystals, normally hexagonal in shape. Snow reaches the earth's surface either separately or combines together to form flakes. The density of snow is usually 0.10 gm/cm3 , which means that 10 cm of snowfall is equivalent to 1.0 cm of rainfall.

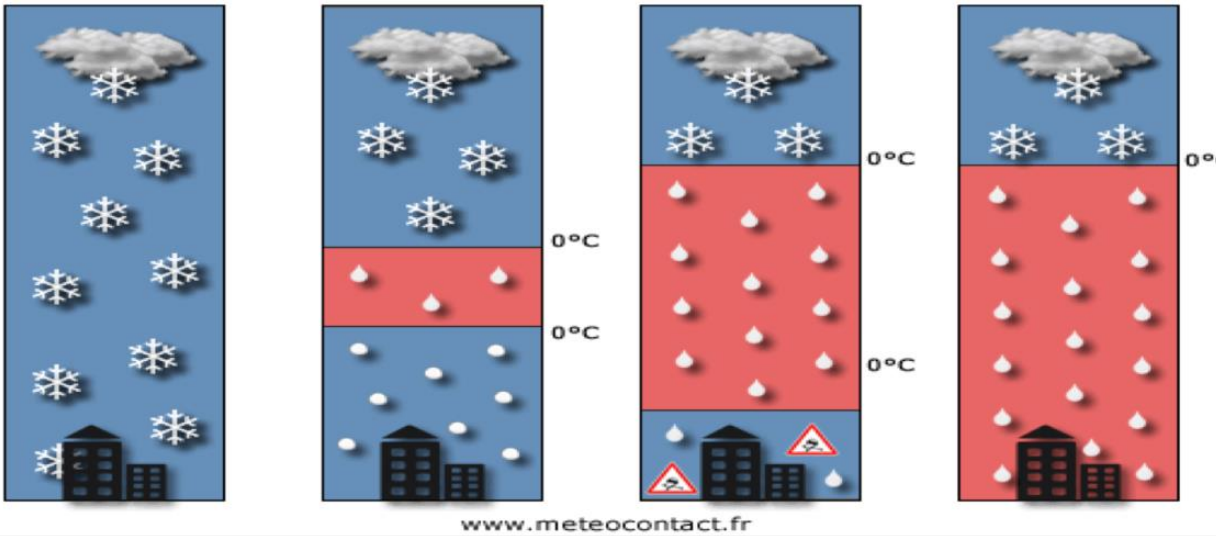
(iii)Drizzle:Drizzle is defined as water droplets of size less than 0.5 mm. It reaches the ground with intensity less than 1.00 mm/h. These water droplets are so light that they appear to be floating in air.

(iv)Glaze:It is the drizzle, which freezes immediately in contact with cold objects of the earth's surface.

(v)Sleet: Where rain falls through air of subfreezing temperature, the drops freeze to form grains of ice, called sleet. Sometimes snow and rain precipitates simultaneously. The rain drops under this circumstance are half frozen.

(vi)Hail:It is the precipitating rain in the form of any irregular form of ice with size ranging from 5.0 mm to 50 mm or above. Clouds with strong vertical currents are responsible for the formation of hail. The densities of hails are normally 0.8 gm/cm3 . While falling they combine together to form bigger sizes.

(vii)Dew: During nights when surface of the objects on earth cools by radiation, the moisture present in atmosphere condenses on the surface of these objects forming water droplets called dew.



Snow **Drizzle** **Sleet** **Rain**

Figure 15. Forms of Precipitations

B.Precipitation: Rainfall .

Rainfallis classified into: Lightrain – ifintensity istrace to 2.5mm/h

Moderate rain – ifintensity is 2.5mm/hrto 7.5mm/hr

Heavy rain – above 7.5mm/hr

C.Measurement Units.

Amount of precipitation/rain (mm or inch)

It is measure astotal depth of rainfall over an area in one day.

Intensity of precipitation/rain (mm/hr or inch/hr) .

It is the amount of precipitation at a place per unit time (rain rate). It is expressed as mm/hror inch/hr

D.Measurement of Precipitation

Measurement of precipitation means determination of amount of precipitation, intensity of precipitation, duration of precipitation and areal extent of precipitation. Precipitation is measured in terms of depth (i.e., millimeter, inches, centimeter or sometimes in meter). Precipitation data is a basic input for the study of any water resources system and should be measured extensively. Due to its great variability in space and time this natural parameter is recorded continuously. Rainfall is collected and measured in instruments called rain-gauges. If snow is the form of precipitation, then it is collected in snow-gauges, melted and its water equivalent is recorded. A rain-gauge in its simplest form is a horizontal circular opening aperture of known cross sectional area in the form of a cylindrical vessel. The circular opening leads its catch to a collecting and measuring jar. Three types of instruments generally used for measurement of rainfall are: (i) non-recording gauge, (ii) recording gauge and (iii) weather radars.

- ✓ **Non-Recording Rain-Gauge** Various types of non-recording rain gauges are available, for instance, A Symons type or a Standard gauge. The two types of gauges are alike but differ in their size proportion and material. A standard gauge is made up of reinforced fiberglass polyester material of different combinations of collectors and bottles. Details of installation of a standard type of rain gauge is shown in (Fig. 16).

Figure 16. Non-Recording Rain Gauge – Model 2601-00

The circular collector opening has an area of either 100 or 200 cm2 from which rain enters into the receiving vessel through a funnel. The collectors are interchangeable. Top of the circular opening is placed at a standard height of 30 cm above ground level. The metal container should be fixed to a concrete block of 60cm x 60cm x 60cm as shown in Fig. 17. The rain catches collected in the bottle is taken out and poured into a graduated measuring glass jar (chosen accordingly for 100 cm or 200 cm collector), which gives directly the depth of rainfall for the day. Degree of accuracy of a graduated jar is 0.1mm. If precipitation on a day is very heavy then more readings should be taken and summed up to give the rainfall depth for the day along with its final observation taken. Such a system can also be used for snow measurement but the snow should be melted to arrive at the equivalent depth of water recorded.

This system needs the service of an attending observer who monitors the gauge at regular intervals, usually daily and hourly during continuous and heavy precipitations. Since the above system does not record rain but simply collects, it is called a non-recording gauge. The ratio of volume of water collected in cm3divided by the area of opening of the gauge mouth in cm2 gives the depth of rainfall for the day. If any non-standard measuring jar is used, then it should be calibrated to give directly the depth of rainfall in centimeters and millimeters. Generally, non-regarding rain-gauge give the amount of rainfall only. They cannot provide the information regarding when exactly the rain commenced, when rain ended, what is the intensity of rainfall and how the intensity of rainfall varies within the duration of the storm.

Figure 17. Direct-reading rain gauge (A). Electronic rain gauge (B).

- ✓ **Recording Rain-Gauge** These rain gauges give a continuous record of rainfall at a place over time. Such gauges give all the required information of a storm like the onset and cessation of rain, i.e., duration of the storm, intensity and the cumulative rainfall. The recording gauges are commonly installed along with a non-recording type gauge for the purpose of checking and calibration. Many types of recording gauges are available in the market. One may use a tipping bucket type, weighing bucket type or syphon type gauge on the consideration of their merits and demerits to suit the conditions prevailing over the site. When such a gauge is fitted with an electronic device to transmit rainfall data to a base station then it is known as Telemetering gauge.

a.Tipping Bucket Type:A Stevens tipping bucket type of rain gauge consists of a 200 mm collector that directs the rain water through a funnel into a two compartmental bucket. The size of each bucket is 0.25 mm of rain. Once rain water fills up a bucket, it over-balances and the water tips down to the casing.of the container bringing thereby the second bucket to its measuring position beneath the funnel. Tipping of the buckets actuates an electric circuit which records the number of tips during rain. This type of gauge can be installed at an inaccessible area from where electric pulses generated due to the tipping of the buckets is recorded at the control room far away from the gauge location. Disadvantages of such a type of gauge are (i) when tipping of buckets takes place, rainfall at that instant is not recorded, (ii) very high intensity rainfall gives close signals, which can make it difficult to record the number of tips and (iii) calibration of tips may change due to rusting and dirt accumulation. (Fig.18)

b. Weighing Bucket Type: This type of gauge can be used for recording rainfall as well as snow. Rain is collected in a receiver bucket supported on a spring balance. A mechanical lever arm of the balance is connected with a pen which touches a clock mounted drum with a graph paper. As it rains, the weight of the bucket gradually increases. This changes the position of the pan of the balance. With time the pen marks a line c" the continuously moving graph paper. The record shows the accumulation of precipitation over time. The recording can be taken after 24 hours or 7 days depending on the clock and drum size. Such gauges are normally used in USA and are becoming increasingly popular.

Disadvantages of such a gauge are (i) when very heavy precipitation occurs, there is good chance that the bucket will overflow and (ii) such instruments are costly. When the pen reaches the upper end of the graph paper it reverses its love, thus continuously recording the precipitation over time.

c. Syphon (Float) type:Such a rain gauge is shown in Fig. 17 Rain entering the gauge is led to a float chamber through a funnel. With increase in rainwater in the chamber, the float rises. A pen mounted on the float through a lever system touches a graph chart warped around the circumference of the drum. The drum is mounted on a mechanical clock. Clock of the rotating drum is wound either for 24 hours or 7 days after which the graph chart is to be replaced. By the time the pen reaches the top of the graph the float also reached the top of the chamber. At this point symphonic action takes place in the chamber and all the water in the chamber below the float empties. The pen comes back to its original zero position. If there is no rainfall, the pen moves horizontally over the graph paper at that level. One symphonic action means 10 mm of rainfall and the time taken to collect the depth of rain can be noted from the horizontal axis of the graph paper. The beginning and the end of the storm, its intensity, duration, distribution of rain and the depth of total storm precipitation can easily be obtained from the plot of the graph.

Figure 18. Tipping bucket rain gauge Stock Photos and Images

- ✓ **Radar Measurement of Rainfall** The meteorological radar is a powerful instrument for measuring the areal extent, location and movement of rain storms. Further, the amounts of rainfall over large areas can be determined through the radar with a good degree of accuracy. The radar emits a regular succession of pulses of electromagnetic radiation in a narrow beam. When raindrops intercept a radar beam, it has been shown that; Pr = C? r2 Where Pr = average echo-power, Z= radar-echo factor, r= distance to target volume and C = aconstant. Generally, the factor Z is related to the intensity of rainfall as; ? = ?I ? Where aand bare coefficients and I = intensity of rainfall in mm/h. The values a and bfor a given radar station have to be determined by calibration with the help of recording rain- gauges. ? = 200 I 1.60 Meteorological radars operate with wavelengths ranging from 3 to 10cm, the common values being 5 and 10 cm. For observing details of heavy flood-producing rains, a 10cm radar is used while for light rain and snow, a 5cm radar is used. The hydrological range of the radar is about 200km. Thus, a radar can be considered to be a remote-sensing super gauge covering an aerial extent of as much as 100,000km^2 . Radar measurement is continuous in time and space. Present-day developments in the field include (i) online processing of radar data on a computer, and (ii) Doppler-type radars for measuring the velocity and distribution of raindrops.

E.Precipitation regimes in Mediterranean regions and in Algeria

Mediterranean rainfall is irregular in terms of spatial distribution, frequency, and amount; some areas receive regular rainfall while others, despite being nearby, remain much drier. In Mediterranean regions, the sea warmed during summer, combined with the large energy reservoir associated with autumn convection, provides strong potential for the development of disturbances in autumn and especially in winter. This type of instability requires an external mechanism to initiate uplift.

The most natural and most effective mechanism is orographic uplift (Banta, 1990). These two conditions (proximity to the Mediterranean Sea and the presence of relief) often give rise to events involving both deep and shallow convection. According to Baldy (1993), a strong similarity is observed between the distributions of a given month (or quarter) for stations located within the same climatic zone and at similar altitudes. It is difficult to reconstruct individual rainfall events at a given location.

Autumn and spring precipitation often shows a bimodal distribution, but it varies greatly from year to year: a particular month may be dry or rainy, and in such cases the average has little meaning. Depending on the season, Mediterranean rainfall is characterized by:

→ **In winter:** rainfall is mainly of the oceanic type, resulting from large-scale westerly disturbances. It generally has low instantaneous intensity but long duration. A reduction in precipitation is noted at high altitudes; however, rainfall increases at mid-altitudes on windward massifs. In more arid regions, their relative importance decreases more rapidly than total rainfall.

→ **In spring and autumn:** and sometimes also in winter in arid-climate regions, most rainfall originates from thunderstorms affecting small areas. Rainfall intensity commonly exceeds 60 mm/h. These rains are generally of short duration and are associated with the movement of fronts. Certain topo-climatic situations favor the frequent development of orographic thunderstorms late in the day, often accompanied by hail.

Northern Algeria lies within the temperate zone and enjoys a mild Mediterranean climate. Owing to its topography, there are strong temperature contrasts that influence rainfall. Precipitation is relatively abundant along the coastal Tell, and rainfall increases from west to east. The mean annual rainfall along the coast is about 400 mm in the west, 700 mm in the central part, and 1,400 mm in the east. Precipitation is highest in the northeastern part of Algeria, where it can reach up to 1,400 mm per year. The Djurdjura massif, located in Kabylia, and the Edough massif, located farther east, are the wettest areas in Algeria (Touazi et al., 2011). The High Plateaus region of Algeria, with a Mediterranean-type climate, receives about 70% of its annual rainfall during the cold season, from October to February. In this region, precipitation becomes scarcer and more irregular, ranging from 250 to 600 mm, most often distributed over 50 to 70 days per year.

The dry season may last up to five or even six months.(Fig.19)

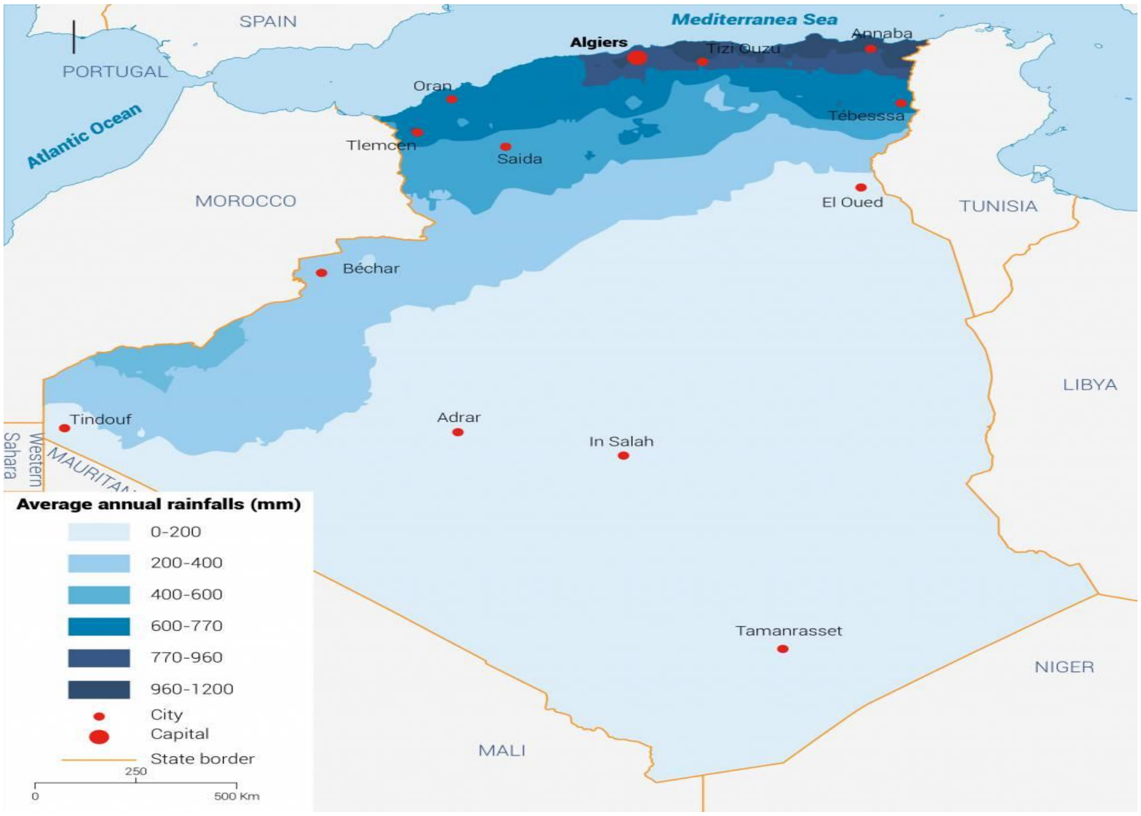


Figure 19. Rainfall map of Algeria

II.2.3.2. Temperatures

temperature, measure of hotness or coldness expressed in terms of any of several arbitrary scales and indicating the direction in which heat energy will spontaneously flowi.e., from a hotter body (one at a higher temperature) to a colder body (one at a lower temperature). Temperature is not the equivalent of the energy of a thermodynamic system; e.g., a burning match is at a much higher temperature than an iceberg, but the total heat energy contained in an iceberg is much greater than the energy contained in a match. Temperature, similar to pressure or density, is called an intensive property—one that is independent of the quantity of matter being considered as distinguished from extensive properties, such as mass or volume.

The precise definition of temperature is not a simple matter, but the concept of temperature is fundamental to any discussion of thermodynamics. For example, a steel rod feels colder than a wooden rod at room temperature simply because steel is better at conducting heat away from the skin. It is therefore necessary to have an objective way of measuring temperature.

In general, when two objects are brought into thermal contact, heat will flow between them until they come into equilibrium with each other. When the flow of heat stops, they are said to be at the same temperature.

Temperature It is the most crucial parameter governing all physiological activities and chemical reactions. Air temperature depends on solar radiation, atmospheric pressure, and the composition of atmospheric gases. Variations in air temperature are strongly buffered by atmospheric humidity, and it is in arid zones that the greatest daily thermal amplitudes are observed. Thermal measurements depend on strict environmental factors (mentioned above). For this reason, care must be taken to ensure that these measurements are not influenced by other factors, such as incident solar radiation reflected by the ground. Temperature is expressed in absolute degrees (K), degrees Celsius (°C), or degrees Fahrenheit (°F). The conversion rules are as follows:

$K = 273.15 + °C$
$°F = (1.8 \times °C) + 32$
$°C = 0.56 \times (°F - 32)$

Temperature and its diurnal variation vary according to the location of observation: latitude, maritime or continental stations, station elevation, and cloud cover. In addition to maximum and minimum temperature measurements.

The temperature of **57.8 °C (or 57.7 °C)** was long claimed to be the world record for heat, recorded in **1922 at El Azizia, Libya**, but it was **invalidated in 2012 by the World Meteorological Organization (WMO)** due to doubts about its reliability. As a result, the **officially recognized record temperature remains 56.7 °C**, recorded at **Death Valley, USA, in 1913**, although more recent measurements such as **54.4 °C** are also considered reliable.

WMO (World Meteorological Organization)

has recognized a temperature of -69.6°C (-93.3°F) at an automatic weather station in Greenland on 22 December 1991 as the lowest ever recorded in the Northern Hemisphere. The temperature record was uncovered after nearly 30 years by "climate detectives" with the WMO Archive of Weather and Climate Extremes. It eclipses the value of -67.8°C recorded at the Russian sites of Verkhoyanksk (February 1892) and Oimekon (January 1933). The world's coldest temperature record; of -89.2°C (-128.6°F) on 21 July 1983; is held by the high-altitude Vostok weather station in Antarctica.The weather station at Verkhoyanksk; which previously held the northern hemisphere cold temperature record; hit the headlines when it recorded a temperature of 38°C on 20 June during a prolonged Siberian heatwave. WMO is currently verifying whether this is a new record high temperature north of the Arctic Circle (a new category for the archive). In the era of climate change; much attention focuses on new heat records. This newly recognized cold record is an important reminder about the stark contrasts that exist on this planet.

A. Meteorological Temperature Measuring Instruments

The thermometer is the most commonly used meteorological instrument. Its operating principle is based on the property of certain substances to expand or contract according to the temperature.

the **Dry Bulb** measures actual air temp, the **Wet Bulb** measures humidity (lower reading due to evaporation), **Min/Max Thermometers** track extremes over time, and a **Thermograph** continuously records temperature, all crucial for understanding weather and climate by assessing air conditions and moisture levels.

Here's a brief overview of how they work together:

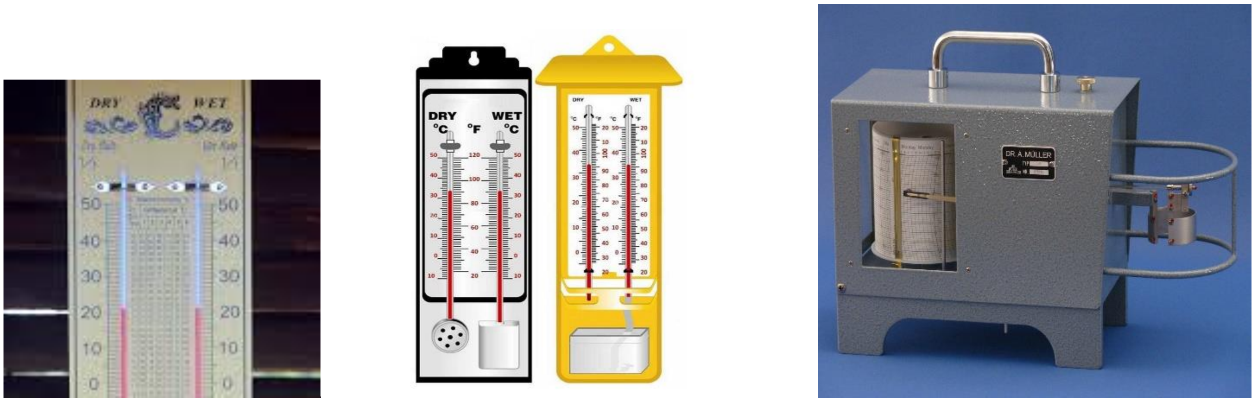
Dry-Bulb Thermometer: Simply measures the ambient air temperature, like a standard thermometer.

Wet-Bulb Thermometer: Its cooling from evaporation shows how much moisture the air can hold; the bigger the difference between dry and wet bulb, the drier the air.

Min/Max Thermometer: Uses tiny markers that get pushed by the mercury, showing the highest and lowest points reached in a period.

Thermograph (Recording Thermometer): A pen traces temperature changes onto a rotating chart, creating a continuous temperature history.

These instruments are often used together in a **psychrometer** (a sling hygrometer) to determine humidity and dew point, vital for weather forecasting and HVAC



Wet-Bulb Thermometer A dry-bulb thermometer Thermograph

Figure 20. Meteorological Temperature Measuring Instruments

In a meteorological station, there is a thermometer that measures the ambient air temperature and a wet thermometer (covered with a wet gauze) that indicates the temperature at which precipitation would occur. Comparing the two readings allows the calculation of air humidity. Air temperatures often differ from soil temperatures, which have very different thermal conductivity.

In the troposphere, air temperature decreases with altitude due to the thinning of the air and increasing distance from the ground, except during thermal inversions (cold air overlain by warmer air), where the decrease is **0.65°C per 100 m**. This gradient is an average between cases of temperature decrease in dry air and in saturated air (100% relative humidity).

When the air is not saturated, the decrease, called the **adiabatic lapse rate**, is **1°C per 100 m**. When the air is saturated, it is **0.5°C per 100 m**, and this is referred to as the **pseudo-adiabatic lapse rate**.

The temperature decrease is compensated during condensation by the release of latent heat; therefore, it is normal that in dry air the decrease is greater.

B. Major Heat Zones of Earth

Geographers divide the earth in different ways. One of the main ways to divide the Earth is to divide it into bands that run parallel to the equator. These different bands help to explain the climate of the region on Earth. The Heat zones of the Earth can be defined as the different zones found on our planet, where the sun's rays hit at different angles. Due to the different heat absorption, different climates occur in these zones. Our planet Earth has three heat zones which are as follows :

- **Frigid Zone**

The word 'Frigid' meaning is cold. The frigid zone is the region which is located between Arctic Circle (66½°N) and the North Pole in the Northern Hemisphere, and between Antarctic Circle (66½°S) and the South Pole in the Southern Hemisphere. This zone receives a very less amount of sun rays therefore the temperature in this zone is very low and the climate is very cold. The frigid zone is also known as the Polar Region.

Every month Polar Regions have a temperature of less than 10°C. Regions with polar climates cover more than 20% of the Earth's area. In the Arctic, the average January temperatures range from about -40° to 0°C, and winter temperatures can drop below -50°C. And the climate of Antarctica is the coldest on Earth. Antarctica has the lowest temperature ever recorded: -89.2°C at Vostok Station.

- **Temperate Zone**

The temperate zone lies between the Tropic of Cancer and the Arctic Circle of the Northern Hemisphere, Capricorn, and the Arctic Circle. This zone has less sunlight than the tropics. This area receives the oblique rays of the sun. These zones are neither too hot nor too cold. It experiences a wide range of temperatures and precipitation where four different seasons are common which are: spring, summer, autumn, and winter. Temperate zones have the most suitable climate as it does not experience the wide variations of some of the more extreme climates. The average temperature in this zone lies between 0° to 20°C. The minimum and maximum temperatures recorded in this zone are -40°C and +40°C respectively.

- **Torrid Zone**

This zone lies between the Tropic of Cancer and the Tropic of Capricorn, so it is the zone on the surface of the Earth that receives the greatest amount of heat. This region receives direct sunlight and vertical rays of the sun all year round. This zone receives the maximum amount of heat from the sun. This zone is also known as the tropical zone.

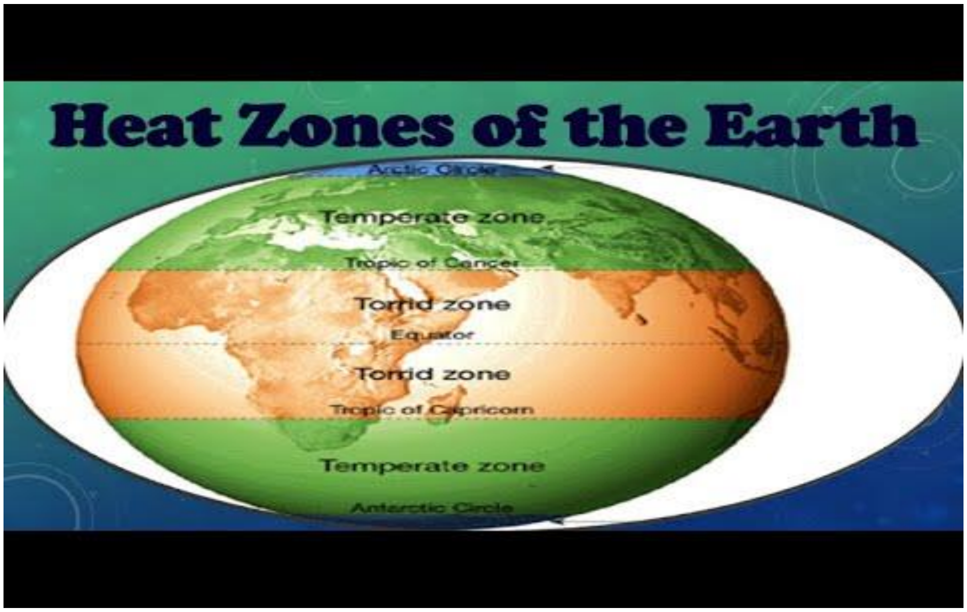


Figure 21. heat zones of earth

II.2.3.3. Atmospheric pressure

A.Definition and Pressure Measurement

Pressure acts in all directions, up and sideways as well as down, but it is convenient in meteorology to regard atmospheric pressure as the weight of an air column acting on unit are a, see fig. 22

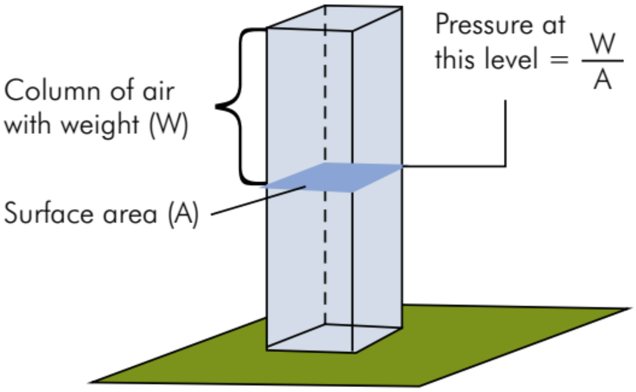


Figure. 22.Atmospheric pressure

The units of pressure are Force divided by Area (or Force per Unit Area N/m2 or Pa (Pascal)). The unit of pressure in meteorology is the hecto Pascal (hPa) which replaces the millibar (mb) which was in use in former times. However the units are of identical magnitude, therefore: 1 mb = 1 hPa

- **The Mercury Barometer**

The Italian physicist Torricelli invented the Mercury barometer in the 17th century, see fig. 23 Atmospheric pressure forces mercury to rise in an evacuated glass tube.

The unit of pressure was then mm Hg (Hg is the abbreviation for mercury). This unit has been replaced by the SI-unit hecto Pascal, hPa. The reading of a mercury barometer has to be manually corrected for the temperature of the mercury column and gravity at each site.

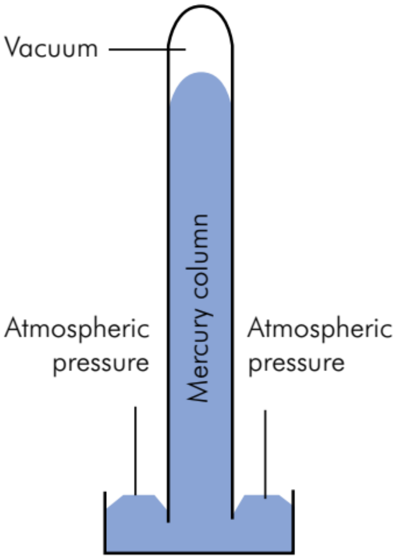


Figure 23 :Mercury barometer

760 mm Hg = 1013 hPa

In the USA barometric pressure is still measured in inches Hg:

29.92 inches Hg = 1013 hPa.

- **Aneroid Barometer**

The aneroid barometer consists of a flexible metallic capsule which is partially evacuated. It compresses under small increases in air pressure and the capsule compression/ expansion is converted by a lever system to drive a pointer on an amplified scale. It is a much more convenient and portable system than a mercury barometer, *see fig. 24*

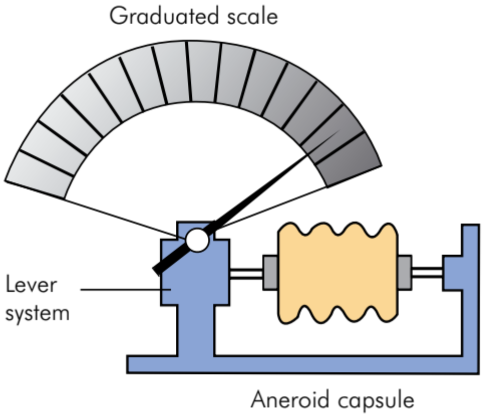


Figure 24. Aneroid barometer

- **The Barograph**

The barograph is an aneroid barometer used in conjunction with a recording drum. Instead of a needle and graduated scale the lever mechanism moves a pointer which leaves an ink trace on a scaled recording paper wrapped around the drum. This leaves a permanent record of the pressure variations. This is used to provide a meteorologist with the pressure tendency, or rise and fall of pressure over time and is an important forecasting tool, *see fig. 25*

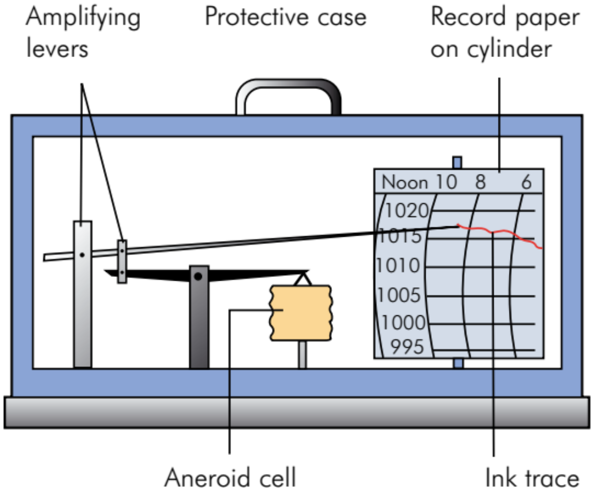


Figure 25. Barograph

B. Pressure Reduction to Mean Sea Level and Pressure Systems

- **Pressure at the Surface (QFE)**

The atmospheric pressure measured on a barometer at an airfield is known as the QFE or Aerodrome Pressure.

The QFE varies widely, both from day to day and place to place, due to variations in the weight of the air column above the surface

- **Pressure at Mean Sea Level (QFF)**

Since QFE is measured at station level, it is not immediately usable for meteorological purposes because of the differences in altitude of the observing stations. In order to be usable in meteorology all pressures need to be measured at the same level. Therefore QFE values have to be adjusted to Mean Sea Level (MSL) and the adjusted pressure is known as QFF.

In temperate latitudes QFF varies between 970 hPa and 1030 hPa, but occasionally pressure falls as low as 900 hPa or rises as high as 1060 hPa.

In different countries different methods are used to calculate this QFF. Sometimes the method is dependent on season. All methods use the observed temperature at the station and some type of assumed temperature profile down to or up to sea level. In meteorology this is called reduction.

Once reduction is done, all points with the same QFF can be joined up with lines of constant pressure referred to as isobars.

- **Pressure Systems**

In order to forecast weather it is important to know the distribution of pressure at mean sea level.

Isobars are usually drawn at intervals 1, 2, 4, 5 or 10 hPa, the custom varies with latitude and country. Local barometric pressures at observation stations (QFE) above sea level are adjusted for the difference in height to bring them all to a common datum, normally Mean Sea Level (MSL) to enable a chart of pressure distribution to be drawn known as a synoptic chart. The adjusted MSL pressures are known as the QFF,

see fig26.

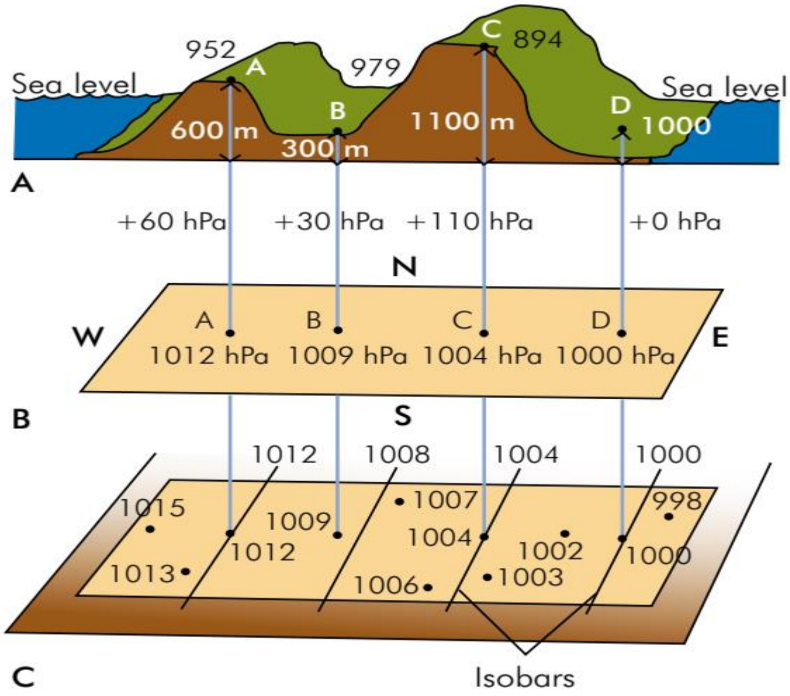


Figure26. Surface isobars

Pressure Patterns Revealed by the Isobars are:

- **Anticyclones or Highs**

These are regions where the pressure at its centre is highest relative to its surroundings. The circulation is clockwise in the northern hemisphere and anticlockwise in the southern hemisphere.

- **Ridge or Wedge**

A region of isobars extending away from a high centre. Pressure along the line of the ridge is higher than its surroundings.

- **Depressions or Lows (or Cyclones)**

These are regions where the pressure at its centre is lowest relative to its surroundings. The circulation is anticlockwise in the northern hemisphere and clockwise in the southern hemisphere.

- **Trough**

A trough is a region of isobars extending away from a low centre and may have sharp curvature. Pressure along the line of the trough is lower than its surroundings.

- ✓ **Col**

A col is a region of nearly uniform pressure situated between a pair of highs and a pair of lows.

Wind circulation around pressure systems is usually along the isobars, *see fig. 27*

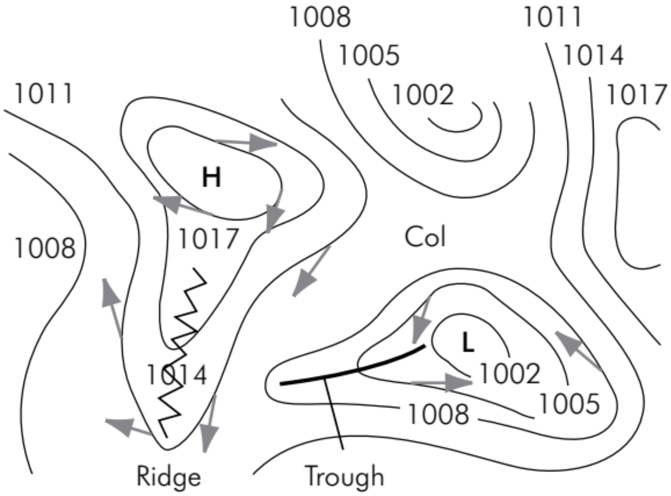


Figure 27. Wind circulation around pressure systems

C. Vertical Pressure Distribution

➢ Variation of Pressure with Height

The pressure at any level in the atmosphere is equal to the weight of air column above a surface of 1m2. It follows therefore that pressure must reduce with height in the atmosphere as the weight of the air column above reduces. How much it reduces depends upon the gravitational acceleration and density of the air column, see fig. *28*

From fig. 28 it can be seen that the most rapid decrease in pressure with height is in the troposphere up to about 500 hPa at which point about 50% of the atmosphere is below this level. The rate of pressure decrease with height begins to decrease significantly as one approaches the tropopause. The pressure will of course be determined by the density of the air above.

Table 4 shows the height change at various altitudes for a pressure change of 1 hPa.

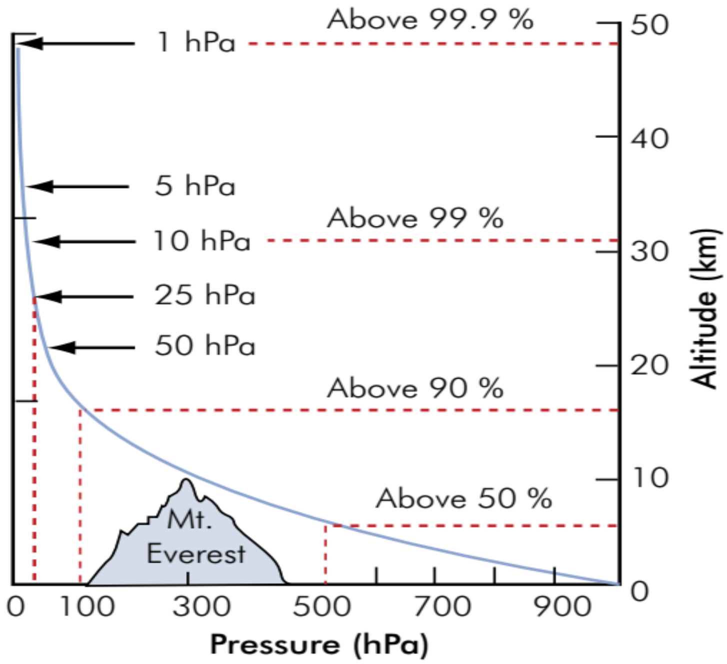
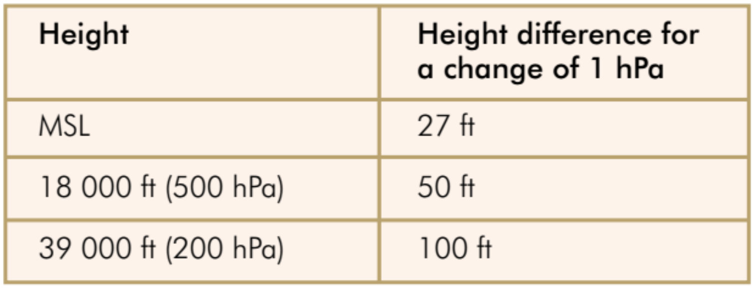


Figure 28. Variation of pressure with height

Table 4: Height variation for 1 hPa pressure change at various heights



Height	Height difference for a change of 1 hPa
MSL	27 ft
18 000 ft (500 hPa)	50 ft
39 000 ft (200 hPa)	100 ft

D. Atmospheric Density

➢ 2.4.1 Density

Density is defined as mass per unit volume, expressed in kg/m3. When air is heated it expands, and the same mass (or weight) occupies a larger volume and so density becomes less. As pressure decreases with height the density of the air is decreasing as well. This will also be dependent on the temperature of the air as warm air is less dense than cold air and warm columns of air will be taller than cold air columns. Assume two columns of air both have the same height and surface pressure. If one column is cooled while the other is heated, the colder column will be more dense and contain less air above the fixed datum of 10 000 ft. The warm column will expand, decreasing in density and pushing more air above the fixed datum, *see fig. 29.*

The pressure at 10 000 ft in the cold column will therefore be less than the pressure at 10 000 ft in the warm air column. This will create pressure differences aloft and result in winds aloft.

The rate of decrease of pressure with height is therefore greater in the cold air than in the warm air, so at any height above the surface the pressure aloft will be lower in the cold air than in the warm air.

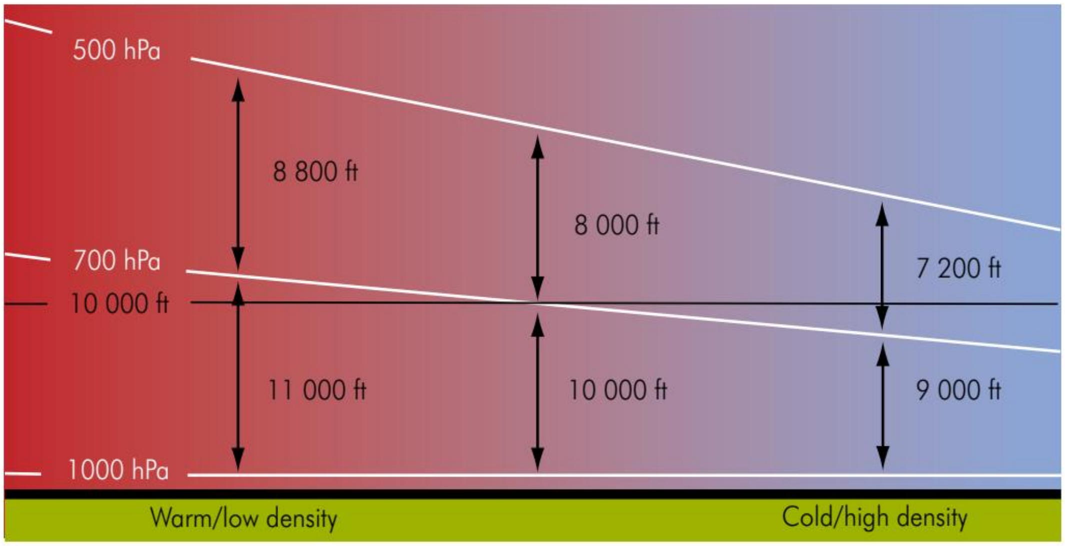


Figure29. Density variations

- ✓ **Density of Dry and Moist Air**

As stated earlier, dry air is made up of 78% nitrogen and about 21% oxygen. When water vapour is introduced into the air it displaces the O2 and N2 molecules. The atomic mass of N 2 is 28 and O2 is 32, both heavier than H 2O with an atomic mass of 18. Thus the density of moist air is less than the density of dry air.

- ✓ **Behaviour of Air**

Air behaves according to the Ideal Gas Equation

$p = T \times \rho \times C$

or *Equation of State* as it is sometimes called.

- ✓ **Pressure and Height Calculations**

It is also useful to know what increase of height corresponds to a pressure change of 1 hPa for any particular value of temperature and pressure. A rough estimate may be made using the following formula: (Note, this formula need not be memorised for exam purposes).

$96T/p$ ft/hPa

Where:

- T is mean temperature on the Kelvin
scale and
- P is the mean pressure in hPa.

Thus at a sea level pressure of 1013 hPa and 15°C (288K) there is approximately a height change of 27 ft for 1 hPa pressure change, and 50 ft at 500 hPa.

Due to variations in surface pressure and density of the air column aloft a more accurate method of calculating the height between layers in the atmosphere is used for the calculation. Data from the upper air is obtained by sending up a radiosonde.

The data is then used to calculate the thickness or height of the various layers in the atmosphere and then used to derive the absolute height of the isobaric surfaces above mean sea level and so to construct contour charts. The pressure/height formula is used for calculation.

$h2-h1 = 221.1 \times T \times (\log10p1-\log10p2)$

While it is not necessary to remember or use the formula in the examination it is reproduced here to emphasise that the height of the pressure levels in the atmosphere is directly dependent on the mean temperature (T), of the atmospheric column above the surface.

II.2.3.4. Relative humidity of the air

A.What is relative humidity?

Humidity is the amount of water vapor present in the air. The variable relative humidity (r_h) is derived from vapor pressure measurements. It expresses the ratio between the actual amount of water vapor in the air (e_a) and the maximum capacity of air to uptake water vapor at a particular temperature (e_{sat}), $rh = e_a/e_{sat}$.

B.What is the unit of relative humidity and how is it measured?

The unit of vapor pressure is Pascal [Pa], but because relative humidity is the ratio of two vapor pressures, that unit cancels out and we obtain percent [%]. On a scale from 0 to 100%, absolutely dry air that contains no water has a relative humidity of 0%, while 100% of relative humidity corresponds to air that is fully saturated with water and the vapor begins to condense. In order to form clouds and precipitation, a relative humidity close to 100% is required along with nuclei (e.g. small dust particles) on which water vapor can condense.

There are two historical instruments to determine relative humidity. One is the hygrometer. It uses an element that contracts and extends depending on moisture, for example a horsehair. Relative humidity is then derived from the length of that horsehair, where longer hair means higher relative humidity. Another measuring instrument is the psychrometer. It consists of one air thermometer and one wet-bulb thermometer. Relative humidity is derived from the temperature difference between the two thermometers, where a smaller temperature difference means higher relative humidity. Nowadays, electronic sensors such as the one that the TAHMO station has are used.

C.What does relative humidity depend on?

Relative humidity is strongly variable with temperature, and air pressure also plays a role. The higher the air temperature the higher the maximum capacity of air to uptake water vapor, because the air expands with temperature. Therefore, the saturation vapor pressure esat is mostly dependent on-air temperature. On the other hand, the actual vapor pressure ea depends on many factors such as advection of atmospheric moisture from the sea over land, evaporation from the soil and lakes, wind, etc. As a result, rh depends on many factors in addition to temperature.

D.Saturation of humid air

Air is a mixture of several gases, including nitrogen, oxygen, and water vapor.

- The total air pressure exerted by a volume of air in a given container on that container is the sum of the individual (partial) pressures of these gases.
- The vapor pressure is the individual or partial pressure of the water vapor.

The warmer the air is, the more moisture it can hold. So its moisture holding capacity changes with temperature.

A Psychometric chart (pictured below) represents the moisture content of air at various temperatures. This chart shows that as the air temperature increases, the amount of moisture that can be held in dry air also increases.

- Dry bulb temperature: Temperature with no moisture in the air; known as “absolute air.”
- Dew point Temperature: Complete saturation – the maximum amount of water vapor that air can hold. Note that water vapor can carry more heat than air. Relative Humidity (at a given temp) equals the amount of Water Vapor (pounds) over Max amount of water vapor the air can hold equals 100 (at that temp)

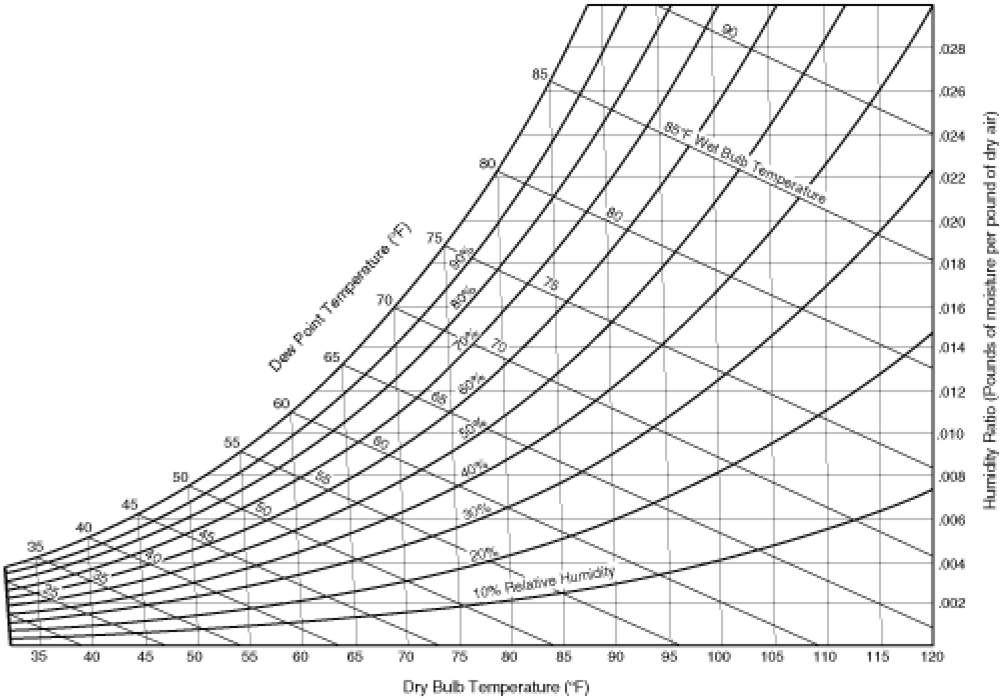


Figure 30. Psychometric Chart (*Zimmerman and Randy. 2023)*

E.Relative humidity, in contrast, is the ratio of the amount of moisture in the air to the maximum amount of moisture the air can hold at a given temperature. It is represented in the formula below:

$$\text{Relative Humidity (at a given temperature)} = \frac{\text{Amount of Water Vapor (lb)}}{\text{Max. Amount of Water Vapor Air can hold}} \times 100 \text{ (at that temp.)}$$

Example 1
Calculate the relative humidity of air when the air contains 0.002 lb of moisture per pound of dry air, while the maximum moisture air can hold at that temperature is 0.005 lb per lb of dry air.

Relative Humidity = lb of moisture per lb of dry air/Max. lb of moisture
per lb of dry air at that temp.
=(0.002 lb/lb of dry air/(0.005 lb/lb of dry air) at that temp)×100=40%

Air is said to be **saturated** when the amount of water vapor in the air is the maximum possible at an existing temperature and pressure.

- Air is said to be saturated at 100 percent *relative* humidity when it contains the maximum amount of moisture possible at that specific temperature.
- Air holding half the maximum amount of moisture at a given temperature has a *relative* humidity of 50 percent.

When relative humidity reaches 100 percent or is saturated, moisture will **condense**, meaning the water vapor changes to liquid vapor.

Thus, the saturation level of air is related to the air's temperature. As air temperature increases (or becomes warmer), more water remains in a gas phase. As temperature decreases (or becomes colder), the water molecules slow down, and it is more likely that they will condense onto nearby surfaces. (EGEE,2022)

F.Dew Point

Is the temperature at which air reaches 100 percent relative humidity. If the air is cooled below dew point, moisture in the air condenses.

Moisture will condense on a surface whose temperature is below the dew point temperature of the air next to it. For air at a given absolute humidity, the colder the surface, the higher the relative humidity next to that surface. So the coldest surface in a room is the place where condensation will probably occur first (called the first condensing surface).

G.The Mollier diagram

Relative humidity and enthalpy are plotted in a diagram against temperature and specific humidity to form the Mollier diagram. The curved lines in the diagram are relative humidity while the diagonal lines are enthalpy.

The left hand diagram is the Mollier diagram used in many countries. The right hand diagram is normally called a Psychrometric chart and is used in most English speaking countries. The diagrams are really the same – they give the same results but the temperature and specific humidity scales are reversed.(Fig 31)

The **Mollier diagram** is a **graphical chart used to describe the thermodynamic properties of moist air**. It is widely used in **meteorology, climatology, and HVAC (heating, ventilation, and air conditioning)**.

- ✓ **What does the Mollier diagram show?**

It represents the relationships between several properties of **humid air**, including:

- **Dry-bulb temperature** (air temperature)
- **Humidity ratio** (amount of water vapor in the air)
- **Relative humidity (%)**
- **Dew point temperature**
- **Specific enthalpy** (heat content of air)
- **Specific volume**

✓ **Why is it useful?**

The Mollier diagram allows you to:

- Analyze **air-conditioning and heating processes**
- Understand **humidification and dehumidification**
- Determine **dew point and condensation conditions**
- Visualize how air properties change during physical processes

✓ **Main features of the diagram**

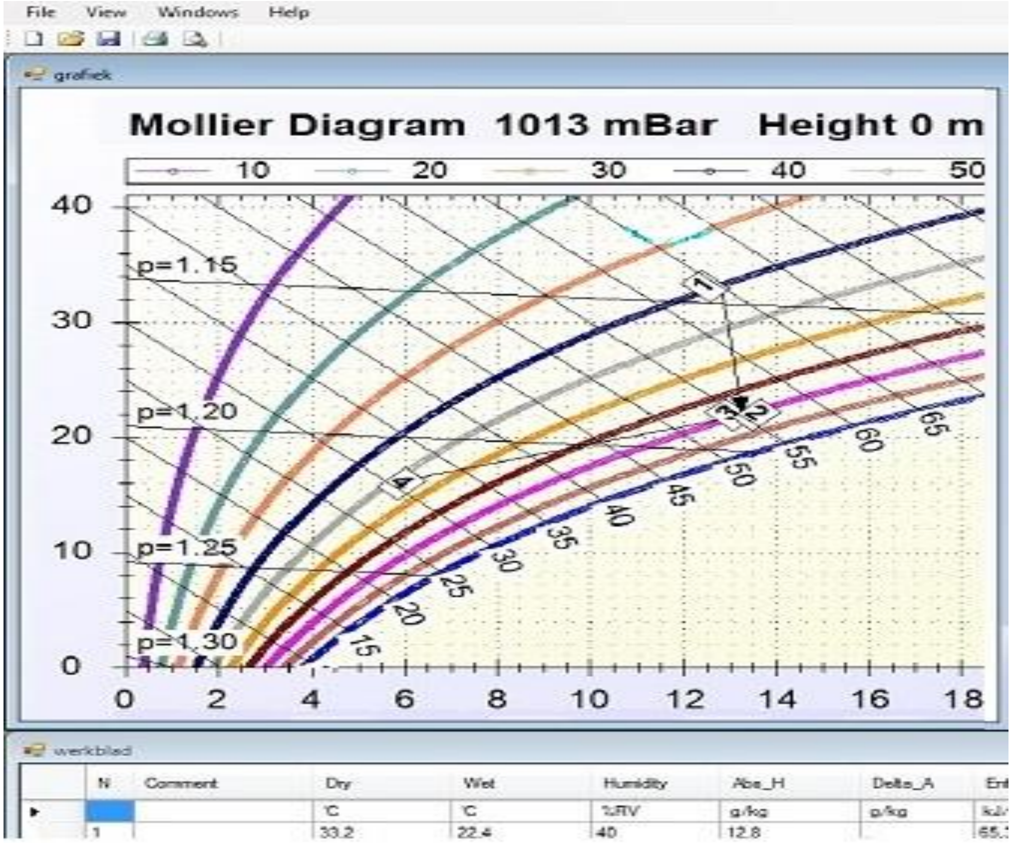
- **Horizontal axis**: Dry-bulb temperature (°C)
- **Vertical axis**: Humidity ratio (g/kg or kg/kg of dry air)
- **Curved lines**: Relative humidity (0–100%)
- **Diagonal lines**: Enthalpy (kJ/kg of dry air)
- **Upper boundary curve**: Saturation line (100% relative humidity)

Example

If air is cooled at constant humidity:

- Its temperature decreases
- Relative humidity increases
- When it reaches the **saturation line**, condensation begins (dew point)
-
  Temperature resolution of 0.1 °C and RH resolution of 1%

✓ **Screenshots of Mollier diagram Pro in different use cases**



	N	Comment	Dry	Wet	Humidity	Abs_H	Delta_A	En
▸			°C	°C	%RV	g/kg	g/kg	kJ
	1		33.2	22.4	40	12.8		65.

Figure 31. Mollier diagram

II.2.3.5. Sunshine (direct light of the sun)

The sun is the ultimate source of all energy on earth and is the most important driving force of the climate system (Beer et al, 2000). Sunshine duration can be considered a proxy measure of global radiation. Presently, there is wide-spread evidence that large changes in the level of radiation reaching the ground have and are occurring over large regions of the globe. Natural and anthropogenic change in the amount of insolation has important implications for climate change studies as well as agriculture, water resources and solar energy applications. Knowledge about solar radiation variability and trends is of great interest because it is a fundamental variable in the energy balance on a range of scales from global to microscale, aside from its impacts on physical and biological systems, and also on the economy and society. Solar radiation received at the top of the atmosphere and by absorption and scattering due to clouds, aerosols, and gases including carbon dioxide, ozone, water vapour, oxygen and nitrogen dioxide.

The shining of the sun, or its direct light, is called **solar radiation** or simply **sunlight**, representing the energy (photons) from its core (fusion of hydrogen to helium) traveling to Earth, measured in units like lumens or watts/m², providing light and warmth, and appearing bright white when unobstructed.

- **Key Terms**: Sunlight, solar radiation, solar energy, solar luminosity.
- **Source**: Nuclear fusion within the Sun's core converts hydrogen into helium, releasing immense energy that travels as photons.
- **Intensity**: Earth receives about 1,368 W/m² (solar constant) of direct sunlight (or about 1,050 W/m² at zenith), but this varies by location and atmosphere.
- **Appearance**: The Sun appears white, its visible surface called the photosphere, emitting light that reaches Earth in about 8 minutes and 20 seconds.
- **Impact**: This energy drives Earth's climate, powers photosynthesis, and is the source of virtually all life's energy.

A.**Sunshine duration**

Sunshine duration describes the duration of direct solar radiation over a certain period of time (e.g. one month) at a certain location. It therefore provides information about the weather and climate at that location. Direct radiation is the main energy input to the earth’s surface. Both, the energy and the water balance are driven by incoming radiation. Sunshine duration anomaly is correlated to cloud distribution and is based on the reference period 1981–2010 for station data and 1991–2020 for satellite data. It is presented as relative anomaly (percent of the normal value for the reference period) and as absolute anomaly (difference to value for the reference period in hours). In addition to its climatological value, sunshine duration is relevant to tourism and solar energy production.

Until December 2017, the calculation of the maps was based on station data. They cover the following parameters:

- Totals
- Anomalies (absolute, relative) For reasons of quality improvement, the data basis was changed from station to satellite data in January 2018.

The years before (backward until 1983) also were recomputed using satellite data. The map display has not been changed. In addition, some more derived products have been added, so that the following products are available now:

- Totals
- Anomalies (absolute, relative, standardized)
- Percentiles

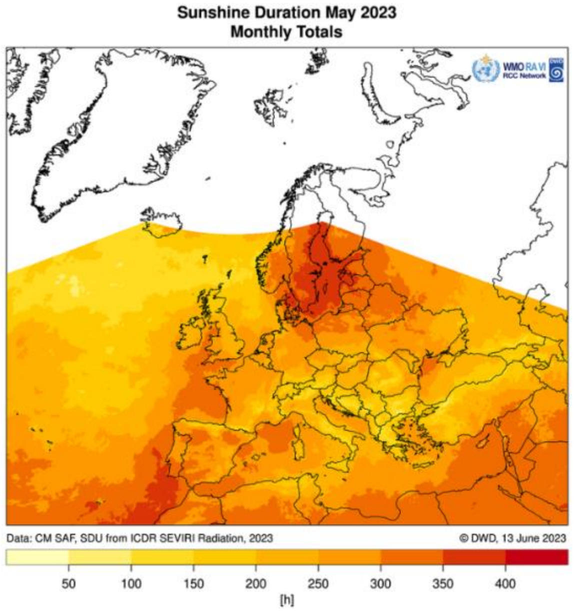


Figure32. Sunshine duration

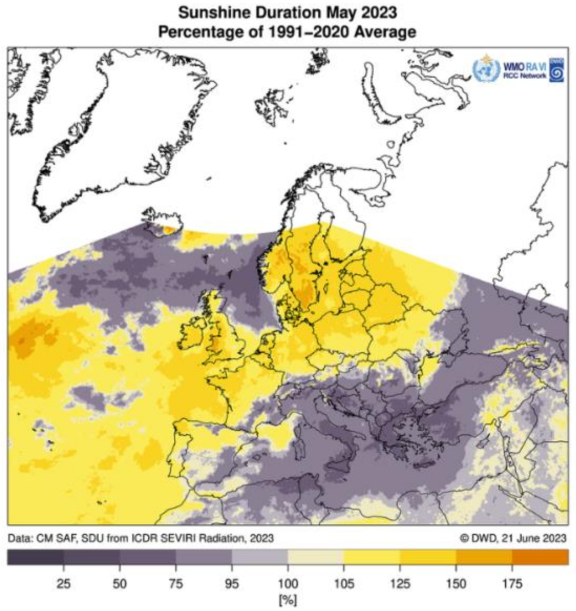


Fig. 33 Sunshine duration percentage of the long-term average

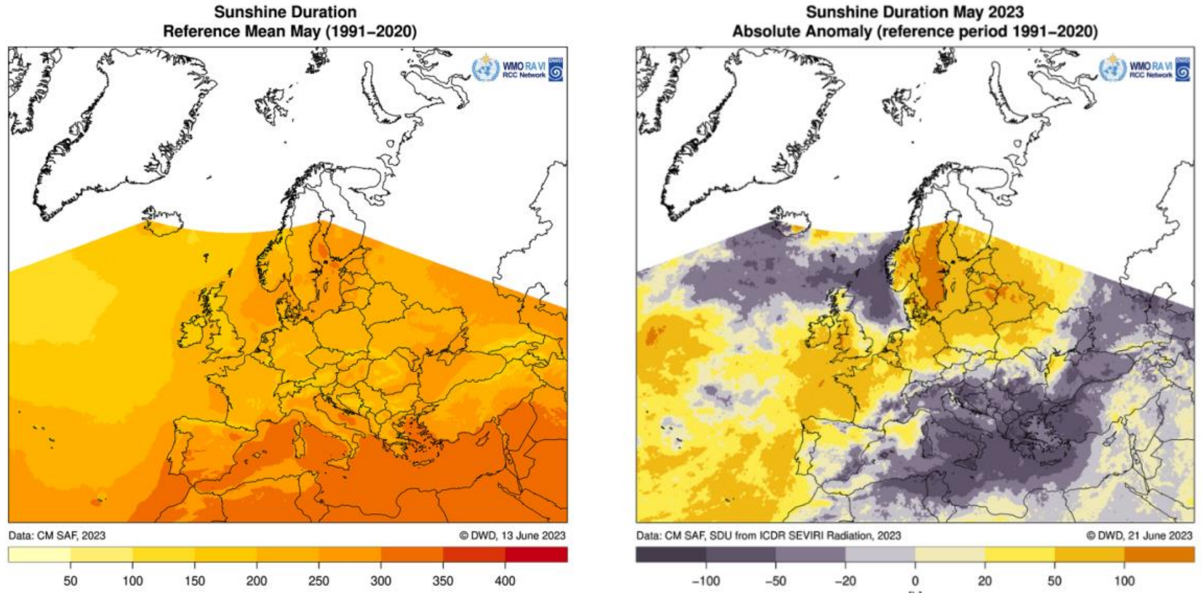


Fig 34.35. Absolute anomalies of sunshine duration.(RCC,2023)

B.How to Measure Sunshine Duration?

Since 1950s, the Observatory has been using conventional Campbell-Stokes sunshine recorder to record the sunshine duration at King's Park. Sunshine recorder essentially consists of a glass sphere mounted in a spherical bowl and a metallic groove which holds a record card. Sun's rays are refracted and focused sharply on the record card beneath the glass sphere, leaving burnt marks on the card. As the sun traverses, continuous burnt marks will appear on the card. Observers can measure the sunshine duration based on the length of the burnt marks.

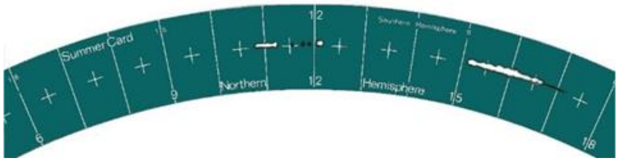


Figure 37. Burn marks on the record card

Figure 36. Campbell-Stokes sunshine recorder

Figure 38. CSD sunshine meter

Although the design and operation of sunshine recorder are quite simple, it requires manual observations of burnt marks on record cards as well as manual change of cards. To streamline operations, the Observatory started using a fully automatic CSD sunshine meter to record sunshine duration since 2005. The sunshine meter consists of three sensors. When sunlight is detected by the sensor, it will be transformed into electricity. Solar radiation can be calculated based on the generated voltage. The sensor at the front, which is used for measuring global solar radiation, is not shaded and receives sunlight from all around. The sensors in the middle and to the rear are partly shaded. The purpose for the shading is to avoid direct sunshine for measurement of diffuse solar radiation. By using the values of global and diffuse solar radiation, the direct solar radiation can be computed and the sunshine duration can be determined according to the latest World Meteorological Organizations definition.(LAM,2023)

Footnote

Sunshine duration during a given period (e.g. within one day) is defined as the sum of the time for which the direct solar irradiance exceeds 120 W/m^2.

II.2.3.6. Wind

Wind is defined as the moving air of atmosphere parallel to earth’s surface (air in horizontal motion). All other masses of air in motion (vertical) should be called as Air Currents. Wind is an invisible weather element but the effect of wind can be seen from the movement of tree branches, dust particles and by feeling. The pattern and intensity of wind is affected by various factors.

A. Origin of Wind

Wind is caused by differences in atmospheric pressure, which are primarily due to temperature differences. When a difference in atmospheric pressure exists, air moves from the higher to the lower pressure area, resulting in winds of various speeds. On a rotating planet, air will also be deflected by the Coriolis effect, except exactly on the equator. Globally, the two major driving factors of large-scale wind patterns (the atmospheric circulation) are the differential heating between the equator and the poles (difference in absorption of solar energy leading to buoyancy forces) and the rotation of the planet. Outside the tropics and aloft from frictional effects of the surface, the large-scale winds tend to approach geostrophic balance. Near the Earth's surface, friction causes the wind to be slower than it would be otherwise. Surface friction also causes winds to blow more inward into low-pressure areas.(Makarieva et al., 2013)

Winds defined by an equilibrium of physical forces are used in the decomposition and analysis of wind profiles. They are useful for simplifying the atmospheric equations of motion and for making qualitative arguments about the horizontal and vertical distribution of horizontal winds. The geostrophic wind component is the result of the balance between Coriolis force and pressure gradient force. It flows parallel to isobars and approximates the flow above the atmospheric boundary layer in the midlatitudes. (Fig.39)The thermal wind is the *difference* in the geostrophic wind between two levels in the atmosphere. It exists only in an atmosphere with horizontal temperature gradients. The ageostrophic wind component is the difference between actual and geostrophic wind, which is responsible for air "filling up" cyclones over time. The gradient wind is similar to the geostrophic wind but also includes centrifugal force (or centripetal acceleration). (MAM,2009)

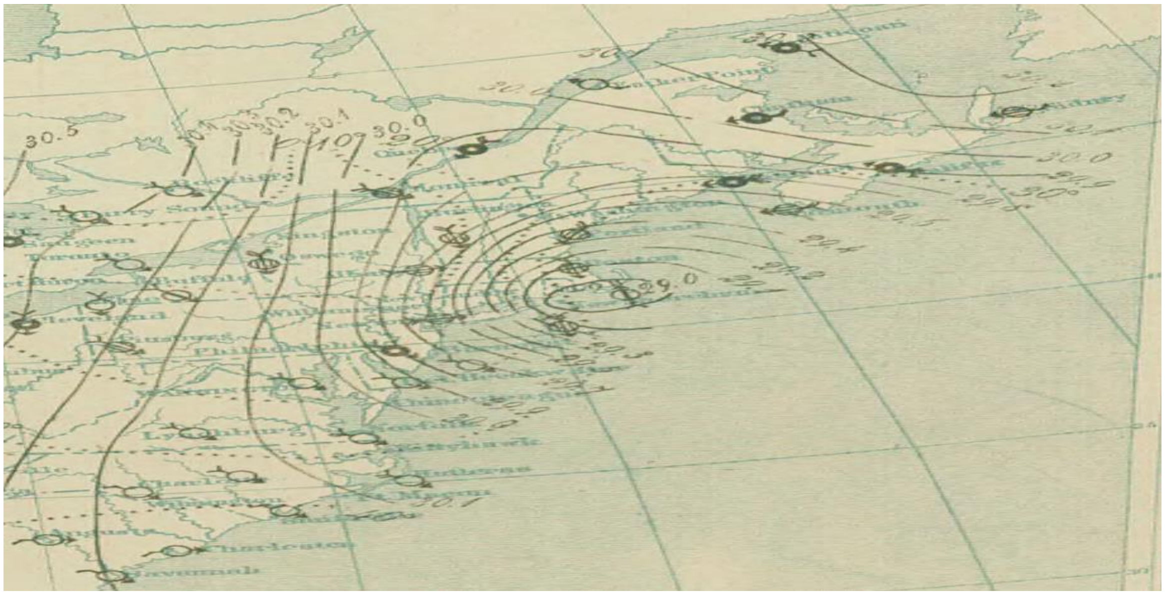


Figure 39.Surface analysis of the Great Blizzard of 1888. Areas with greater isobaric packing indicate higher winds.

B.How we measure wind

The instruments used to measure wind are known as anemometers and can record wind speed, direction and the strength of gusts.

The normal unit of wind speed is the knot (*nautical mile per hour = 0.51 m sec-1 = 1.15 mph*). Wind direction is measured relative to true north (*not magnetic north*) and is reported from where the wind is blowing. An easterly wind blows from the east or 90 degrees, a southerly from the south or 180 degrees and a westerly from the west or 270 degrees.

Wind speed normally increases with height above the earth's surface and is much affected by such factors as the roughness of the ground and the presence of buildings, trees and other obstacles in the vicinity.

The optimal exposure for the measurement of wind is over level ground of uniform roughness with no large obstacles within 300 m of the tower. In practice few sites in the observing network meet this requirement exactly for all incident wind directions, but most are reasonably representative of an open site.

- **Cup anemometer**

Wind speed is normally measured by a cup anemometer consisting of three or four cups, conical or hemispherical in shape, mounted symmetrically about a vertical spindle. The wind blowing into the cups causes the spindle to rotate. In standard instruments the design of the cups is such that the rate of rotation is proportional to the speed of the wind to a sufficiently close approximation.

At intervals of no longer than five years, anemometers are calibrated in a wind tunnel to identify any departures in the relationship between spindle rotation and wind speed specified by the manufacturer. Calibration corrections are applied to the measured wind speed.

Figure 40. Measuring wind direction

Wind direction is measured by a vane consisting of a thin horizontal arm carrying a vertical flat plate at one end with its edge to the wind and at the other end a balance weight which also serves as a pointer. The arm is carried on a vertical spindle mounted on bearings which allow it to turn freely in the wind. The anemometer and wind vane are each attached to a horizontal supporting arm at the top of a 10 m mast.

- **Sonic anemometer**

Where wind measurements are made in extreme weather conditions, such as on the top of mountains, a heated sonic anemometer is used having no moving parts. The instrument measures the speed of acoustic signals transmitted between two transducers located at the end of thin arms. Measurements from two pairs of transducers can be combined to yield an estimate of wind speed and direction.

The distortion of the air flow by the structure supporting the transducers is a problem which can be minimized by applying corrections based on calibrations in a wind tunnel.

Figure 41. Measuring gusts and wind intensity

Because wind is an element that varies rapidly over very short periods of time it is sampled at high frequency (*every 0.25 sec*) to capture the intensity of gusts, or short-lived peaks in speed, which inflict greatest damage in storms. The gust speed and direction are defined by the maximum three second average wind speed occurring in any period.

A better measure of the overall wind intensity is defined by the average speed and direction over the ten minute period leading up to the reporting time. Mean wind over other averaging periods may also be calculated. A gale is defined as a surface wind of mean speed of 34-40 knots, averaged over a period of ten minutes. Terms such as 'severe gale', 'storm', etc are also used to describe winds of 41 knots or greater.

C. Large-scale Wind systems of the Earth

➢ General Circulation Winds

General circulation winds are large-scale wind systems generated by the Earth's rotation and the uneven heating of its surface by the sun. These winds are governed by three primary atmospheric circulation cells:

- Hadley Cell: Drives trade winds in tropical regions, characterized by rising air near the equator and descending air at subtropical latitudes.
- Ferrel Cell: Located in the mid-latitudes, this cell governs the westerlies and facilitates the dynamic exchange of warm and cold air masses.
- Polar Cell: Found in polar regions, this cell drives the polar easterlies and contributes to the maintenance of temperature gradients between high and mid-latitudes.

Major atmospheric cells are also influenced by the Coriolis effect, a force caused by the Earth's rotation that deflects north-moving winds to the east in the Northern Hemisphere and to the west in the Southern Hemisphere. These winds govern global weather patterns and include the following major wind types:

1. Trade Winds

Trade winds are consistent winds that blow from east to west in tropical regions, typically between 30 degrees north and 30 degrees south latitude. They are driven by the Hadley cell, a circulation pattern where warm air rises near the equator, moves poleward at high altitudes, and descends in subtropical regions.

Relevance to the Wind Industry

- Offshore wind farms in tropical regions can harness the reliability of trade winds for consistent energy production.
- Long-term studies of trade winds aid in optimizing site selection and energy output predictions.

2. Westerlies

Westerlies are prevailing winds that blow from west to east in the mid- latitudes (30 to 60 degrees latitude in both hemispheres). These winds are particularly strong during winter and are associated with cyclonic weather systems.

Relevance to the Wind Industry

- Many onshore and offshore wind farms in Europe, North America, and parts of Asia are strategically positioned to capture the power of westerlies.
- Seasonal variability in westerlies necessitates advanced studies to ensure stable energy production throughout the year.

3. Polar Easterlies

Polar easterlies are cold, dry winds that blow from east to west in high- latitude regions near the poles. They originate from the polar high-pressure areas and flow toward lower latitudes.

Relevance to the Wind Industry

- While less commonly utilized for large-scale wind farms, polar easterlies are significant for research stations and emerging projects in cold-climate regions.

4. Jet Streams:

Jet streams are high-altitude wind currents that flow at speeds of up to 300 km/h near the tropopause, the boundary between the troposphere and the stratosphere. They form at the convergence of warm and cold air masses.

– Polar Jet Stream: Situated between 50 and 60 degrees of latitude, these winds exhibit their peak strength during the winter months. They significantly influence the trajectories of storm systems and weather patterns in mid- latitudes.

– Subtropical Jet Stream: Positioned approximately 30 degrees of latitude, these winds exhibit a generally lower magnitude compared to the polar jet stream. Nevertheless, they still contribute to the formation and evolution of large-scale weather patterns.

Relevance to the Wind Industry

- Jet streams influence surface-level wind patterns and global weather systems, though not directly harnessed by turbines.
- Analyzing the jet stream’s behaviour reveals long-term climate trends and their impact on wind energy resources.

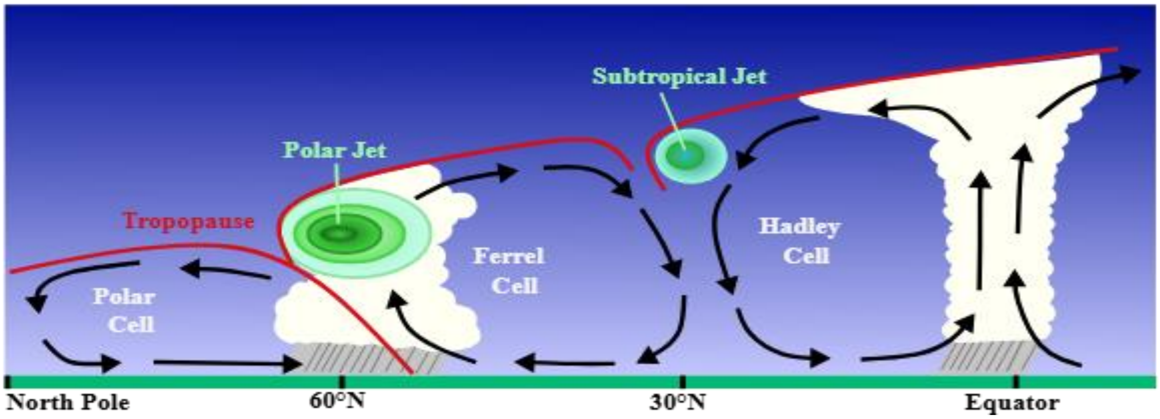


Figure 42. Cross section of the subtropical and polar jet streams by latitude. (National Weather Service Jet Stream Vector.2023)

➢ Linear Flow vs. Turbulence in General Circulation Winds

General circulation winds, characterized by their broad and steady patterns, can exhibit variability due to localized factors such as topography and atmospheric conditions.

Linear Flow

In open regions like oceans or plains, general circulation winds exhibit smooth and uniform flow. Linear flow ensures stable energy generation and reduces wear on turbine components.

Turbulence

Near coastlines, mountains, or urban areas, general circulation winds can become turbulent. Turbulence impacts turbine efficiency and increases maintenance requirements.

Relevance to the Wind Industry

- Turbine Design: Offshore turbines, often placed in areas dominated by linear flow, prioritize efficiency and reliability. Turbines near land or complex terrain must account for turbulence.
- Modeling: High-resolution data and simulations are crucial for predicting how general circulation winds interact with local landscapes, ensuring optimal turbine placement.

In conclusion, a comprehensive understanding of general circulation winds is essential for the wind energy industry to optimize energy production, enhance turbine performance, and ensure efficient site selection. Understanding general circulation winds is vital for macro-level planning, as it helps identify regions with reliable wind resources for large-scale projects. It also plays a crucial role in forecasting by enabling the development of accurate models to predict both seasonal and long-term wind patterns. Additionally, understanding these winds is essential for risk mitigation, allowing the anticipation of shifts in global wind behavior due to climate change and the adaptation of strategies accordingly.(Bosch,2013)

D. Mesoscale Motions

These motions are also referred to as *cyclonic disturbances*. They are caused by differences in heating between land and sea. They typically extend over distances of about 500 to 1,200 km, and their main wind systems are monsoons and cyclones.

- **Monsoon:**

These are seasonal winds characteristic of Asian regions. During summer, they blow from the sea toward the land, while in winter the flow is reversed. In all cases, they bring heavy precipitation and are often the cause of natural disasters in areas of South Asia, particularly in India, Bangladesh, Myanmar, Thailand, and the Philippines.

The monsoon phenomenon is comparable, on a large scale, to sea and land breezes. It results from seasonal changes in barometric pressure systems.

During winter in the Northern Hemisphere, dry and dense air establishes a strong anticyclonic zone over Siberia. Strong northeasterly winds blow toward the sea; these are known as the dry monsoons.

In summer, the land heats up more rapidly than the sea. The anticyclone weakens, and in its place a low-pressure system develops, attracting moist maritime winds.

from the southwest, accompanied by very heavy rainfall; these are the wet monsoons.

The monsoon returns every year, but it sometimes fails to occur or produces only limited rainfall. The consequences are then catastrophic for farmers, whose crops depend heavily on precipitation.

- **Cyclones:**

These are strong atmospheric disturbances generated by frontal systems and atmospheric pressure differences. Two categories are distinguished: extratropical cyclones and tropical cyclones (storms).

E. Small-scale Motions (Local Winds)

They are called *local winds* because they blow over a limited area. The best-known local winds include:

- **The Mistral:** a cool or cold, often violent wind affecting the northern part of the western Mediterranean basin.
- **The Sirocco:** a violent Saharan wind, very dry and very hot, blowing over North Africa and the southern Mediterranean Sea.

Changes in wind speed and direction at altitudes of around 100 m are very important for wind-energy conversion applications. Local winds are strongly influenced by factors such as the sea, the land, and mountains.

During the day, the land heats up more rapidly than the sea, causing warm air to rise and then flow seaward. Cooler air from the sea is immediately drawn toward the low-pressure area created over the land due to heating: this is the **sea breeze**. At night, the direction of this breeze reverses (**land breeze**).

Relief features, especially mountains, greatly favor many interesting climatological phenomena. Air begins to rise toward the mountain summit, producing what is known as an **upslope (anabatic) breeze**. At night, the phenomenon reverses and a **downslope (katabatic) breeze** occurs.

Another phenomenon caused by mountains and hills is known as the **tunnel effect** (or funneling effect), in which wind speed increases significantly within the corridor. This phenomenon is often exploited in the installation of wind turbines.

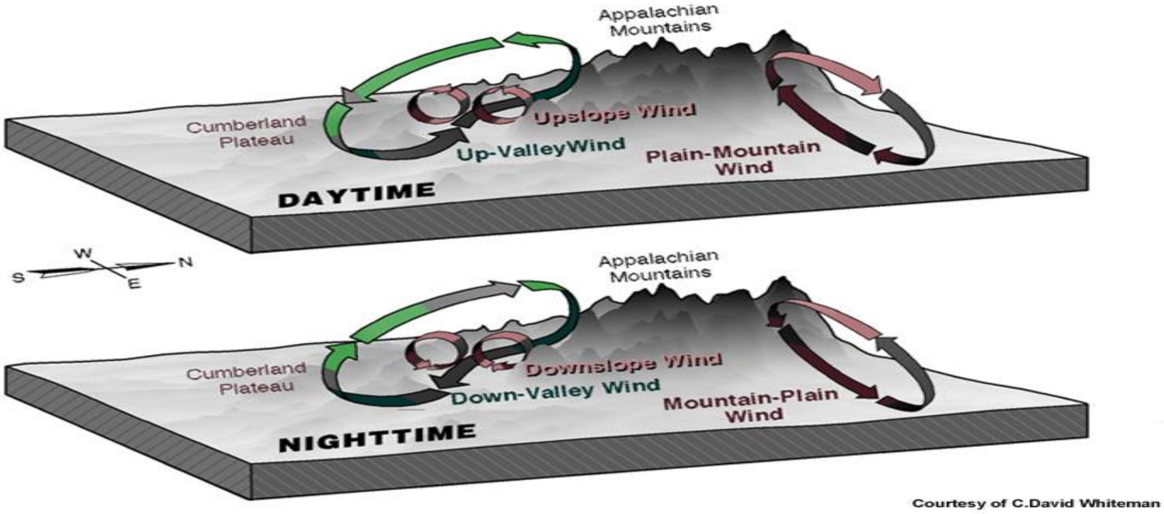


Figure 43. Local wind.[Diurnal wind system variation in the Appalachian mountain range. Whiteman 2015)

F. Wind rose

A wind rose is a chart used to represent the direction and frequency of winds at a given location over a specific period. Although they are often used to display wind direction and speed, they also have many other potential uses.

The diagram's irregular shape resembles a rose, thus its name, a wind rose. Some wind roses contain information about the air temperature.

Wind rose diagrams help airport engineers identify potential engineering issues that may impact airport operations. Graphical vector analysis of a wind rose helps identify the best runway orientation for an airport.

- **Types of Wind Rose Diagrams**

A typical wind rose consists of concentric circles, radial lines emanating from the circles' centre and polar coordinates.

There are two main types of wind roses; Type-I and Type–II.

Type – I

This wind rose plots the wind's direction and duration. The radial lines show the direction of the wind, while the circles indicate the duration of the wind in that direction.

Type – II

It shows the strength, duration and direction of wind. The size of the circles represents the speed of the wind. Each section's value indicates the annual average percentage of time that winds of that strength blow from that direction. The angle of the radial lines indicates the direction of the wind.

Some Type-II wind rose diagrams have additional data encoded in the colours of their spokes. Every spoke is colour-coded to indicate a different range of speeds, and the length of the banding on the spoke denotes the frequency.

The size of the circle in the middle represents the percentage of times when wind conditions are calm (calm period). The larger it is, the more the times that calm wind conditions prevail. In a calm period, the wind speed from any direction is less than 6.4 kilometres per hour.

Wind data for a wind rose should be acquired for at least 5 years, and preferably for 10, to provide a credible average.

- **Uses of wind rose**

-Presented in a circular format, the modern wind rose shows the frequency of winds blowing from particular directions over a specified period.

-The length of each "spoke" around the circle is related to the frequency that the wind blows from a particular direction per unit time.

- Each concentric circle represents a different frequency, emanating from zero at the center to increasing frequencies at the outer circles.

-A wind rose plot may contain additional information, in that each spoke is broken down into color- coded bands that show wind speed ranges.

- Wind roses typically use 16 cardinal directions, such as north (N), NNE, NE, etc although they may be subdivided into as many as 32 directions.

-In terms of angular measurement in degrees, North corresponds to 0°/360°, east to 90°, South to 180° and West to 270°.

-Compiling a wind rose is one of the preliminary steps taken in constructing airport runways, as aircraft typically perform their best takeoffs and landings pointing into the wind.

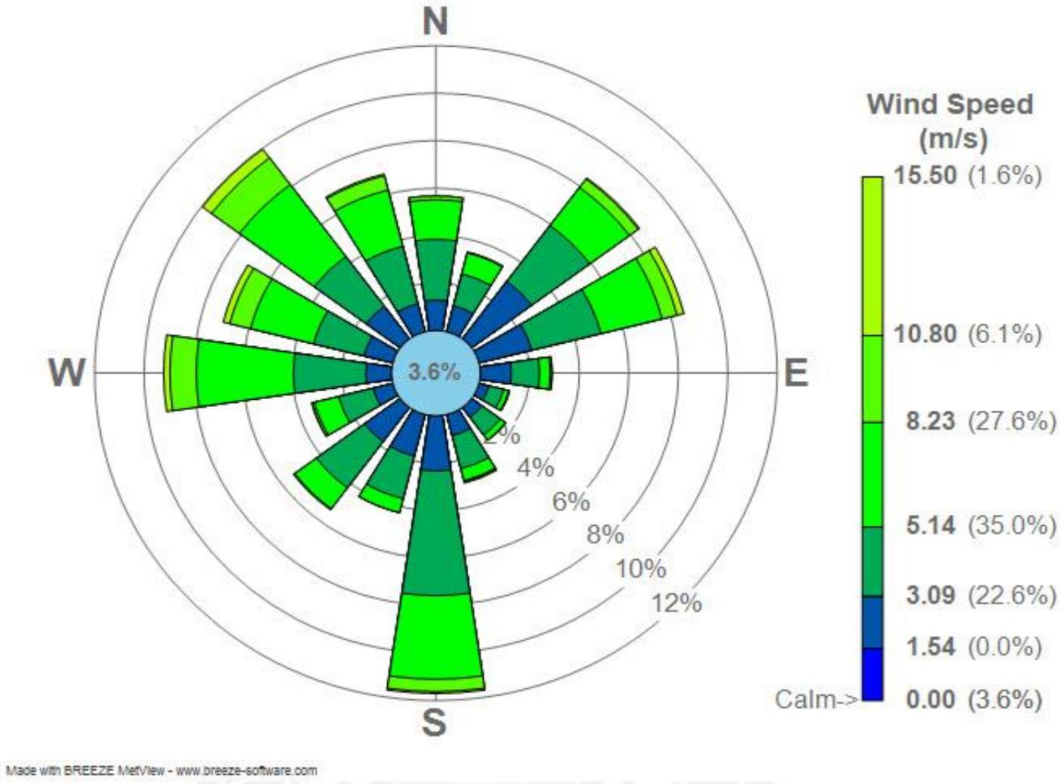


Figure 44. wind Rose Diagram

[Source:https://en.wikipedia.org/wiki/File:Wind_rose_plot.jpg]

G. Lapse Rate (Vertical Temperature Gradient)

As an air parcel rises in the Earth's atmosphere, it experiences decreasing pressure from the surrounding air. This decrease in pressure causes the parcel to expand, which in turn leads to a drop in its temperature.

Under ideal conditions—when the air parcel does not exchange heat with its surroundings and contains no moisture (dry air)—it cools at a rate of approximately 1 °C per 100 m of ascent. This is known as the dry adiabatic lapse rate. Conversely, when the parcel descends, it warms at the same rate.

For a given location and time, the actual air temperature profile can be measured using a balloon equipped with a thermometer. The balloon moves through the air masses rather than with them. The resulting vertical temperature profile is called the environmental lapse rate or prevailing lapse rate.

Several types of lapse rates can be distinguished:

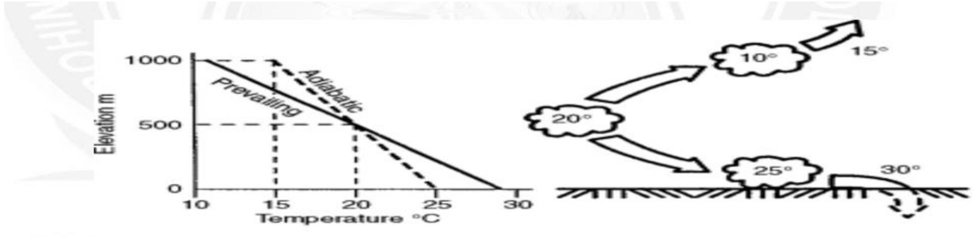
- A super-adiabatic lapse rate (strong lapse rate) occurs when the atmospheric temperature decreases at a rate greater than 1 °C per 100 m.
- A sub-adiabatic lapse rate (weak lapse rate) occurs when the temperature decreases at a rate of less than 1 °C per 100 m.
- A special case of a weak lapse rate is a temperature inversion, where a warmer air layer lies above a colder air layer.

Under super-adiabatic conditions, the atmosphere is unstable. This is illustrated in Figure 45. For example, an air parcel at 500 m altitude with a temperature of 20 °C, when lifted to 1000 m, cools to 15 °C according to the dry adiabatic lapse rate. However, if the surrounding air at 1000 m is 10 °C, the parcel remains warmer than its environment and continues to rise.

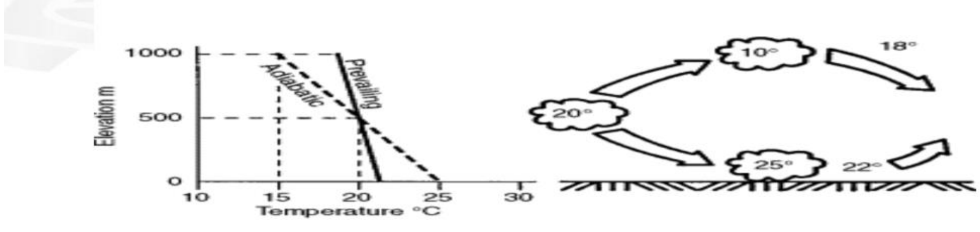
If the same parcel is displaced downward, it becomes colder than its surroundings and continues to sink. Therefore, super-adiabatic conditions are characterized by strong vertical air motion and high atmospheric turbulence.

In contrast, sub-adiabatic conditions represent a stable atmosphere. In this case, a parcel of air lifted from 500 m (20 °C) to 1000 m would cool to 15 °C, but the surrounding air is warmer, so the parcel becomes denser and returns to its original level.

Similarly, if the parcel is forced downward, it becomes warmer than the surrounding air and rises back to its initial position. Thus, stable conditions are associated with weak vertical mixing of air, while unstable conditions promote strong convection and turbulence.



A. Super-adiabatic conditions (unstable)



B. Sub-adiabatic conditions (stable)

Figure 45. Stability and vertical air movement
(Source:https://www.sciencedirect.com/browse/journals-and-books)

H. Mechanisms of the general circulation of wind systems (Trade winds)

a. Centers of action: Anticyclone and depression

- **Anticyclone**

An anticyclone is a closed area of high atmospheric pressure, or a center of action characterized by isobars with pressures higher than 1,013.25 hPa. In high-pressure areas, cold air masses descend and become drier (Fig. 12). Consequently, there is no precipitation under an anticyclone.

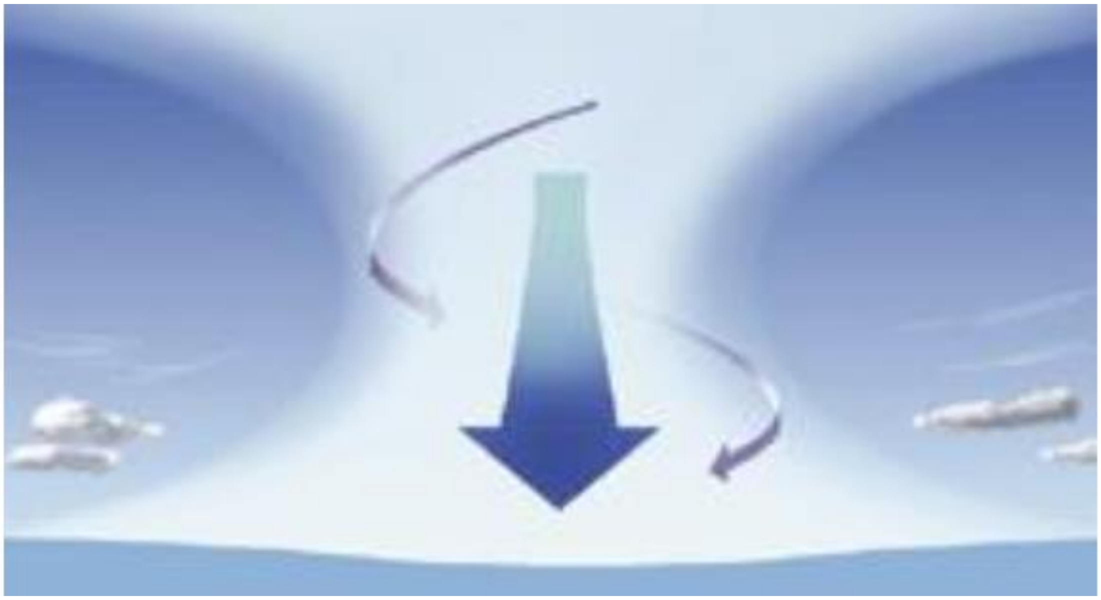


Figure 46. Downward movement of air in an anticyclone.

Winds are weaker under an anticyclone, with the consequence that anticyclonic conditions can lead to peaks in pollutant concentrations, especially in winter when the air is colder and therefore more stable. Indeed, anticyclones are more persistent in summer.

- **Depression (Low-pressure system)**

The centers of action of low-pressure contours, namely pressures lower than 1,013.25 hPa, are called depressions. Precipitation generally occurs in low-pressure areas because warm, moist air rises there and, as it cools, rapidly becomes saturated with moisture (Fig. 13). The amount of water vapor that can be contained in an air mass is proportional to its temperature; when this air rises and cools, there comes a point at which the amount of water vapor becomes too great for the temperature. This is referred to as 100% relative humidity. As a result, condensation occurs, first in the form of clouds and then as precipitation.

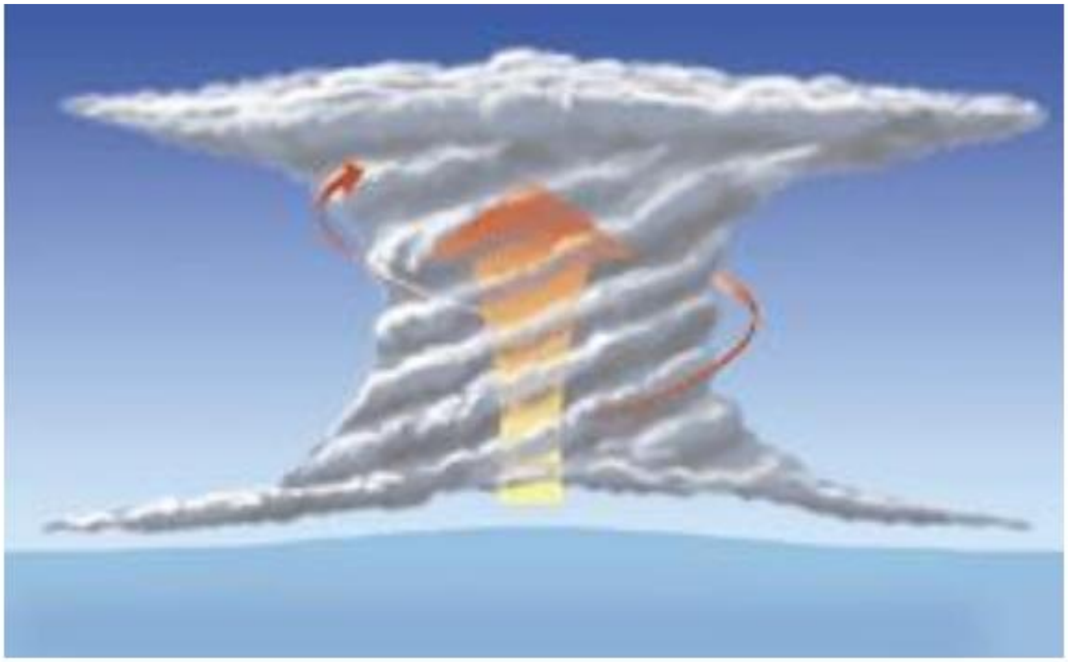


Figure 47. Déplacement de l'air ascendant dans une dépression

b.Surface wind direction

The study of weather maps shows that winds, cloud movements, and weather conditions can be correlated with differences in atmospheric pressure between two regions. Air masses generally move from areas of high pressure to areas of low pressure. The movement of clouds and the direction of winds are influenced by the Coriolis force, which results from the Earth's sphericity and its west-to-east rotation.

On a global scale, areas of rising air (the equator and 60° latitude) correspond to low-pressure zones. Conversely, the sinking of cold air generates high pressure (in the tropics and at the poles). Thus, trade winds are directed from the tropics toward the equator, blowing from east to west due to the Coriolis force (Fig. 48). Similarly, in the temperate zone, winds blow from the tropical high-pressure areas toward low-pressure zones near 60° latitude, but are deflected eastward by the Coriolis force.

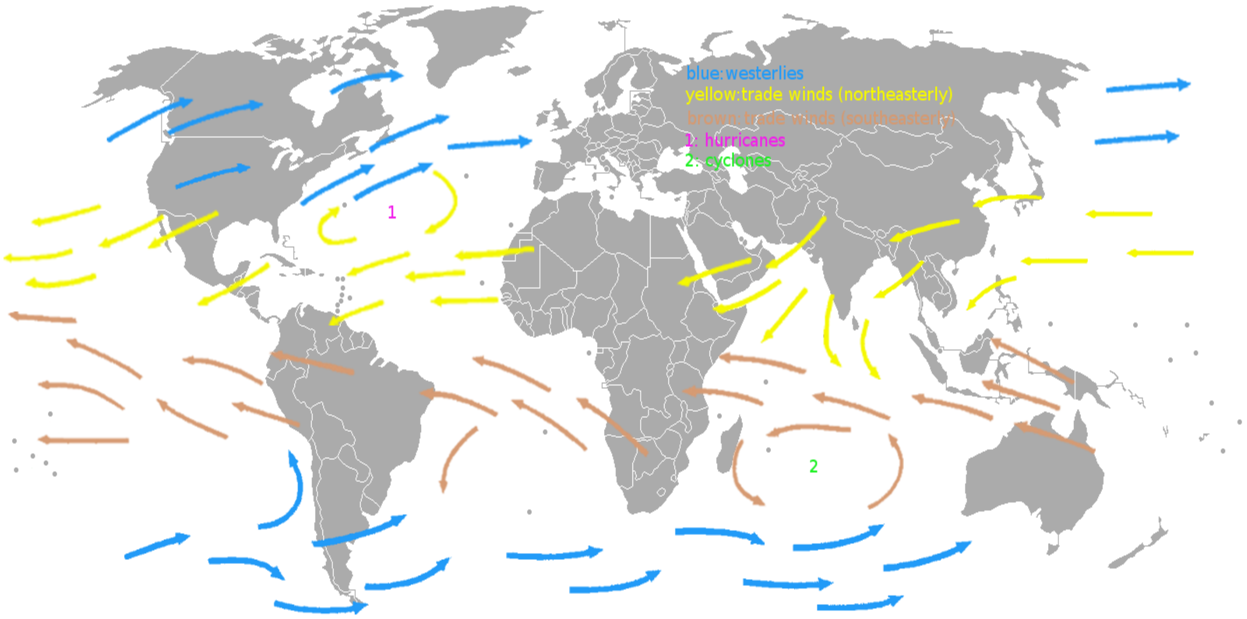


Figure 48. Directions and speeds of the main surface winds (Trade Winds)

Chapter III. The Atmosphere and the tropospheric circulation

The atmosphere is usually recognized as layers of mixture of gases that surrounds the Earth, extending from the Earth's surface up many hundreds of kilometers, becoming increasingly thinner with altitude but always held by the Earth's gravitational attraction. Figure 1, Illustrates its main features. The atmosphere surrounds the Earth and holds the air we breathe; it protects us from outer space; and holds moisture (clouds), gases, and tiny particles .

It can be stated that, the atmosphere helps make life possible by providing us with air to breathe, shielding us from harmful ultraviolet (UV) radiation coming from the Sun, trapping heat to warm the planet, and preventing extreme temperature differences between day and night. Without the atmosphere, temperatures would be well below freezing everywhere on Earth's surface. Instead, the heat absorbed and trapped by our atmosphere keeps our planet's average surface temperature at a balmy 15°C (59°F) **(UCAR,2021)**.

Figure 49. The layered structure of Earth's atmosphere surrounds the Earth **(UCAR, 2021).**

The Earth's atmosphere is an extremely thin sheet of air extending from the surface of the Earth to the edge of space. The Earth is a sphere with a roughly (6500 km) radius; the thickness of the atmosphere is about (100 km)

It can be seen that, the atmosphere as the thin blue band between the surface and the blackness of space. If the Earth were the size of a basketball, the thickness of the atmosphere could be modeled by a thin sheet of plastic wrapped around the ball. Gravity holds the atmosphere to the Earth's surface. Within the atmosphere, very complex chemical, thermodynamic, and fluid dynamics effects occur. The atmosphere is not uniform; fluid

properties are constantly changing with time and location .

The various layers of the atmosphere as shown in figure 46 illustrate how the properties of the atmosphere change most sharply near the ground. Barometric pressure, air density and temperature decrease with increasing height above the Earth's surface. These changes with altitude, in temperature, humidity, density, and viscosity are all quantitatively important in aviation and in their effect on a suspended solids and spore in the atmosphere **.**

Therefore, It is important to represent and describe these layers in order, from ground-level upwards, beginning with the troposphere, the stratosphere, the mesosphere, the thermosphere, and exosphere. The order of these layers is shown in fig 50.

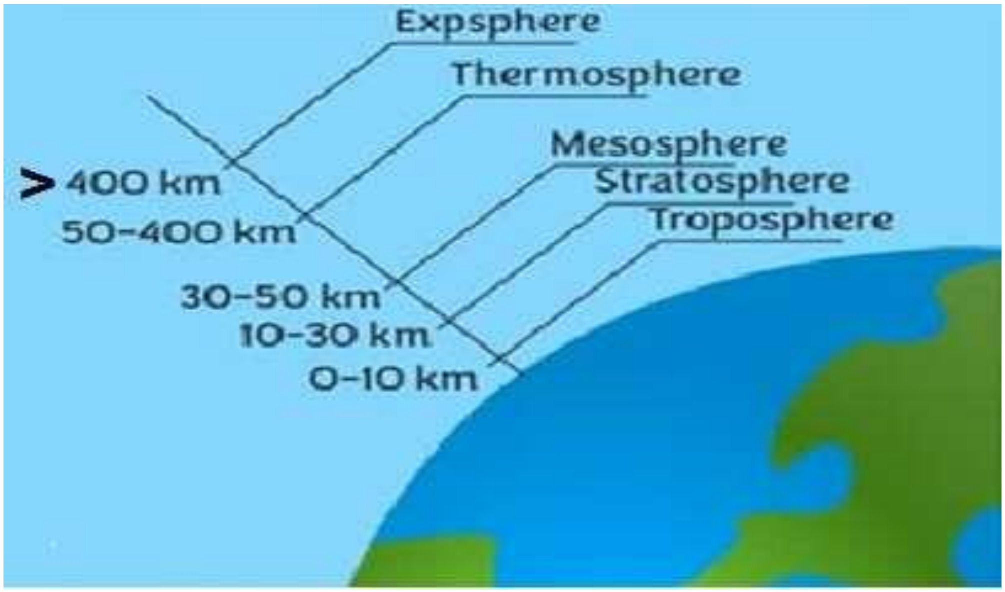


Figure 50. The layers of the atmosphere **(Careers ,2025)**

III.1. Structure of the atmosphere

The atmosphere consists of layers divided vertically into five layers based on temperature and altitude above the Earth's surface. Each layer has its own physical and chemical characteristics and properties such as density, pressure, chemical and electrical and temperature properties .

III.1.1 The Troposphere

The troposphere is the name given collectively to the lower layers of the atmosphere extending from the ground to a height of approximately 10 km., and is a region characterized by a decrease in temperature with increasing height at 'lapse rate' of o.6°C. per l00 meters . Since air is transparent to the short-wave radiation of sunlight, solar radiation falling on the Earth's surface is temporarily absorbed by the earth's surface. This mechanism gives rise to heating the earth surface thus increase its temperature. This condition allows the earth to emit a radiation of longer wave-length that is more readily absorbed by air **.**

The emitted radiation now heats the layer of air near the ground and the heat later becomes diffused through the lower layers of the atmosphere from below upwards. Therefore, air temperature is thus highest near the ground and decreases with increasing height.
At the top of the troposphere is the tropopause the boundary between troposphere and stratosphere It can be stated that almost all weather occurs in the troposphere. Also in the troposphere as the density of gases in this layer decreases with height, the air becomes thinner. Therefore, the temperature in the troposphere also decreases with height**.** In addition, the height of the troposphere varies from the equator to the poles. At the
equator it is around (18-20 km) high, and at the poles just under (6.5 km) high **.** The elemental composition of the troposphere is a uniform mixture of different sorts of gases, predominantly

molecular nitrogen (N2) (78%), molecular oxygen (O2) (21%), and argon (Ar) (0.9%) and other minor gasses, hydrogen (H) and several other gases (0.1%)). All weather is confined to the troposphere; it contains 90% of the Earth's atmosphere and 99% of the water vapor .

III.1.2 The Stratosphere

The region above 10 km to about 50 km is called the stratosphere . This layer holds 19 percent of the atmosphere's gases but very little water vapor. Temperature increases with height as an ultraviolet radiation is increasingly absorbed by oxygen molecules which lead to the formation of Ozone . Incoming solar radiation at wavelengths below 240 nm is able to break up (dissociate) molecular oxygen (O2) into individual oxygen atoms. Each of these atoms in turn may combine with an oxygen molecule (O2) to form ozone. A molecule of ozone consists of three oxygen atoms (O3).

The ozone gas reaches a peak density of a few parts per million at an altitude of about 25 km [8]. The increasing temperature in the stratosphere from an average (-60°C) to a maximum of about (-15°C) makes it a calm layer with movements of the gases slow .

On the other, the dust of the stratosphere, including organic spores is believed to be meteoric and to have entered the Earth's atmosphere from space except for occasional incursions in air currents dragged up into the stratosphere by volcanic eruptions and hydrogen bombs . However, recent studies of atmospheric circulation have pointed out that an exchange of air between troposphere and stratosphere has been confirmed .

III.1.3.The mesosphere

The mesosphere extends from the stratopause to about (85 km) above the earth. The density of gases in the mesosphere, continue to become thinner with height. As a result, the warming process in the mesosphere by ultraviolet radiation becomes less, leading to a decrease in temperature with height from about (-15°C) to as low as (-120°C) . Starting at heights of 80 km, the gas becomes so thin that free electrons can exit for short periods of time before they are captured by a nearby positive ion . However, meteors or falling stars occur in this layer .The gases in the mesosphere are thick enough to slow down meteorites hurtling into the atmosphere, where they burn up, leaving fiery trails in the night sky . When a meteoroid enters Earth's upper atmosphere, it heats up due to friction from the air . The heat causes gases around the meteoroid to glow brightly, and a meteor appears. Meteors are often referred to as shooting stars or falling stars because of the bright tail of light they create as they pass through the sky .

III.1.4. Thermosphere

The thermosphere is directly above the mesosphere and below the exosphere. It is a layer of the Earth's atmosphere that extends from 100 km to around 1000 km. It is made up of N2 , O2, and atomic O.

The thermosphere is characterized by high atmospheric temperature and is influenced by variations in solar extreme ultraviolet radiation, X-rays and geomagnetic activity . The thermosphere is closely coupled with the ionosphere, which is formed by solar X-rays and ultraviolet radiation. Solar activity strongly influences temperature in the thermosphere. The ionosphere and thermosphere together form a complex coupled system that plays a critical role in space weather applications, communications, navigation and scientific understanding . Figure 51 explains the interaction mechanism between the

thermosphere and the ionosphere. The thermosphere and the ionosphere have the same space but different physical elements. Normal elements such as N2, O2, and atomic O are referred as the thermosphere. Ionized elements such as e-, O+, and O2+ are referred as the ionosphere .

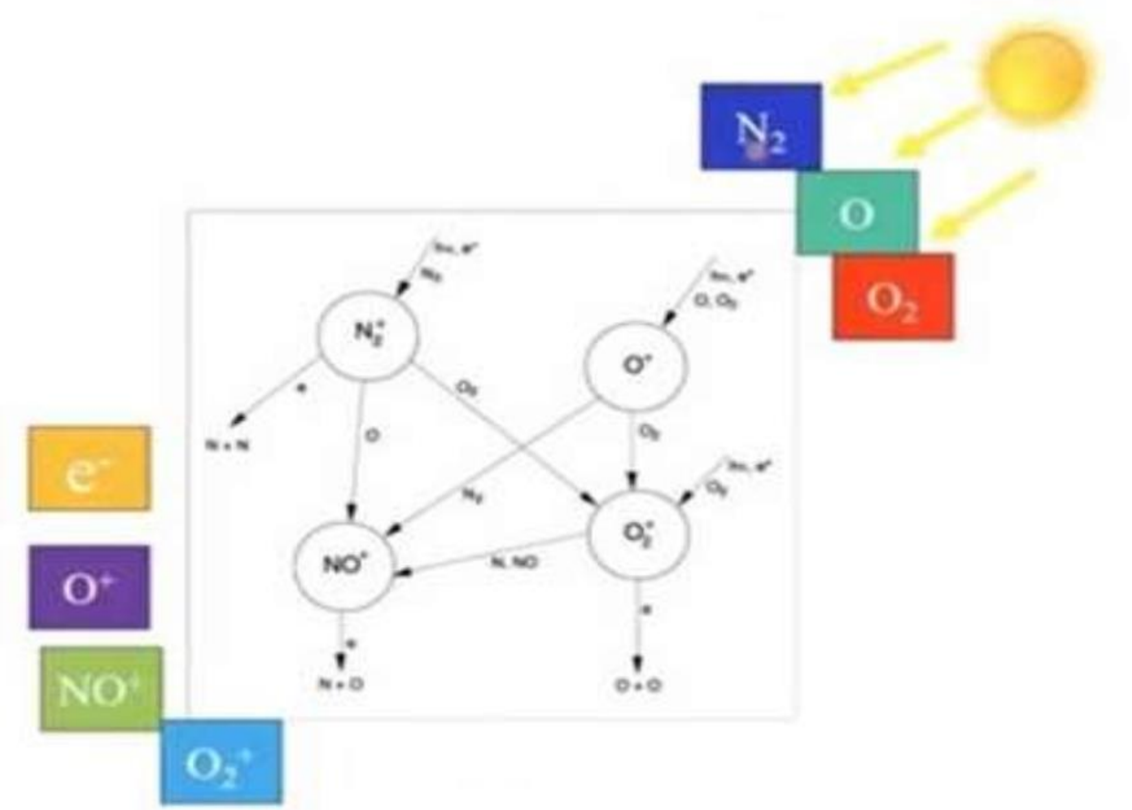


Figure 51. Shows the coupling mechanism of the thermosphere with the ionosphere **.**

The thermosphere typical temperature is about 200°C and about 500°C when the solar activity isstrongly very active .

III.1.5.Earth's Ionosphere

The ionosphere occupies 70-1000 km above the sea surface, is affected daily by solar activity from space and atmospheric events such as typhoons, volcanic eruptions, and earthquakes**.** During volcanic eruptions and earthquakes, various atmospheric waves such as the Lamb wave (ultrasonic elastic waves) and sound waves were excited and propagated up to the ionosphere, which caused significant disturbances to the ionospheric density and structure .

The ionosphere, which occupies 70-1000 km above the sea surface, is affected daily by solar activity Charged particles (photons, electrons, protons, and other ions) from space collide with atoms and molecules in the thermosphere at high latitudes, exciting them into higher energy states. Those atoms and molecules shed this excess energy by emitting photons of colorful light called aurora displays **.**

Although the ionosphere only contains a small fraction of atmospheric material, it is very important because of its influence on the passage of radio waves. Most of the ionosphere is electrically neutral, but when solar radiation (the extreme ultraviolet and X-ray part of the spectrum) strikes the chemical constituents of the atmosphere electrons are dislodged from atoms and molecules to produce the ionospheric plasma **.**

The presence of the ionospheric plasma makes the upper atmosphere an electrical conductor, which supports electric currents and affects radio wave **. However,** the ionosphere lies well above where aircraft fly zones, but is located at altitudes where many satellites and the Space Shuttle orbit **.**

Earth's ionosphere is classified into three distinct regions according to the electron density and the ionization within a region (referred to as the ionosphere D layer, E layer, and F layer, overlaps with and shares the same space with the electrically neutral thermosphere **.** The term _layer_ refers to the ionization within a region.

The lowest is the D-region, covering altitudes between about 50 and 90 km. The E-region lies between 90 and 150 km, and the F-region is the ionosphere above the E-region as shown in figure 52.

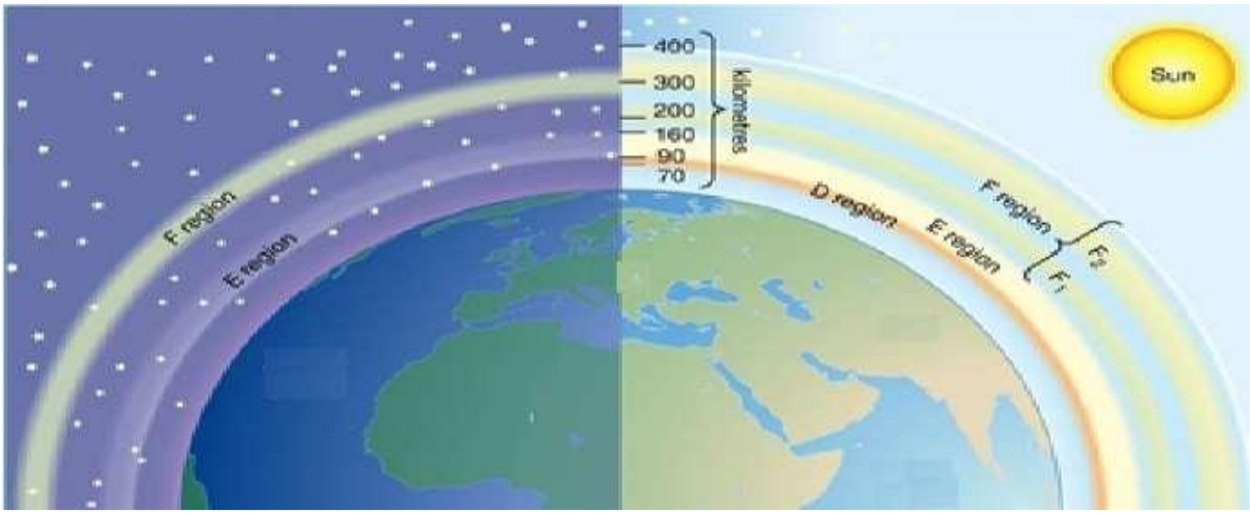


Figure 52. Shows regions of ionized particles, D layer, E layer, and F layer

✓ **The D region**

The main characteristics of the D region are listed below**:**

- The dominant ions are NO+ and O2+.
- Ionization here is due to Lyman series-alpha hydrogen radiation at a wavelength of 121.5 nanometer (nm) ionizing nitric oxide (NO).
- is mainly responsible for absorption of HF radio waves, particularly at 10 MHz and below,
- Smaller absorption as the frequency gets higher.
- The absorption is small at night and greatest about midday.
- A common example of the D layer in action is the disappearance of distant AM broadcast band stations in the daytime

✓ **The E region**

The main characteristics of the E region are listed below

- The dominant ions are NO+ and O2+.
- Ionization is due to soft X-ray (1-10 nm) and far ultraviolet (UV) solar radiation ionization of molecular oxygen (O2).

This layer can only reflect radio waves having frequencies less than about 10 MHz

- At night the E layer begins to disappear because the primary source of ionization is no longer present

- The E region peaks at about 105 km.

✓ **The F region**

The main characteristics of the F region are listed below

- In general, the F region has the highest concentration of free electrons and ions anywhere in the atmosphere.

- F-region is divided into two layers, the F1 (the lower level) and F2 (the higher level) layers.

- The top of the ionosphere is at about 1000 km, but there is no real boundary between the plasma in the ionosphere and the outer reaches of the Earth's magnetic field

- The F2 layer, where electron concentrations reach their highest values is the most important layer from of Navigation and Communication

- The 2 presence or absence of these layers in the ionosphere and their height above the Earth vary with the position of the Sun **.**

- At high noon, radiation in the ionosphere above a given point is greatest, while at night it is minimum.

When the radiation is removed, many of the ionized particles recombine. During the time between these two conditions, the position and number of ionized layers within the ionosphere change **.**

- Since the position of the Sun varies daily, monthly, and yearly with respect to a specific point on Earth, the exact number of present layers is extremely difficult to determine **.**

III.1.6.The Exosphere

The exosphere is at the highest atmospheric level that is still affected by earth's gravity and has a very rarefied presence of the lightest gases, hydrogen (H) and helium (He) and traces of other gases such as atomic oxygen and carbon dioxide. Due to the fact that, this region, is extremely rarified (of extremely low density) and therefore, it is not able to refract radio waves . The exosphere is perfect for placing satellites as there is very little friction and they are able to orbit fairly easily without being disrupted**.**

The pressure in the exosphere is created by solar wind storms that compress it and temperature in the exosphere varies greatly and can reach up to over 1700 0C. It is colder at night and much hotter during the day **.** Near sea level, air density is about 2x1019 particles/cm3; at a height of 600 km above it is only about 2x107 particles/cm3 . At sea level, an atom or molecule can be expected, on the average, to move about 7x10-6 cm before colliding with another particle; at the 600 km level this distance, called the "mean free path," is about 10 km. Near sea level, an atom or molecule, on the average, undergoes about 7x109 collisions each second; near 600 km, this number is about 1 each minute .

However, the exosphere connects the earth's atmosphere to interplanetary space, thus the variations of the atmosphere on daily basis is due to Sun – Earth interaction **.** At the exosphere Hydrogen is the most dominant species, followed by Helium and Oxygen. Although the exosphere is the most distance layer of earth's atmosphere it is the layer that is the planet's first line of defense against the sun's rays. It is also the first layer to come into contact and protect the earth from meteors, asteroids, and cosmic rays **.** (Hamouda, 2025)

III. 2.Tropospheric circulation

Atmospheric air masses are driven by significant movements. These atmospheric "circulations" result from the unequal distribution of solar energy reaching the Earth's surface and from the Earth's rotation on its axis. It is within the troposphere that surface winds originate, allowing the homogenization of temperature over the globe's surface. Movements in the troposphere are convective in nature (upward motion) and may be turbulent. Air masses generally move from areas of high pressure (anticyclones) toward areas of low pressure (depressions) (Fig. 53). The Coriolis force then deflects air masses to the right (relative to the direction of motion) in the Northern Hemisphere and to the left in the Southern Hemisphere.

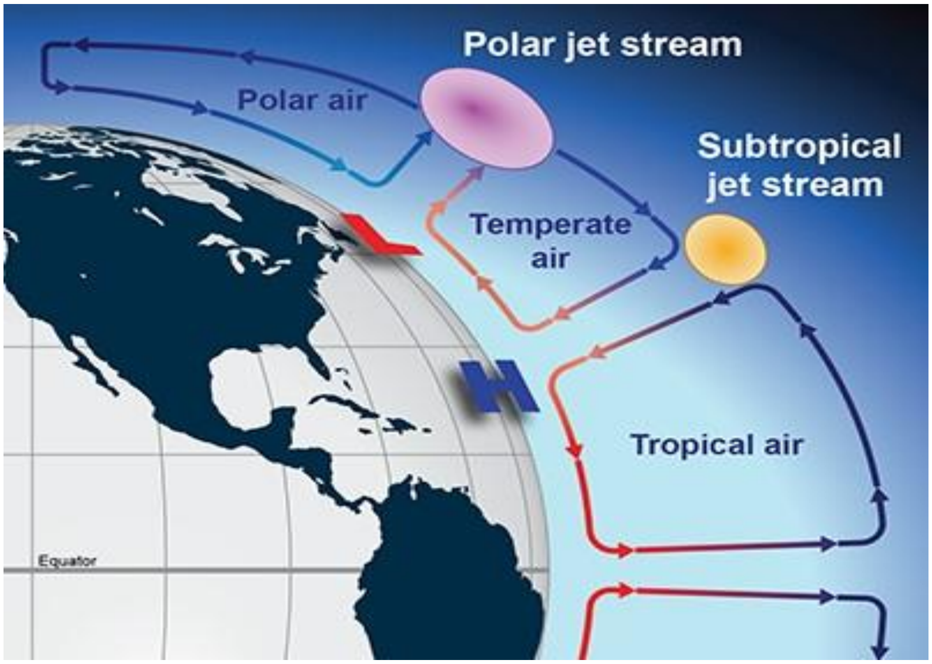


Figure 53. Cross section of the Northern Hemisphere showing jet streams and tropopause elevations.

In the Northern Hemisphere, air moves away from anticyclonic areas in a descending spiral rotating clockwise and converges toward low-pressure systems, where it rises in an ascending spiral rotating counterclockwise. In anticyclonic regions of the Northern Hemisphere, air follows a descending clockwise spiral as it diverges and moves toward a low-pressure area, where it ascends in a spiral rotating counterclockwise (Fig. 53). These opposite rotational motions within the same hemisphere are explained by the combined effects of the Coriolis force, anticyclonic outward forces, and cyclonic inward (suction) forces.

At the planetary scale, tropospheric circulation is characterized by three major helical and symmetrical circulation cells in each hemisphere (Fig. 54).

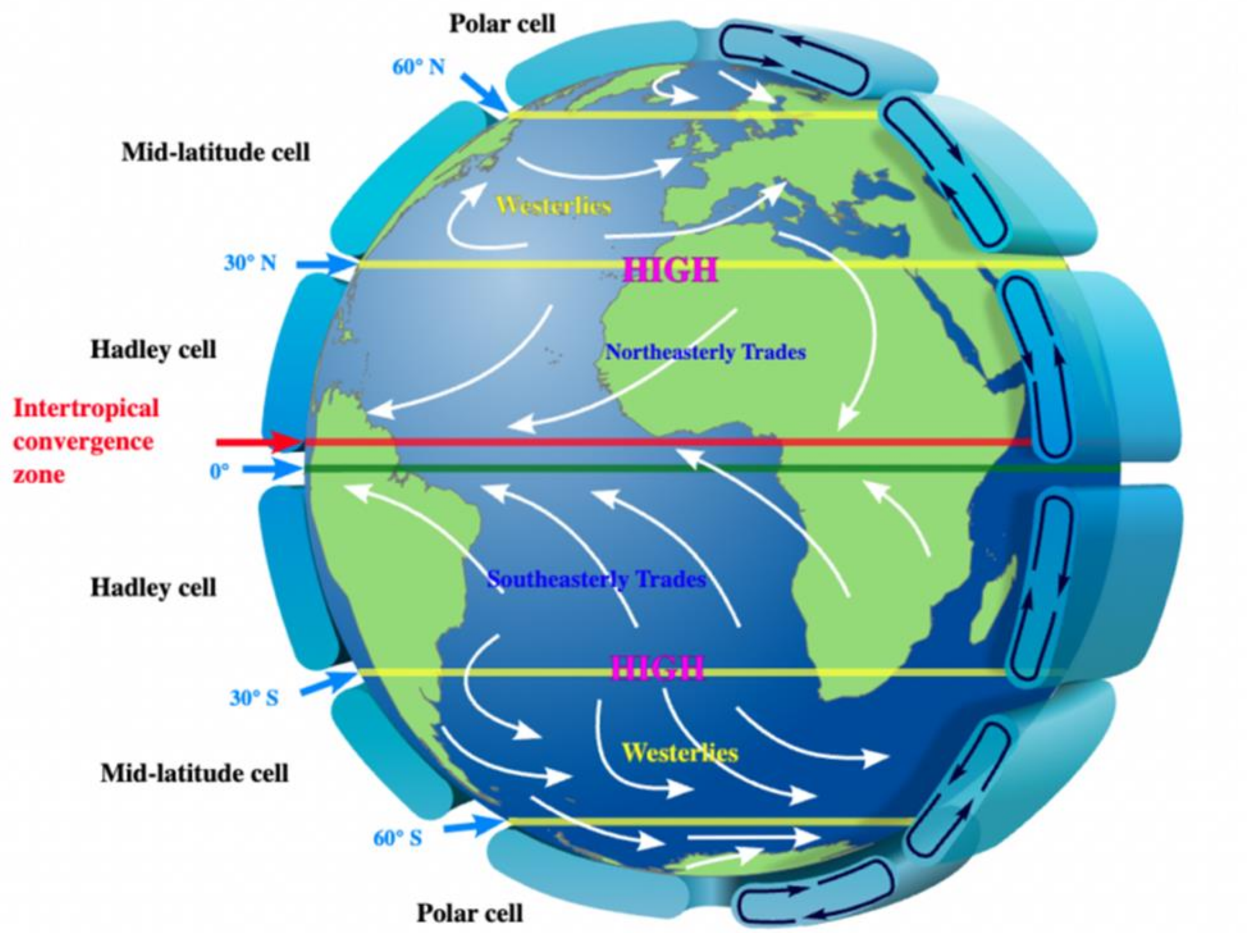


Figure 54. Tropospheric circulations

Idealised depiction (at equinox) of large-scale atmospheric circulation on Earth. By Kaidor – Own work based on File: NASA depiction of earth global atmospheric circulation.jpg, CC BY-SA 3.0.

Tropospheric circulations are organized into three symmetrical cells in each hemisphere. Due to the Coriolis force, surface winds are deflected clockwise in the Northern Hemisphere and counterclockwise in the Southern Hemisphere; as a result, thermal circulation cells form a continuous spiral within each latitudinal belt.

• **A “tropical” cell**, characterized by the ascent of warm, moist air at the equator (the equatorial chimney), accompanied by its cooling, its poleward movement aloft (around 12,000 meters), and its subsidence in the lower atmosphere near 30° north or south latitude. The return flow toward the equator at low altitude is deflected to the right in the Northern Hemisphere (and to the left in the Southern Hemisphere): these are the trade winds of the intertropical zone, slow and regular winds blowing from east to west.

• **A “temperate” cell**, with the ascent of mild, temperate air near 60° latitude and subsidence in the tropical zone (around 30° north or south latitude). The low-altitude return flow of the air mass toward 60° latitude is associated with the westerly winds characteristic of temperate regions.

• **A “polar” cell**, associated with the same ascent of mild, temperate air near 60° north or south, but with the descent of cold air over the poles. In these high latitudes, cold and dry easterly winds prevail.

Chapter IV | Solar Radiation and the Earth’s Radiative Balance

IV.1. Solar Radiation

The sun is a spherical source of about 1.39 million km diameter, at an average distance of 149.6 million km from earth. Radiation from the sun sustains life on earth and determines the climate. The solar radiation can be divided into two types, extraterrestrial and terrestrial.

IV.1.1. Extraterrestrial Solar Radiation (H)

is the solar radiation which falls on a surface normal to the rays of the sun outside the atmosphere of the earth. A typical spectral distribution of extraterrestrial radiation is shown in Figure 55. The curve rises sharply with the wavelength and reaches the maximum value of 2074 W/m2 -µm at a wavelength of 0.48 µm. It then decreases asymptotically to zero.

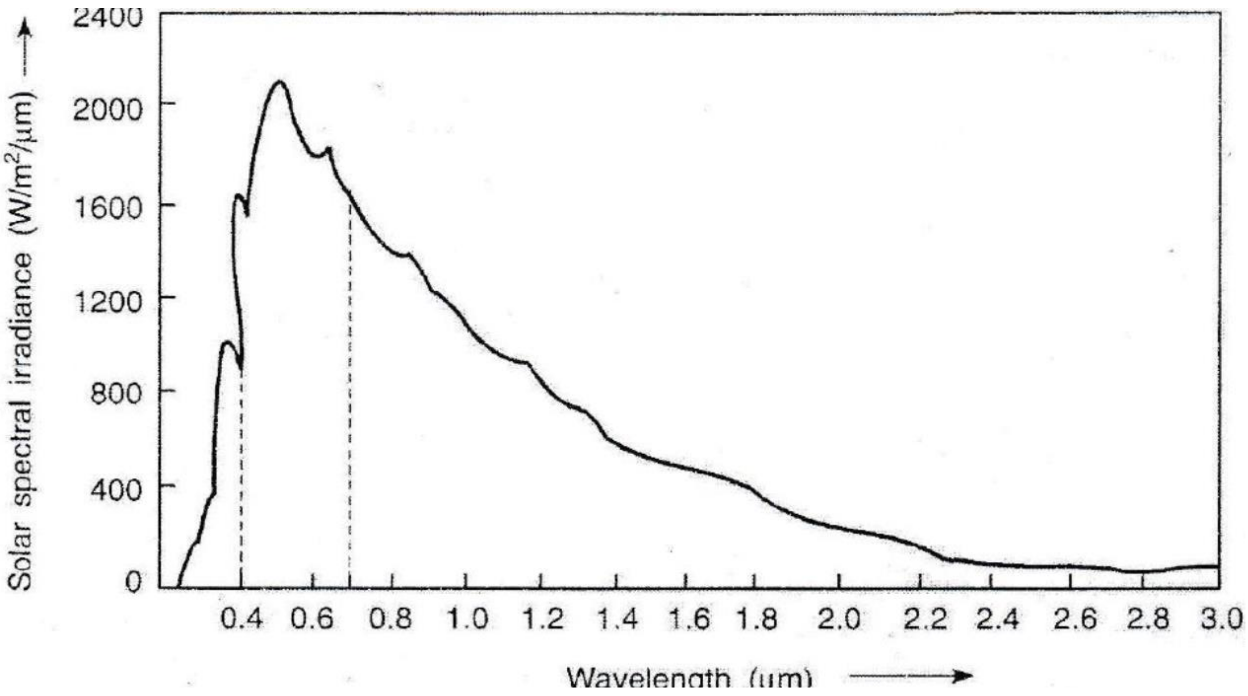


Figure 55. Spectral distribution of extraterrestrial radiation

This extraterrestrial solar radiation at the mean earth sun distance, D o , is called the **solar constant, H**o . Using the value obtained by measurements from NASA, the solar constant is said to be 1353 W/m 2 . Thus, the extraterrestrial solar radiation, H, can be calculated by using the following equation :

$$H = H_{O}\left(1 + 0.034 Cos\left(\frac{360.d_{n}}{365.25}\right)\right)$$

Where dn is the day's number from year which can be estimated from table 5 (where i is day number from month). A plot for estimating the extraterrestrial solar radiation as a function of the time of year is shown in figure 55

Table 5. The value of nth day of year

month	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sep.	Oct.	Nov.	Dec.
d_n	i	31+i	59+i	90+i	120+i	151+i	181+i	212+i	243+i	273+i	304+i	334+i

.

IV.1.2. Energy and Radiation

Radiation: The transfer of energy via electromagnetic waves that travel at the speed of light. The velocity of light in a vacuum is approximately 3 x 108 m/s. The time it takes light from the sun to reach the Earth is 8 minutes and 20 seconds. Heat transfer by electromagnetic radiation can travel through empty space. Any body above the temperature of absolute zero (-273.15o C) radiate energy to their surrounding environment.

The many different types of radiation is defined by its wavelength. The electromagnetic radiation can vary widely.

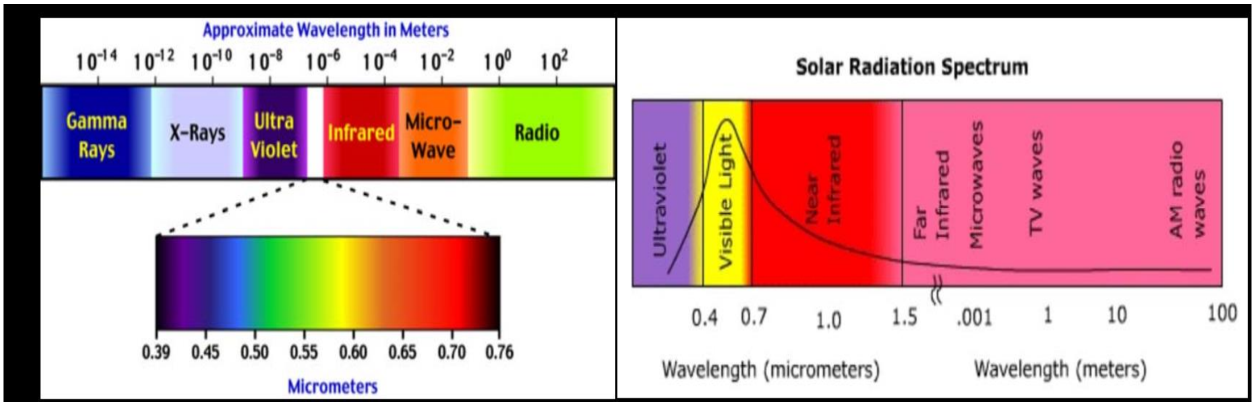


Figure 56. Types of radiation

(http://www.uwsp.edu/geo/faculty/ritter/geog101/textbook/energy/nature_of_electromagnetic_radiation.html http://www.physicalgeography.net)

IV.1.3. Sun Radiation Spectrum

Visible light has a wavelength of between 0.40 to 0.71 micrometers (µm). The sun emits only a portion (44 %) of its radiation in this range. Solar radiation spans a spectrum from approximately 0.1 to 4.0 micrometers. About 7 % of the sun's emission is in 0.1 to 0.4 micrometers wavelength band (UV). About 48 % of the sun's radiation falls in the region between 0.71 to 4.0 micrometers (near infrared : 0.71 to 1.5 micrometers; far infrared: 1.5 to 4.0 m micrometers (near infrared : 0.71 to 1.5 micrometers; far infrared:1.5 to 4.0 micrometers).

Solar radiation incident outside the earth's atmosphere is called extraterrestrial radiation. On average the extraterrestrial irradiance is 1367 W/m2. This value varies by ±3% as the earth orbits the sun.

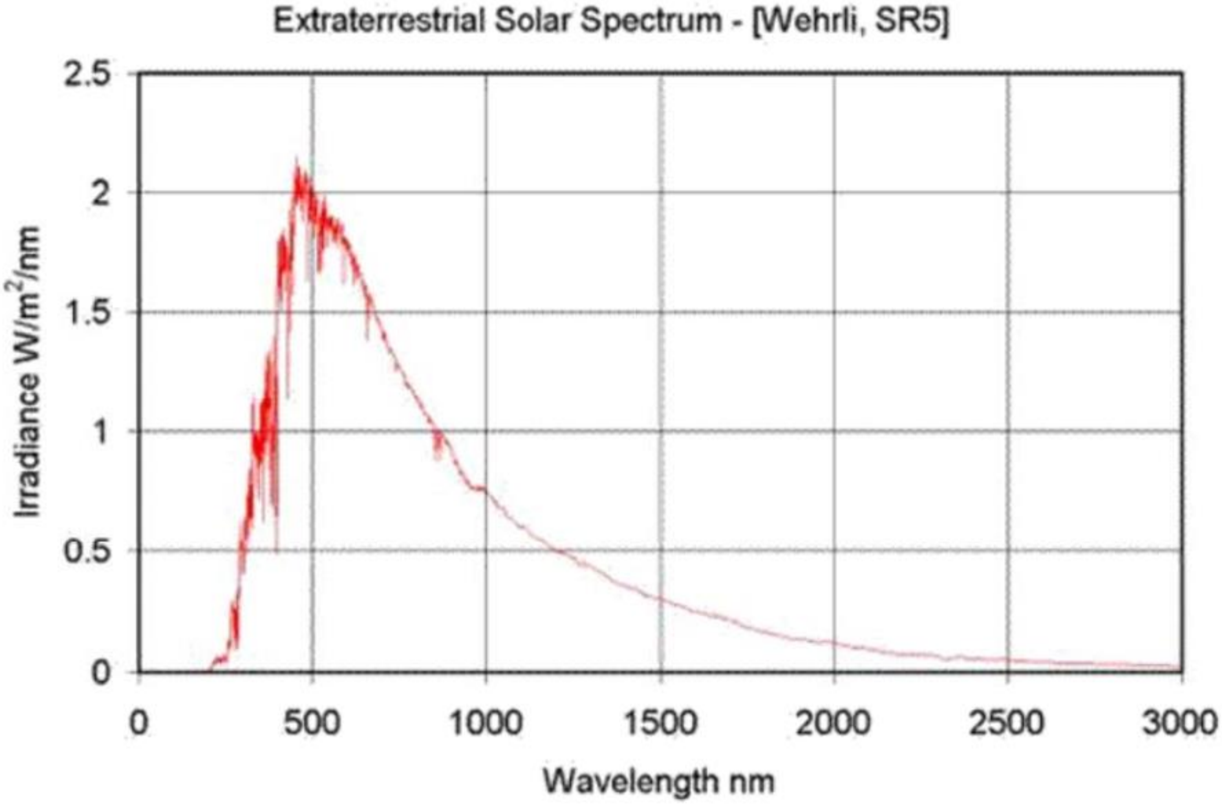


Figure 57. Sun Radiation Spectrum

IV.1.4. Stephan-Boltzmann Law

The amount of electromagnetic radiation emitted by a body is directly related to its temperature. If the body is a perfect emitter (black body), the amount of radiation given off is proportional to the 4th power of its temperature as measured in degrees Kelvin. This natural phenomenon is described by the Stephan-Boltzmann law:

$$E = \sigma T^4$$

Where σ = 5.67 x 10-8 Wm-2k-4 and T is in K

In general, good emitters of radiation are also good absorbers of radiation at specific wavelength bands. This is especially true of greenhouse gases. Some objects in nature have almost completely perfect abilities to absorb and emit radiation. We call these objects black bodies. The radiation characteristics of the sun and the Earth are very close to being black bodies.

IV.1.5. Atmospheric Effects on Incoming Solar Radiation

The Earth is a planet with an atmosphere and is largely transparent to the incoming solar radiation. There are constituents in the atmosphere which prevent some kinds of radiation from reaching the surface, such as ozone which stops the ultraviolet. A fair proportion of the Earth is covered by clouds which reflect a lot of the Sun's radiation and thus affecting the surface temperature.

The process of scattering occurs when small particles and gas molecules diffuse part of the incoming solar radiation in random directions without any alteration to the λ of the electromagnetic energy. Scattering does, however, reduce the amount of incoming radiation reaching the Earth's surface. A significant proportion of scattered shortwave solar radiation is redirected back to space. The amount of scattering that takes place is dependent on two factors: λ of the incoming radiation and the size of the scattering particle or gas molecule. In the Earth's atmosphere, the presence of a large number of particles with a size of about 0.5 µm results in shorter wavelengths being preferentially scattered. This factor also causes our sky to look blue because this color corresponds to those wavelengths that are best diffused. If scattering did not occur in our atmosphere the daylight sky would be black.

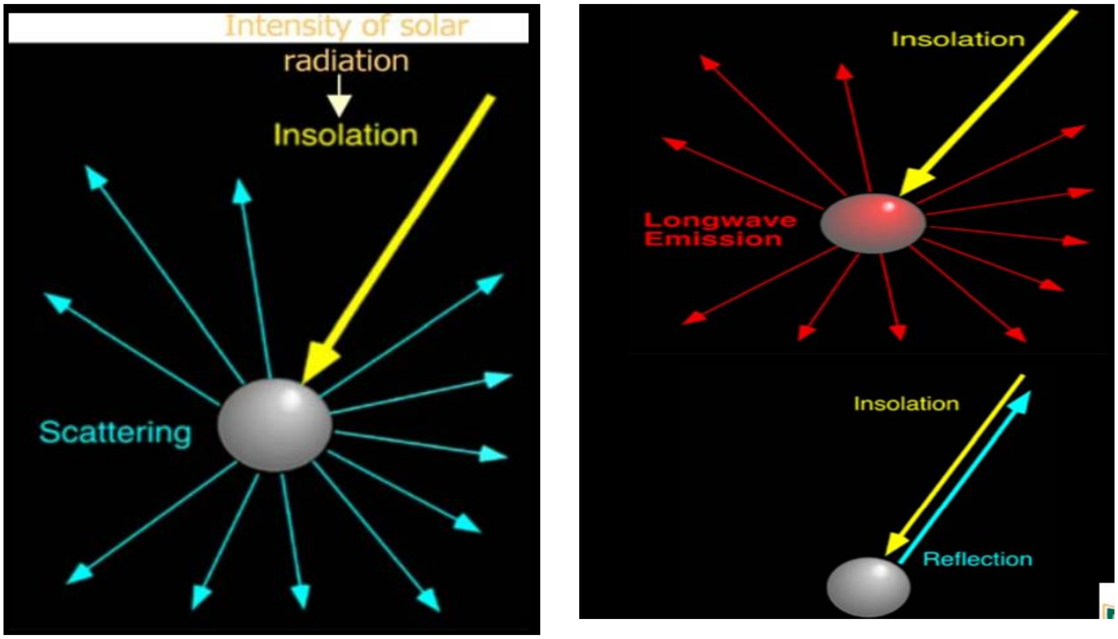


Figure 58: Atmospheric Effects on Incoming Solar Radiation

If intercepted, some gases and particles in the atmosphere have the ability to absorb incoming insolation. Absorption is defined as a process in which solar radiation is retained by a substance and converted into heat. The creation of heat also causes the substance to emit its own radiation. In general, the absorption of solar radiation by substances in the Earth's atmosphere results in temperatures that get no higher than 1800° C. Bodies with temperatures at this level or lower would emit their radiation in the longwave band. Further, this emission of radiation is in all directions so a sizable proportion of this energy is lost to space.

The third process in the atmosphere that modifies incoming solar radiation is reflection. Reflection is a process where sunlight is redirect by 180° after it strikes an atmospheric particle. This redirection causes a 100 % loss of the insolation. Most of the reflection in our atmosphere occurs in clouds when light is intercepted by particles of liquid and frozen water. The reflectivity (albedo) of a cloud can range from 40 to 90 %.

At the smallest scale the electromagnetic radiation behaves as a particle, like when light is emitted by a single atom or molecule. When energy is given off there is a change in the orbital pattern of the electrons that surround the nucleus of an atom. As the orbit changes, a bundle of energy called a "**photon**" is released. However, particles of light differ from particles of matter: they have no mass, occupy no space, and travel at the speed of light. The amount of energy carried by a photon varies inversely with wavelength, the shorter the wavelength the more energetic is the photon. Normally, light is formed from a large number of photons, with the intensity related to the number of them.

The gasses that comprise our atmosphere absorbs only particular wavelengths of light. Electrons orbit the nucleus of an atom at fixed orbital distances called orbital shells. The orbital shell for each atom is different and discrete. That is, for a given atom like hydrogen, its electrons can only orbit at particular distances and are different than those for atoms of other gases.

IV.1.6. Selective Absorption of the Atmosphere

The amount of energy carried by a photon depends on the wavelength. Thus the atoms that comprise a gas can only absorb, or emit, particular wavelengths of energy (i.e. photons of energy). We can see this selective absorption by examining Figure below. The graph shows very little absorption for atmosphere as a whole in the shortwave end of the spectrum, especially in the visible light band (the band of maximum emission for the Sun). The atmosphere absorbs far better in the long wave end of the electromagnetic spectrum which is the region of maximum emission (10µm) for the Earth.

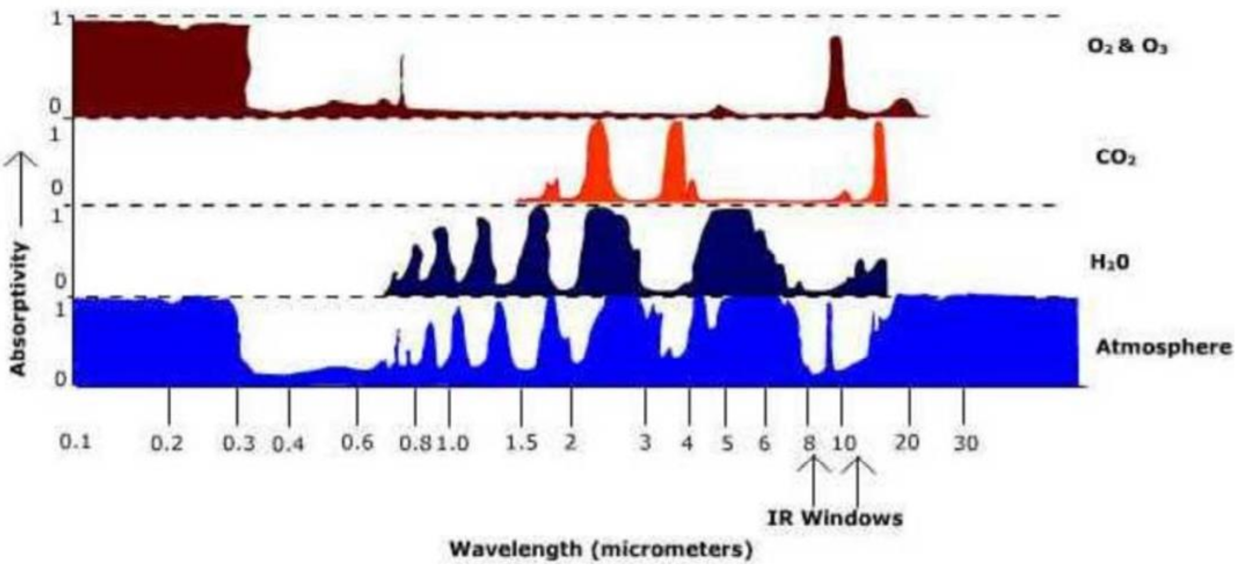


Figure 59. Selective Absorption of the Atmosphere

Sunlight reaching the Earth's surface unmodified by any of the atmospheric processes is termed direct solar radiation. Solar radiation that reaches the Earth's surface after it was altered by the process of scattering is called diffused solar radiation. Not all of the direct and diffused radiation is available at the Earth's surface. Some of the radiation received at the Earth's surface is redirected back to space by reflection.

Of all the sunlight that passes through the atmosphere annually, only 51 % is available at the Earth's surface; to heat the Earth's surface and lower atmosphere, evaporate water, and run photosynthesis in plants. Of the other 49 %, 4 % is reflected back to space by the Earth's surface, 26 % is scattered or reflected to space by clouds and atmospheric particles, and 19 % is absorbed by atmospheric gases, particles, and clouds.

IV.1.7. Sun-Earth Relationships

The solar constant, GSC is the energy from the sun, per unit time, received on a unit area of surface perpendicular to the direction of propagation of the radiation, at mean earth-sun distance, outside of the atmosphere.

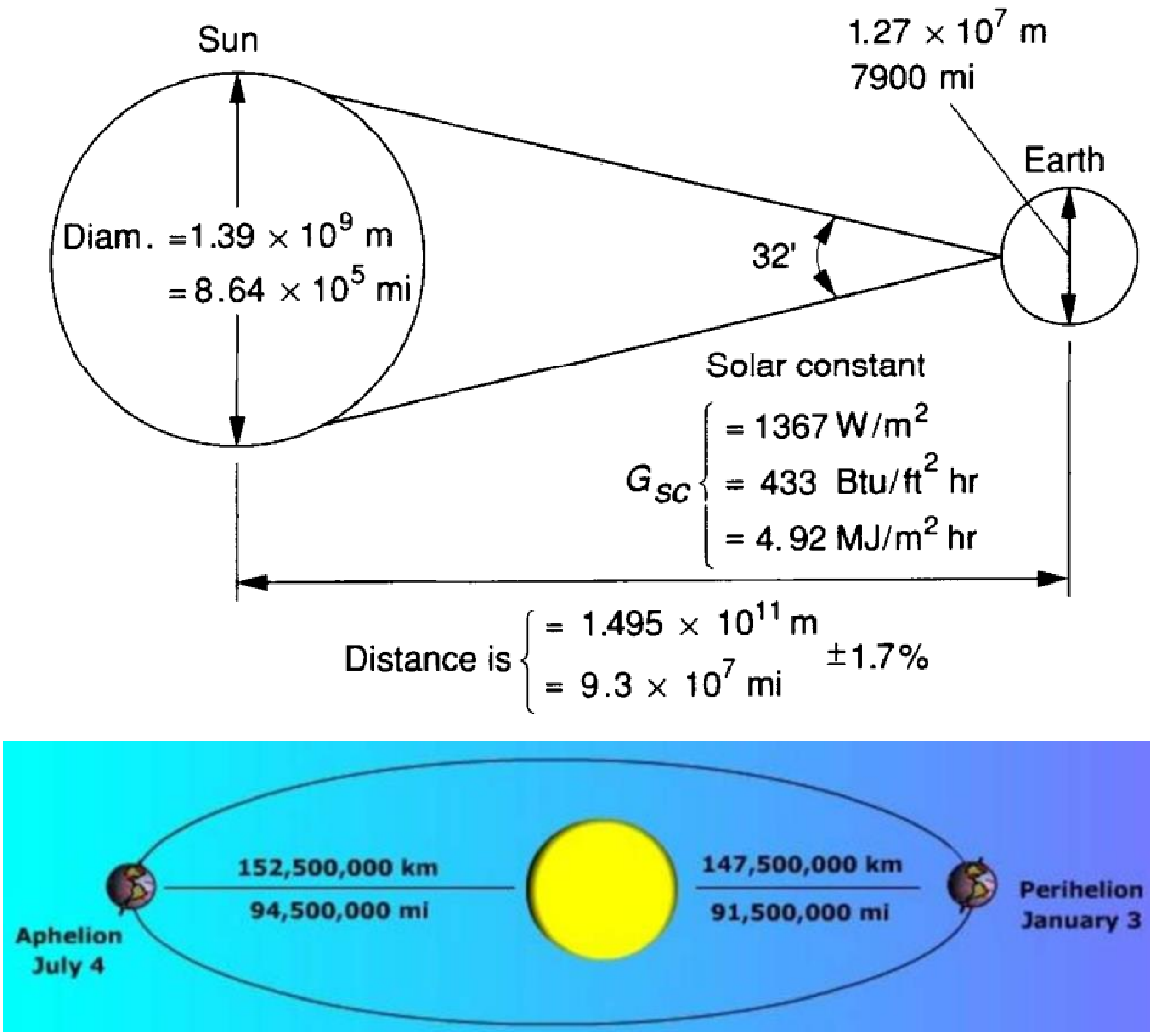


Figure 60. Earth's elliptic orbit the elliptical path causes only small variations in the amount of solar radiation reaching the earth.

The Earth's axis is tilted 23 1/2 degrees from being perpendicular to the plane ofbthe ecliptic. The axis of rotation remains pointing in the same direction as it revolves around the Sun, pointing toward the star Polaris. The constant tilt and parallelism causes changes in the angle that a beam of light makes with respect to a point on Earth during the year, called the "***sun angle***". The most intense incoming solar radiation occurs where the sun's rays strike the Earth at the highest angle. As the sun angle decreases, the beam of light is spread over a larger area and decreases in intensity. During the summer months the Earth is inclined toward the Sun yielding high sun angles. During the winter, the Earth is oriented away from the Sun creating low sun angles.

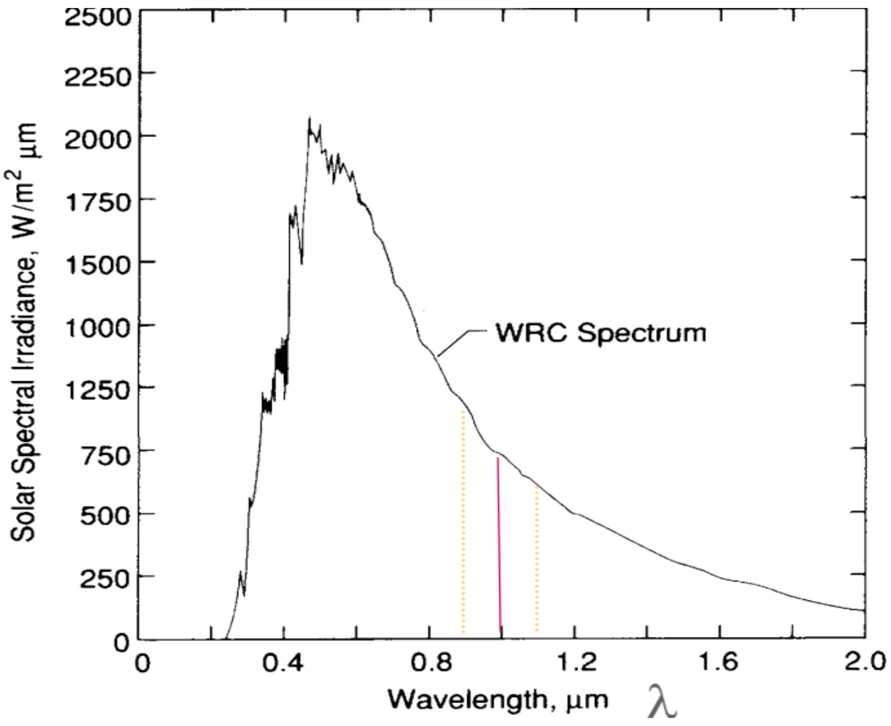


Figure 61: Spectral Distribution of Extraterrestrial Radiation

$G_{SC,\lambda}$: The average energy over small bandwidths centered at wavelength λ;

$F_{0-\lambda}$: The fraction of the total energy in the spectrum that is between wavelengths 0 and λ.

**The radiation that would be received in the absence of the atmosphere at mean-earthsun distance* (World Radiation Center (WRC) standard) (Goswami *et al* ., 2000).

- **Air Mass**

The path length of the solar radiation through the Earth's atmosphere in units of Air Mass (AM) increases with the angle from the zenith. The AM 1.5 spectrum is the preferred standard spectrum for solar cell efficiency measurements.

The easiest way to estimate the air mass in practice is to measure the length of the shadow s cast by a vertical structure of height h using

$$AM = \sqrt{1+\left(\frac{s}{h}\right)^2}$$

Air Mass AM : The ratio of the mass of atmosphere through which beam radiation passes to

the mass it would pass through if the sun were at zenith (directly overhead).

At sea level, AM =1 when the sun is at zenith; AM = 2 for a zenith angle θz of 60°.

For 0 < θz < 70o AM= 1/cos θz.

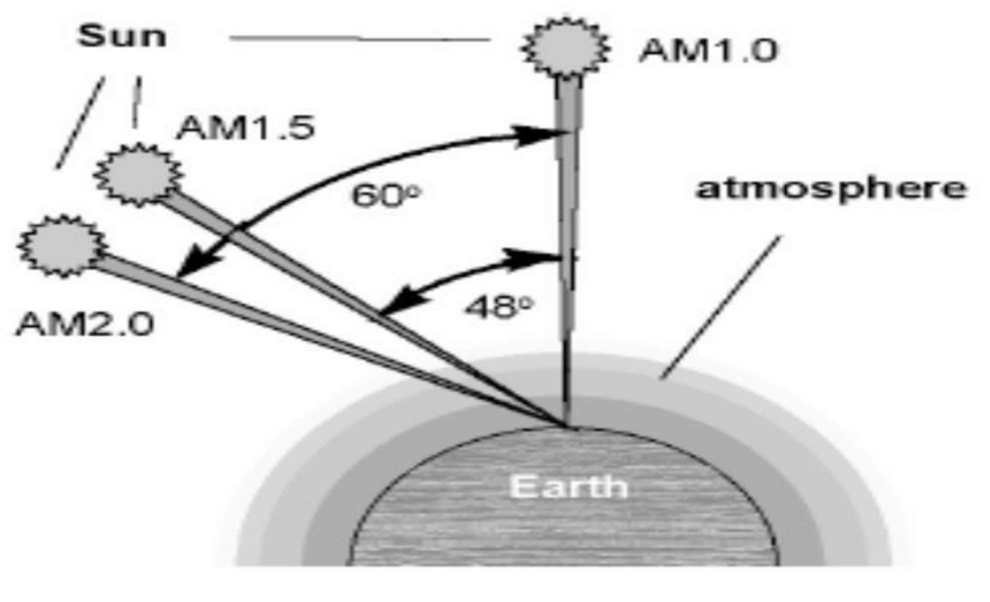


Figure 62. The ratio of the mass of atmosphere

IV.2. Greenhouse Effect and Global Warming

Global warming is the alleged worldwide increase in the average atmospheric temperature of earth's near-surface air and oceans since the mid20th century and its projected continuation. According to the 2007 Fourth Assessment Report by the Intergovernmental Panel on Climate Change (IPCC), global surface temperature increased 0.74±0.18°C (1.33±0.32°F) during the 20th century (IPCC, 2007). This type of climate change is seen as a period of increases in global temperature which is alternating with periods of global cooling and is a natural occurrence as part of an interval warming trend which has occurred multiple times throughout Earth's geological history (Annon , 2010).

IV.2.1. Historical Perspective of Global Warming

The term global warming was probably first used in its modern sense on 8th August, 1975 in a science paper by Wally Brocker in the journal, Science, called, "Are we on the brink of a pronounced global warming?" (Annon , 2010). Broecker's choice of words was new and represented a significant recognition that the climate was warming, previously the phrase used by scientists was, "inadvertent climate modification", because while it was recognized humans could change the climate, no one was sure which direction it was going (Annon , 2010). The National Academy of Sciences first used global warming in a 1979 paper called the Charney Report, it said, "if carbondioxide (CO2) continues to increase, we find no reason to doubt that climate changes will result and no reason to believe that these changes will be negligible (Annon , 2010).

The report made a distinction between referring to surface temperature changes as global warming, while referring to the changes caused by increased CO2 as climate change (Annon , 2010). The distinction is still often used in science reports, with global warming meaning surface temperatures and climate change meaning other changes (increased storms, etc) (Theodore, 2001). Global warming became more widely popular after 1988 when the National Airspace Agency (NASA) scientist, James E. Hansen, used the term in a testimony to the American Congress. He said, "global warming has reached a level such that we can ascribe with a high degree of confidence a cause and effect relationship between the greenhouse effect and the observed warming". His testimony was widely reported and afterward global warming was commonly used by the press and in public discourse.

IV.2.2. Greenhouse effect

It is the process by which absorption and emission of infrared radiation by gases in the atmosphere warm a planet's lower atmosphere and surface. It was proposed by Joseph Fourier in 1824 and was first investigated quantitatively by Syante Arrhenius in 1896 (Spenser, 2008; Annon , 2010). The question in terms of global warming is how the strength of the presumed greenhouse effect changes concentration of greenhouse gases in the atmosphere. The greenhouse effect makes the earth appropriate for people to live on. Without it, the earth would be freezing, or on the other hand it would be burning hot. It would be freezing at night because the sun would be down. We would not get the sun's heat and light to make the night somewhat warm. It would be freezing at night because the sun would be down. We would not get the sun's heat and light to make the night somewhat warm.

During the day, especially during the dry season, it would be burning because the sun would be up with no atmosphere to filter it, so people, plant and animals would be exposed to all the light and heat. Although the greenhouse effect makes the earth able to have people living on it, if there gets to be too many gases, the earth can get unusually warmer and many plants, animals and people will die. They would die because there would be less food (plant like corn, wheat and other vegetables and fruits). This would happen because the plant would not be able to take the heat. This would cause us to have less food to eat, but it would also limit the food that animals have. With less food, like grass, for the animals that we need to survive (like cows), we would even have less food. Gradually, people, plant and animals would all die of hunger .

IV.2.3. The Greenhouse Gases

The heat trapping gases are known as GREENHOUSE GASES (CCN, 2004; Sodipo, 2007) because they produce the greenhouse effect (i.e. these gases absorb the heat energy and tend to prevent infrared heat radiation from escaping into space from the earth, thus causing the greenhouse effect). The principal greenhouse gases according to Sodipo 2007; Annon , 2010 are: Carbondioxide (CO2): It contributes greater than 9-26% of greenhouse effect:

- Methane (CH_4). It contributes 4-9% of greenhouse effect

- Nitrous oxide (N_2O). It contributes 6% of greenhouse effect Others are

-The Halocarbons: They are also ozone depleting and contribute 14% of greenhouse effect

-Ozone (O_3): It causes 3-7% of the greenhouse effect

-Water vapor (H_2O): It causes about 3 6-70% of the greenhouse effect

Clouds also affect the radiation balance, but they are composed of liquid water or ice, and so have different effects on radiation from water vapor.

According to the IPCC, 2007; ANNON a, 2010, naturally occurring greenhouse gases have a mean warming effect of about 33°C (59°F).

IV.2.4. Causes of Global Warming

Most of the observed temperature increase since the middle of the 20th century has been caused by increasing concentrations of greenhouse gases. The increase in the concentrations of these greenhouse gases may be natural or anthropogenic (manmade).

IV.2.4.1 .Natural Causes

Natural causes of global warming are not by people or their activities. They include:

1. Green plants and trees - emit large amount of carbondioxide ($C0_2$) and hydrocarbons which are volatile organic compounds (VOC) .

2. Dust storms - can create large amounts of particulate matter .

3. Volcanic eruptions - they emit particulate matter.

4. Wild animals - in their natural habitat are also considered natural causes of global warming as they emit methane by the digestion of food e.g. cattle.

5. Changes in solar luminous may also lead to global warming.

6. Variations in earths orbit round the sun, leading to temperature changes.

7. Cosmic dust - from natural sources usually large areas of land with little or no vegetation. Natural causes of global warming is being supported by climate change reported in other planets apart from the earth where human activities do not take place.

The average temperature on Mars has risen 0.6°C (1.1°F) just as the average temperature on earth has risen. Human industrialization is clearly not to blame for the change on. Neptune is also undergo global warming. Measurements taken at the Lowell observatory in Arizona, U.S.A. have shown an increase in Neptimes brightness and temperature since 1980, and this may be due to solar variations. Pluto has also been found to be undergoing global warming. The overall temperature increase in Pluto has been greater than on the earth. On the other hand, Uranus has had no net change in temperature since 1977. A rapid increase in temperature reversed itself. The reasons for this are not understood.

IV.2.4.2. Anthropogenic Causes

Human activity since the Industrial Revolution (about 1750-1850) has increased the amount of greenhouse gases in the atmosphere, leading to increased radiative forcing from carbondioxide (CO2), methane (CH4), trophospheric ozone (O3), chlorofluorocarbons (CFCs) and nitrous oxide (N2O). The concentrations of CO2 and CH4 have increased by 36% and 148% respectively since 1750. These levels are much higher than at any time during the last 650,000years, the period for which reliable data has been extracted from ice cores . Less direct geological evidence indicates that CO2 values higher than this were seen about 20 million years ago (Ramaswamy *et al.,* 1992; Annon , 2010).

Some of the causes of anthropogenic global warming are:

1. Increase in population: The rapid expansion of population is one of the most important factors of global warming. The present world population would be doubled after 40years. This increase in population leads to global warming and emission of greenhouse gases. Increase of population is directly related to loss of forest and natural resources .

2. Agricultural activities: Agricultural operation, those that raise animals and grow crops, can generate emission of gases, particulate matter and chemical compounds e.g. animals confined to a born or areas (rather than field grazing) produce large amounts of manure. Manure emits various gases into the air. These gases can be emitted from the animal houses, manure storage areas or from the land after the manure is applied.

3. Land use change especially deforestation: Plants maintain the balance of CO2 and oxygen (O2) in nature. Plants purify air by using CO2 for photosynthesis. Fast-increasing population is responsible for deforestation . In the 1990s, Nigeria lost nearly 500sq miles of forested land annually in part to firewood consumption (NCA, 2003; Sodipo, 2007).

4. Burning of fossil fuels and fires: They produce three quarters of the increase in CO2 over the past 20 years. The conventional source of energy source of energy is wood, coal and fossil fuels, etc. About 98% of energy we use in our homes and industries are generated by oil, natural gases and coal. These are mainly fossil fuels. According to the Special Report on Emissions Scenarios (SRES) of the IPCC, by the year, 2,100, the atmospheric concentration of CO2 could range between 90-250% above the concentration in the year 1750. Fossil fuel reserves are sufficient to reach these levels and continue emissions past 2,100 if coal, tar sands or CH4 clathrates are extensively exploited. Also, the National Oceanic and Atmospheric Administration (NOAA) an agency of the United States Government, stated that CO2 levels in the atmosphere are rising due to human activity, and that the surface of the earth has warmed, on average, quickly over the last 50 years.

5. Chlorofluorocarbons: (CFCs). They are a family of inert, non-toxic and easily liquefied chemicals used in refrigeration, air-conditioning, packaging, insulation, or as a solvent or aerosol propellant; because they are not readily destroyed in the lower atmosphere, drift into the upper atmosphere (the stratosphere) (FEPA, 1991), where it contributes to global warming by destroying the stratospheric ozone .

6. Cement manufacture also increases greenhouse gases.

7. Garbage: When we throw our garbage away, the garbage goes to landfills. Landfills are those big hills that you go by on an expressway that stink. They are full of garbage. The garbage is then sometimes burned. This sends an enormous amount of greenhouse gases into the air and makes global warming worse (Annon , 2010).

Chapter V | Aridity

V.1. Concept of Aridity

Aridity is a climatic condition characterized by a **chronic deficiency of precipitation compared to potential evapotranspiration**, resulting in a long-term shortage of available water. It reflects a permanent feature of climate, typical of arid and semi-arid regions, and differs from drought, which is temporary.

The **degree of aridity** is not the same in all deserts, which is why they are subdivided into **three main domains** (Boudjellal, 2009; Wang, 2015):

- ✓ **Hyper-arid or absolute deserts**:

  They receive less than **50 mm of precipitation per year**. These deserts are the rarest and cover about **7.5% of the Earth's land surface**.
- ✓ **Arid deserts proper**:

  Annual precipitation ranges between **50 and 150 mm**. They occupy nearly **12.5% of the Earth's land surface**.
- ✓ **Semi-arid deserts**:

  They receive between **150 and 250 mm**, and sometimes up to **500 mm of precipitation per year**. These deserts cover approximately **17.7%** of the land surface.

In **Algeria**, the arid zone represents nearly **95% of the national territory**, of which **89% belongs to the hyper-arid domain** (Madani, 2008).

Another typology classifies arid zones into **zonal and non-zonal deserts**:

a. **Zonal deserts**, located along the tropics:

- Along the **Tropic of Cancer**: deserts of the United States and Mexico, the Sahara, the Arabian Desert, the Iranian deserts, and the Thar Desert. The name of the state of **Arizona** means “arid zone.”
- Along the **Tropic of Capricorn**: the Atacama Desert, the Kalahari Desert, and the Australian deserts.

b. **Non-zonal deserts**, which have different origins:

- **Rain-shadow zones on the leeward side of mountain ranges**: American deserts of the Great Basin and deserts of Argentina.
- **Interior continental deserts**: deserts of Central Asia, influenced by cold currents along the western continental margins.

V.2. Concept of Desert

V.2. 1.Definition of a Desert

Area with less than 25 cm of precipitation annually. It is not defined by temperature - it is defined by ardity.

Distribution: Zones of high pressure at ~30˚N & S, as well as 90˚N & S. Also leeward sides of mountains.

Deserts have no permanent surface water, <15% vegetation cover. Arid nature produced by high and low temperatures as well as orographic lifting. Little chemical weathering - bare bedrock, wind blown sand, cobbles, and salt precipitation.

Desert land surfaces often include:
- Exposed bedrock
- Accumulated clasts
- Unweathered sediment
- Precipitated salt
- Windblown sand

Mirages, which look like distant water, result from light interacting with heated air just above the ground surface. Each desert has unique characteristics of landscape and vegetation. Geologists group deserts into one of five classes.

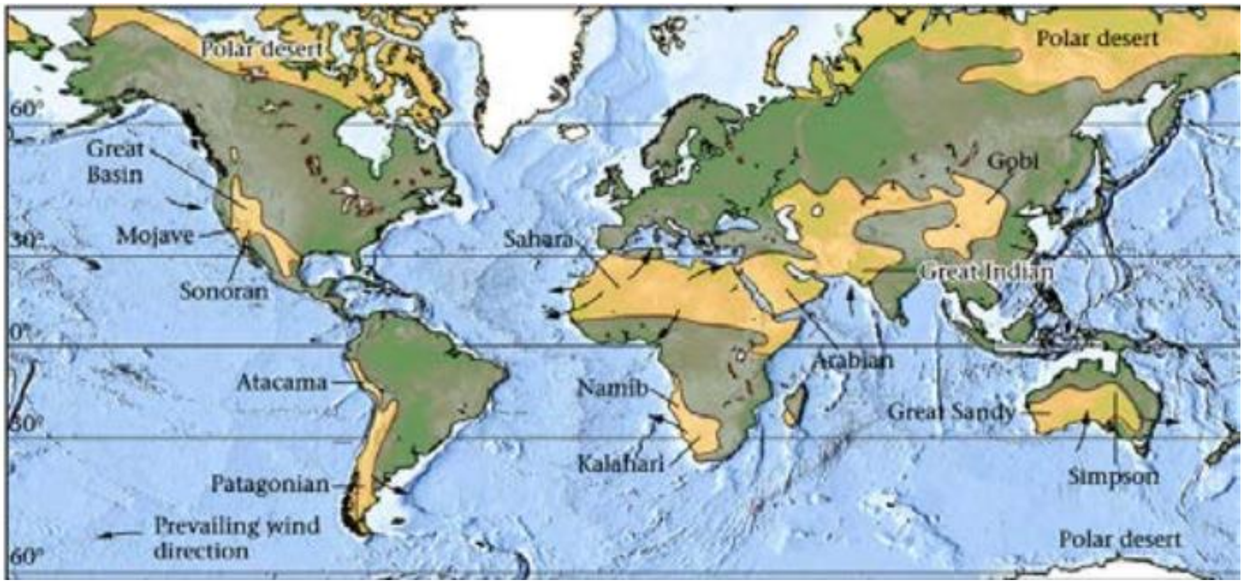


Figure. 63: Desert land surfaces

V.2. 2.Types of Deserts

Five Categories:

- **Subtropical Deserts**

(Sahara, Arabian, Kalahari, Australian) form where convection cells diverge. Has very little water, which has condensed out after rising at the equator. Dense air mass moves to the equator with high evaporation rates as sinking dense air heats up. Found from 20º to 30º N and S latitude across geologic time.

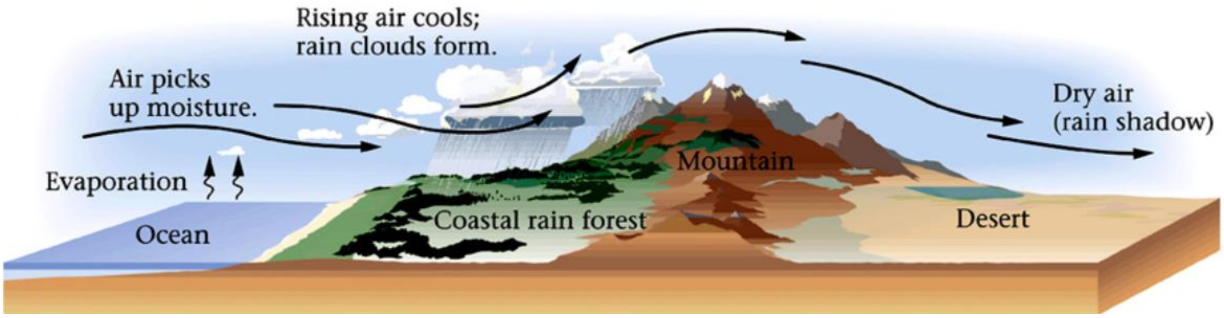


Figure 64. Subtropical Deserts

- **Coastal Deserts**

formed along cold coastal currents. The cold Humboldt current flows from Antarctica to southern Chile. Sucks the heat (and moisture) out of the air. Atacama Desert had no rain from 1570-1971.

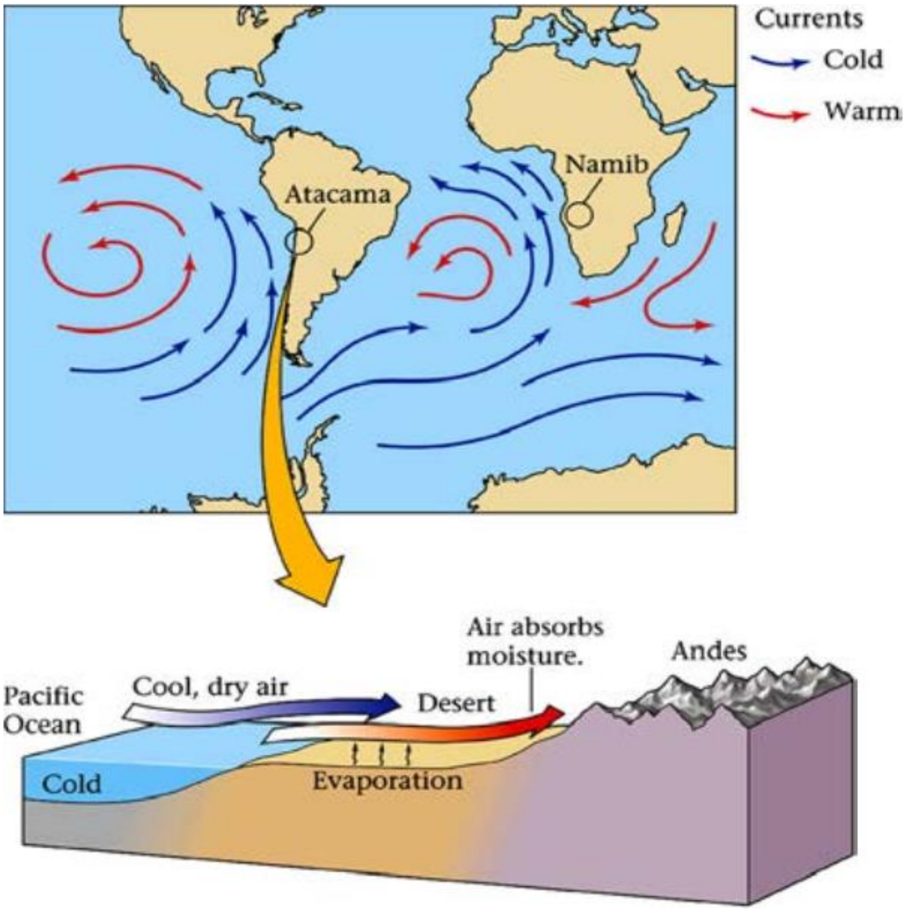


Figure 65. Cool air over cold ocean water holds little moisture. This air absorbs moisture when it interacts with land.

- **Continental Interior Deserts**

Long way from oceans (e.g., centralAsia), air has to rise from ocean and drops moisture close to the coast.

- **Deserts of the Polar Regions**

air has moved north and cooled by cold oceans (reduced moisture). Now it rises, expands and rises further. Above 66º N and S latitude there is very little moisture in the air due to cold temperatures. Air circulation carries air to the polar regions, but it is so cold, the air can’t hold any moisture. Plate tectonics plays important role in distribution of deserts on the continents.

➤ Weathering & Erosion in Deserts

• Weathering

Physical weathering occurs along joints - expansion and contraction due to temperature changes. Lack of soil allows these blocks to build up (**as TALUS**) at the bottom of slopes and keeps bedrock exposed on slopes.

Chemical weathering does occur, but slowly. Dew and some rain percolates in cracks and fractures and leaches material out of the rock, reducing its integrity. Amount of water is not enough to flush it out of the system. Deposits material lower down - if calcite has been dissolved ‘calcrete’ is deposited because it cements loose grains together.

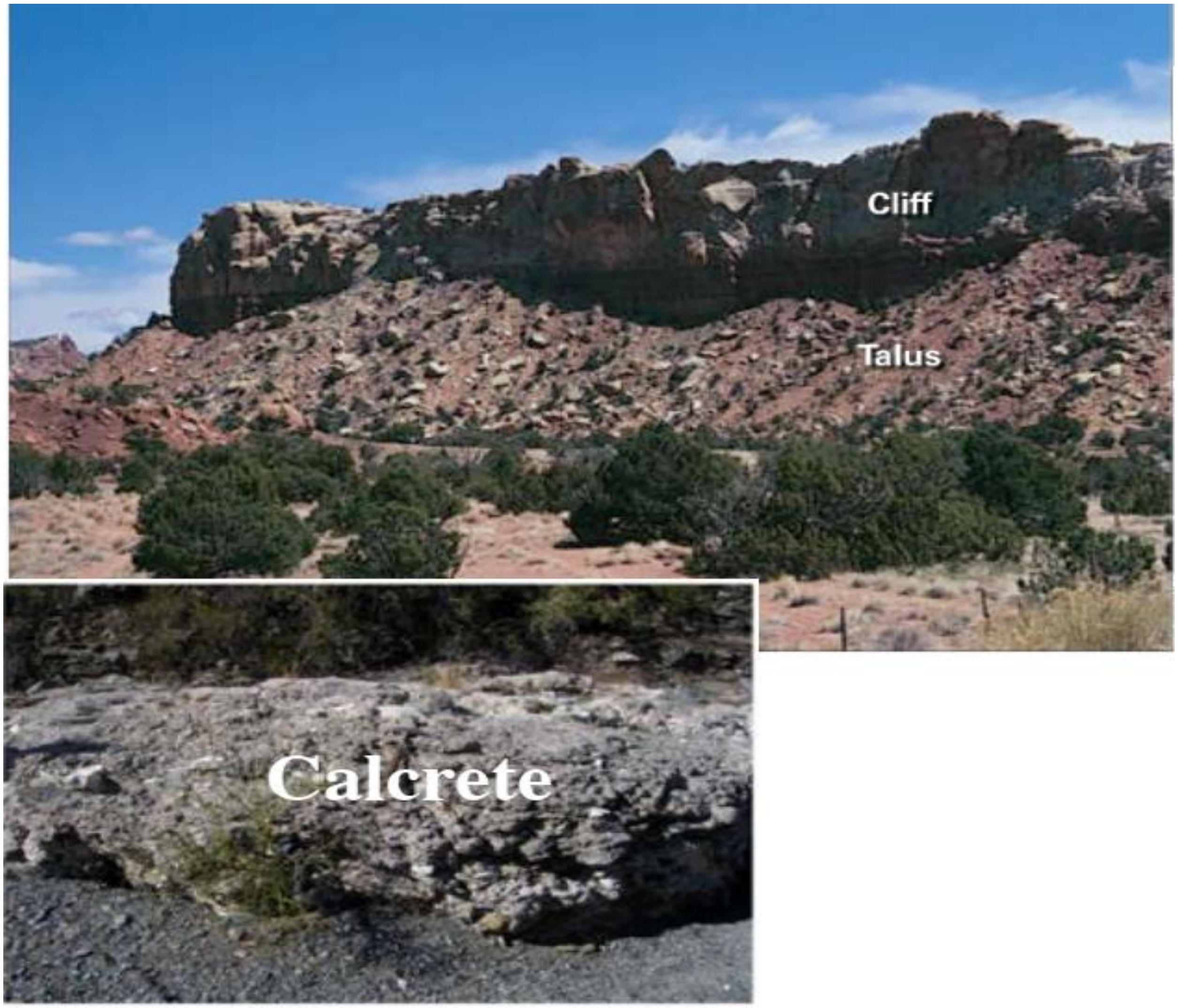


Figure 66. Desert Varnish: wind-borne dust settles on rocks. When dew precipitates, bacteria metabolize these particles and deposit Fe- and Mn-oxides. Takes a long time to form, but Native Americans made use of it for artwork (petroglyphs).

Figure 67: Lack of vegetation means variations in bedrock color stands out (e.g., Painted Desert, N. Arizona - variations in the amount of Fe and/or the amount of oxidation).

- **Water Erosion**

Deserts get most of their rain all at once. Lack of vegetation means loose material is easily moved. Streams are ephemeral.! Deep channels with steep sides are carved, called **Dry Washes** or **Arroyos** in the US - **Wadis** in the Middle East. Flash floods are common.

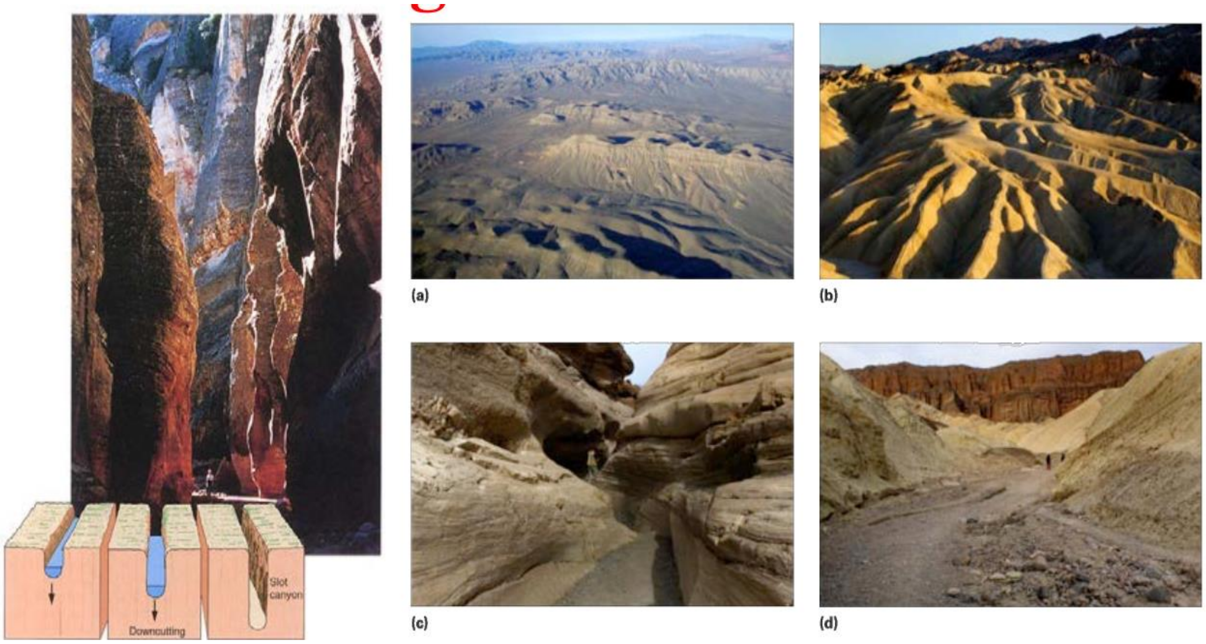


Figure 68. Though rare, water is the dominant force shaping landscapes. Desert landscapes reveal dry drainages. Sediment erodes quickly when torrential rains generate dangerous flash floods characterized by rapid flow of thick, muddy, and viscous water. Flash floods quickly infiltrate dry streambeds.

- **Wind Erosion**

Can carry sediments long distances, including uphill.

Initial movement = deflation – requires dry grains that are not restricted by vegetation (**or water**).

Deflation = the sorting out, lifting, and removal of loose dry, finegrained particles by turbulent eddy action of a fluid.

Critical Velocity = velocity of fluid flow at which flow changes from laminar to turbulent. In comparison, water can move larger material with lower velocity.

Settling Velocity: the rate at which suspended solids subside and are deposited.

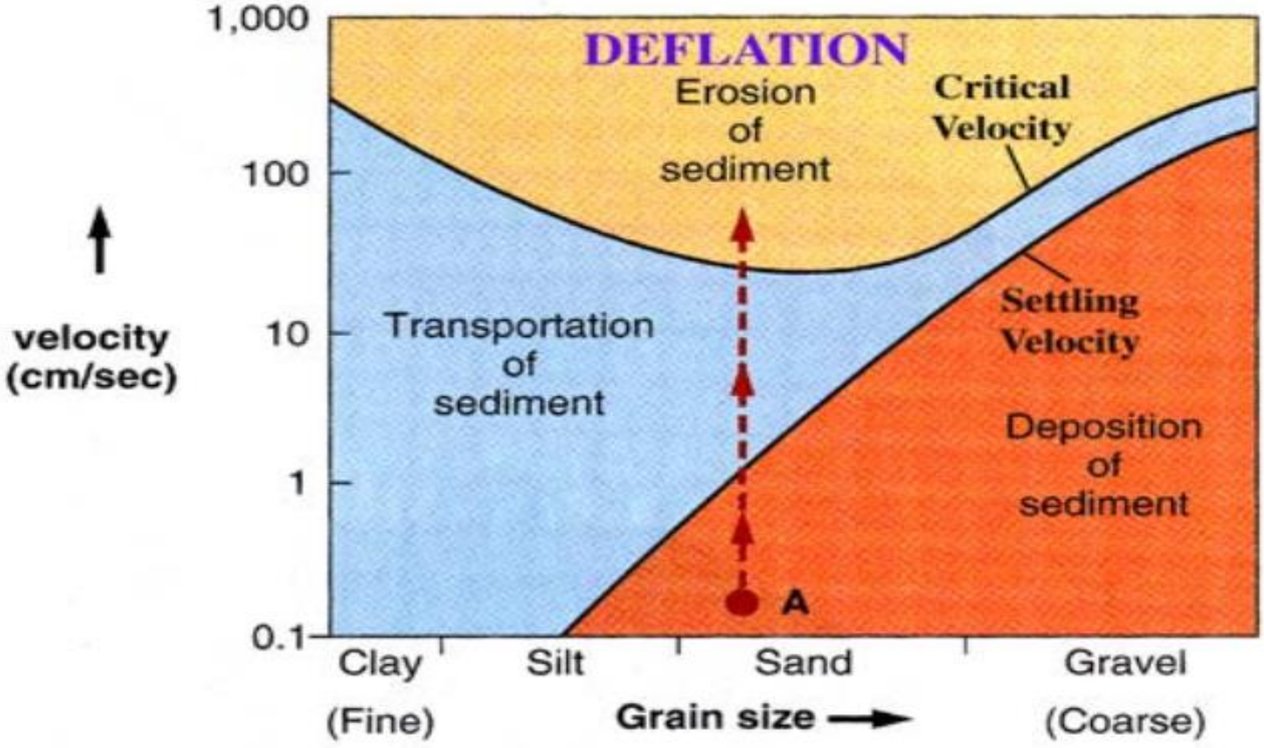


Figure 69. **Deflation** (the sorting out, lifting, and removal of loose dry, finegrained particles by turbulent eddy action of a fluid).

- **Desertification**

Desertification is land degradation in arid, semi-arid, and dry sub-humid areas resulting from many factors, including human activities and climatic variations (UNCCD, 1994; Glossary). Arid, semi-arid, and dry sub- humid areas, together with hyper-arid areas, constitute drylands (UNEP, 1992). Consequently, although land degradation occurs anywhere across the world, it is defined as desertification when it occurs in drylands. Desertification is not limited to only irreversible forms of land degradation, nor is it limited to processes of desert expansion, but is used to represent all forms and levels of land degradation occurring in drylands. In turn, land degradation is a deterioration or persistent decline in land conditions resulting in long-term reduction or loss of the biological productivity of land, its ecological complexity, and/or its human values, caused by direct and/or indirect human-induced processes or impacts, including climate change). Thus, desertification is manifested through the reduced provision of the sum of dryland ecosystem services .

The geographic classification of drylands is often based on the aridity index - the ratio of average annual precipitation amount (P) to potential evapotranspiration amount (PET) (Figure 70). Hyper-arid areas, where the aridity index is below 0.05, are included in drylands, but are excluded from the definition of desertification (UNCCD, 1994). Moreover, aridity is different from drought: aridity is a long-term climatic feature, whereas drought is a temporary climatic event. Droughts are not restricted to drylands, but occur both in drylands and humid areas. IPCC (2014) defines drought as “a period of abnormally dry weather long enough to cause a serious hydrological imbalance”

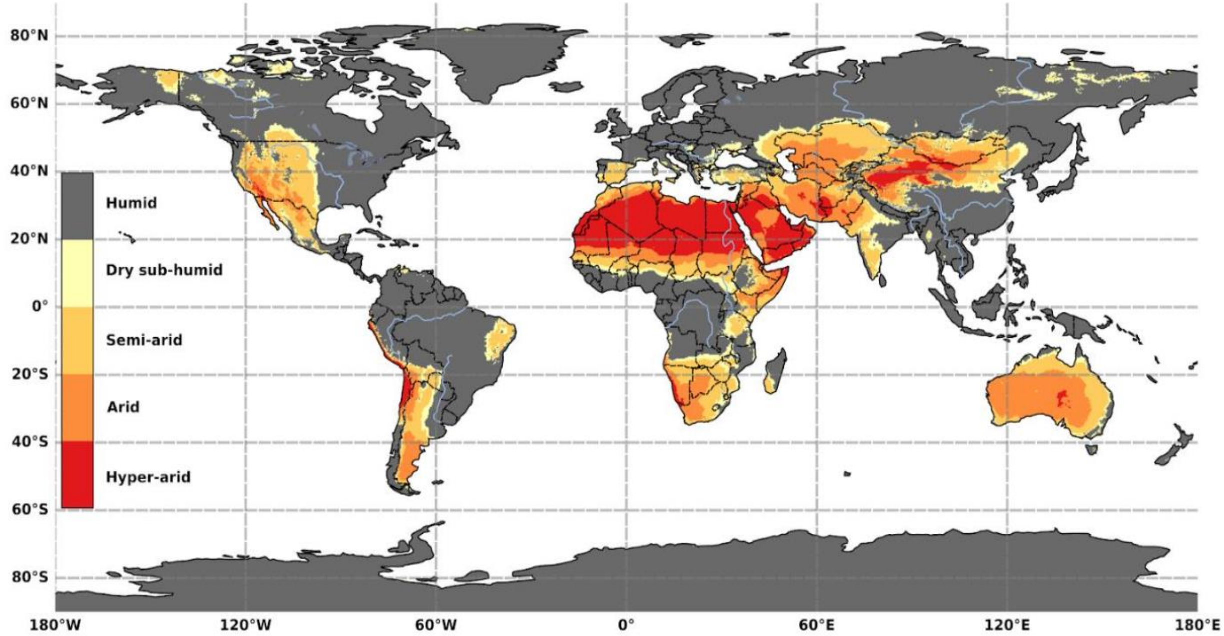


Figure 70. Geographical distribution of drylands, delimited based on the Aridity Index. The classification of the aridity index (AI) is: Humid AI>0.65, Dry sub-humid 0.50 < AI < 0.65, Semi-arid 0.20 < AI < 0.50, Arid 0.05 < AI < 0.20, Hyper-arid AI < 0.05. Data: TerraClimate precipitation and potential evapotranspiration 26 (1980-2015) (Abatzoglou *et al.*, 2018).

V.3. Aridity Indices

Aridity Indices are quantitative measures used to assess the degree of dryness of a climate by relating precipitation to temperature and/or potential evapotranspiration. They are widely used in climatology, hydrology, agriculture, and environmental studies to classify climates and evaluate water stress.

V.3.1. De Martonne's Aridity Index (1926)

De Martonne's aridity index is a simple climatic indicator used to evaluate the degree of dryness of a region by relating **precipitation** to **temperature**.

Formula

$$I = \frac{P}{T + 10}$$

where:

- P= mean annual precipitation (in mm)
- T= mean annual air temperature (in °C)
- **10** = constant to avoid negative or zero values at low temperatures
- **Climatic Classification (De Martonne)**

Index value (I)	**Climate type**
$I < 5$	Very arid
$5 \leq I < 10$	Arid
$10 \leq I < 20$	Semi-arid
$20 \leq I < 30$	Sub-humid
$30 \leq I < 60$	Humid
$I \geq 60$	Very humid

Applications

- Climate and bioclimatic classification
- Evaluation of aridity and desertification risk
- Agro-climatic and environmental studies

Advantages

- Easy to calculate

- Requires only temperature and rainfall data

Limitations

- Does not account for evapotranspiration or seasonal rainfall distribution

V.3. 2. Monthly De Martonne Aridity Index

The **monthly version** of De Martonne's aridity index is derived by applying the classic annual formula to **monthly climate data**. It provides a way to assess **seasonal water availability and dryness** throughout the year.

Formula (Monthly)

For each month:

$$I_m = \frac{P_m}{T_m + 10}$$

where:

- I_m= De Martonne aridity index for month *m*
- P_m= Mean monthly precipitation (mm)
- T_m= Mean monthly temperature (°C)
- **10** = Constant to prevent division by very small numbers and reduce sensitivity at low temperatures

Interpretation

- Low values of $I_m \Rightarrow$ **drier month**
- Higher values of $I_m \Rightarrow$ **wetter month**
- You can compare I_m values across months to identify **dry/wet seasons**

There are no formal universal classes for monthly values like for annual indices, but generally:

I_m **Range**	**Indicative Dryness**
<5	Very dry
5 – 10	Dry
10 – 20	Moderately dry
>20	Moist to wet

How to Use It

1. **Collect data:** Monthly average temperature and monthly total precipitation for each month of the year.
2. **Compute** I_m for each month using the formula.
3. **Plot or tabulate values** to visualize seasonal changes.

V.3. 3. Angström Aridity Index (1936–1937)

The **Angström aridity index** is a climatic indicator used to evaluate the **degree of dryness** of a region by relating **precipitation** to **temperature**. It is mainly applied in climatology and agro-climatic studies.

Formula

$$I_A = \frac{P}{1.07\,T}$$

where:

- I_A= Angström aridity index
- P= mean annual precipitation (mm)
- T= mean annual air temperature (°C)
- **1.07** = empirical coefficient

Interpretation

- **Low values of** I_A→ arid or dry climate
- **High values of** I_A→ humid climate

V.3. 4. Giacobbe Summer Drought Index (GSDI)

The **Giacobbe Summer Drought Index** is a climatic index designed to evaluate **summer drought intensity**, particularly in **Mediterranean and semi-arid regions**. It focuses on the balance between **summer precipitation** and **summer temperature**, making it suitable for agro-climatic and ecological studies.

Formula

$$\text{GSDI} = \frac{P_s}{T_s}$$

where:

- P_s= total **summer precipitation** (mm)
- T_s= mean **summer air temperature** (°C)

Summer usually corresponds to **June–July–August (JJA)**, but the period may be adapted to local climatic conditions.

Interpretation

- **Low GSDI values → severe summer drought**
- **High GSDI values → humid or less dry summer conditions**

Typical indicative ranges (may vary by region):

GSDI value	**Summer condition**
< 1	Very dry
1 – 2	Dry
2 – 4	Moderately dry
> 4	Humid

V.3. 5. Annual Rainfall Index of Moral (1954)

The **Moral annual rainfall index** (Indice pluviométrique annuel de Moral) is a **simple pluviometric indicator** used to characterize **wet and dry years** by comparing the **annual rainfall of a given year** to the **long-term mean annual rainfall** of the station or region.

Formula

$$I_M = \frac{P_i}{\bar{P}}$$

where:

- I_M= Moral annual rainfall index
- P_i= annual precipitation of year i (mm)
- $\bar{P}$= long-term mean annual precipitation (mm), calculated over a reference period (e.g. 30 years)
- **Interpretation**

I_M value	Rainfall condition
$I_M < 0.75$	Very dry year
0.75 – 0.90	Dry year
0.90 – 1.10	Normal year
1.10 – 1.25	Wet year
$I_M > 1.25$	Very wet year

V.3. 6.Mangenot Humidity Index (1954)

The **Mangenot humidity index** is a bioclimatic indicator used to assess the **degree of humidity or aridity of a climate**, particularly in **Mediterranean and semi-arid regions**. It relates **annual precipitation** to **thermal conditions**, making it useful for ecological and biogeographical studies.

Formula

$$I_H = \frac{P}{\sum T}$$

where:

- I_H= Mangenot humidity index
- P= mean annual precipitation (mm)
- $\sum T$= sum of **positive mean monthly temperatures** (°C)

Only months with $T > 0^\circ$Care considered.

Climatic Interpretation (indicative)

I_H value	Climate type
<10	Very arid
10 – 20	Arid
20 – 30	Semi-arid
30 – 50	Sub-humid
> 50	Humid

(Thresholds may vary slightly depending on authors and regions.)

V.3. 7.Emberger's Xerothermic Index (1942)

Emberger's xerothermic index is a **bioclimatic index** developed to characterize **Mediterranean-type climates**, with particular emphasis on **summer drought intensity**. It links **precipitation** with **thermal extremes**, making it especially useful for vegetation and phytogeographical studies.

Formula

$$X = \frac{1000\,P}{M^2 - m^2}$$

where:

- X= Emberger's xerothermic index
- P= mean annual precipitation (mm)
- M= mean maximum temperature of the hottest month (in **Kelvin**)
- m= mean minimum temperature of the coldest month (in **Kelvin**)

Bioclimatic Interpretation (indicative)

Xerothermic index (X)	Bioclimatic stage
<20	Saharan
20 – 40	Arid
40 – 70	Semi-arid
70 – 100	Sub-humid
100 – 200	Humid
> 200	Very humid

V.3. 8.Ombrothermic Diagram of Bagnouls and Gaussen (1953)

The **ombrothermic diagram** developed by **Bagnouls and Gaussen (1953)** is a **graphical climatic method** used to identify **dry and wet periods** during the year. It is especially useful in **Mediterranean and semi-arid climates** to analyze **seasonal drought** and its impact on vegetation.

Principle

The diagram is based on the comparison between **monthly precipitation (P)** and **monthly mean temperature (T)** using the rule:

$$\boxed{P \leq 2T \quad \Rightarrow \quad \text{Dry month}}$$

where:

- P= monthly precipitation (mm)
- T= monthly mean temperature (°C)

Construction

1. **X-axis:** Months of the year
2. **Y-axis:**
   - Temperature scale (°C)
   - Precipitation scale (mm) with the ratio **1 °C = 2 mm**
3. **Plot:**
   - Monthly temperature curve
   - Monthly precipitation histogram or curve

Interpretation

- **Dry period:** months where the precipitation curve lies **below** the temperature curve ($P < 2T$)
- **Wet period:** months where $P > 2T$
- The **length and continuity** of dry months indicate the **severity of drought**

V.4.Mapping and monitoring spatiotemporal desertification patterns in the arid transition zone of Algeria .

Desertification represents a critical threat to ecosystems, agriculture, and livelihoods in arid and semi-arid regions. This study provides a comprehensive analysis of the spatio-temporal evolution of desertification across Algeria's steppic and northern Sahara regions from 2002 to 2022.

According to the United Nation's IPCC special report published in 2019, the scale and intensity of desertification have most likely increased over the past few decades in certain dryland areas (Pete et al., 2019). From the 1980s through the 2000s, deserts expanded to cover more than 9% of arid lands, affecting the livelihoods of more than 500 million persons by 2015. Prăvălie (2016) estimated that out of the 54 African nations, 46 are at risk of desertification, with 38 out of 48 Asian countries currently experiencing its impacts. Algeria stands out as one of the nations hardest hit by desertification, demonstrated by a significant decline in indigenous plant biodiversity from 1975 to 2006 (Belala et al., 2018). The Sahara and Sahel Observatory reports that the number of species in southwestern Algeria's steppe land declined from 234 in 1978 to 95 in 2011 due to prolonged droughts and human-induced degradation (Observatoire du Sahara et du Sahel, 2013). Past interventions, such as the Green Dam project, have not been effective in stopping or reversing this trend (Mihi et al., 2024). The desert currently spans nearly 2 million km, accounting for 80% of the total land area, and approximately 8 out of 20 million hectares of the steppe are considered vulnerable to desertification (Khaldi, 2014). This 1200 km long region is strategic and a focal point for desertification research, acting as a natural buffer between the Sahara and the fertile lands to the north.

All previous studies have examined different facets of land degradation in different parts of the steppic and northern Sahara regions of Algeria over different periods, but a more global picture of the evolution of this phenomenon over recent decades is yet to be drawn.

The study by Tandjaoui et al. (2025) used Earth Observation (EO) data, particularly Landsat imagery combined with cloud-based processing platforms, to analyze desertification trends over the arid zones in Algeria, including the entire steppe, which forms a buffer zone between the arid Sahara to the south and the more fertile Tell region to the north, from 2002 to 2022. Applying a feature-space model of spectral indices, they defined a Vegetation Sparsity Index (VSI) that effectively captures the annual spatio-temporal variation of vegetation during the fall season, highlighting perennial vegetation. This index also enables the classification of the study area into five vegetation sparsity classes.

They then employed several analytical methods, namely intensity analysis, gravity center change, and regionalization, to characterize the transition patterns and rates between vegetation classes, the movement and distribution of these classes across the study area, and to delineate contiguous regions with similar VSI trajectories.

While the total area of the different vegetation classes remained relatively stable between 2002 and 2022, a closer examination reveals alarming trends. Since 2010, there has been a clear trend towards degradation, marked by the expansion of extremely desertified areas. This underscores the importance of long-term monitoring at appropriate temporal scales.(Fig 71.)

Moreover, the analysis identified three distinct periods: a general greening trend until 2010, followed by rapid degradation until 2014, and a period characterized by a relative continuation of degradation thereafter. Regionalization analysis further revealed that the central-western steppe — an area of critical agricultural and livestock production — is experiencing significant land degradation. Conversely, the eastern regions exhibited a positive greening trend, likely linked to agricultural expansion.

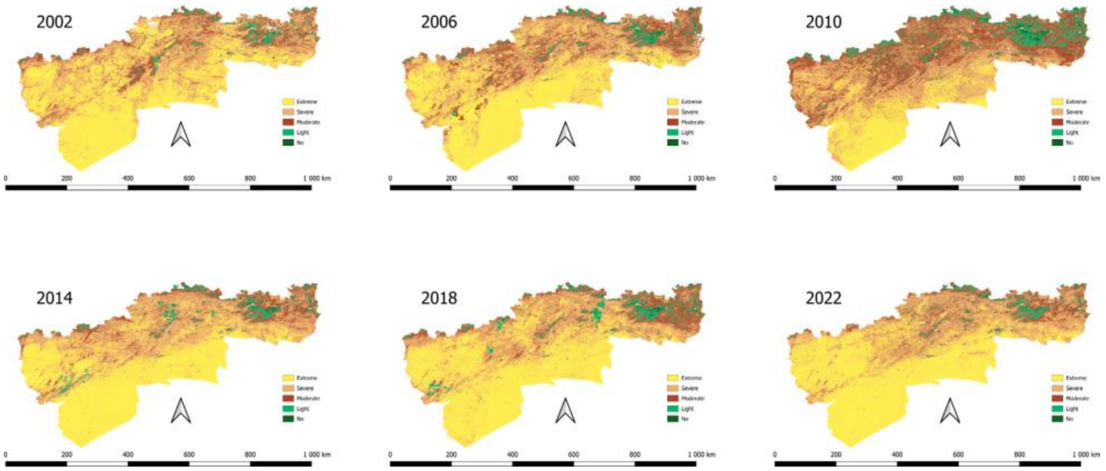


Figure 71. VSI-based vegetation maps.(Tandjaoui et al., 2025)

Chapter VI : Evapotranspiration

VI.1. Definitions

- **Evaporation**

is defined as the process by which water from water bodies (rivers, ponds, lakes) or soil is converted to vapor. It is commonly expressed in mm/hour.

- **Potential Evaporation**

is the quantity of water evaporated per unit time per unit area of an idealized extensive free water surface under existing atmospheric conditions. The time scale for measurement or estimation can be an hour, a day, a month, or a year. It is usually assumed uniform over the area under consideration and is expressed in mm, cm, or inches. Thus, it is commonly expressed in mm/day, cm/month, in/day.

- **Reference Evapotranspiration**

evapotranspiration from a reference surface, not short of water, is called the reference evapotranspiration and is denoted as ETo (UN Food and Agriculture Organization, www.fao.org). The reference surface is a hypothetical grass reference crop with specific characteristics. It is commonly expressed in mm/day or cm/month.

- **Evapotranspiration (ET)**

consumptive use include both the transpiration by vegetation, and evaporation from water surfaces, soil, snow, ice, and vegetation. For all practical purposes, the terms consumptive water use and evapotranspiration are synonymous. ET or consumptive uses converts water to a form (water vapor) which is not available for use again. This is in contrast to, say hydropower generation, where water is subsequently available for use again. ET is typically expressed in the units of depth (mm or cm) for a given period. ET is an important component of the hydrologic cycle. Estimation of ET is necessary in many studies, such as catchment modeling, agricultural water management, determination of water balance, assessment of the impact of land use changes on the hydrologic response of a catchment, etc. In many watersheds, the return of moisture to the atmosphere through the process of ET is a large proportion of input precipitation.

The evapotranspiration rate from a reference surface, not short of water, is called the reference crop ET or reference evapotranspiration and is denoted as ET0 (Allen *et al.*, 1998). The reference surface is a hypothetical grass reference crop with specific characteristics. Further, crop ET under standard conditions (ETc) refers to the evapotranspiration from excellently managed, disease-free, large, well-watered fields that achieve full production under the given climatic conditions. Further, due to suboptimal crop management and environmental constraints that affect crop growth and limit evapotranspiration (ETc) under non-standard conditions generally requires a correction

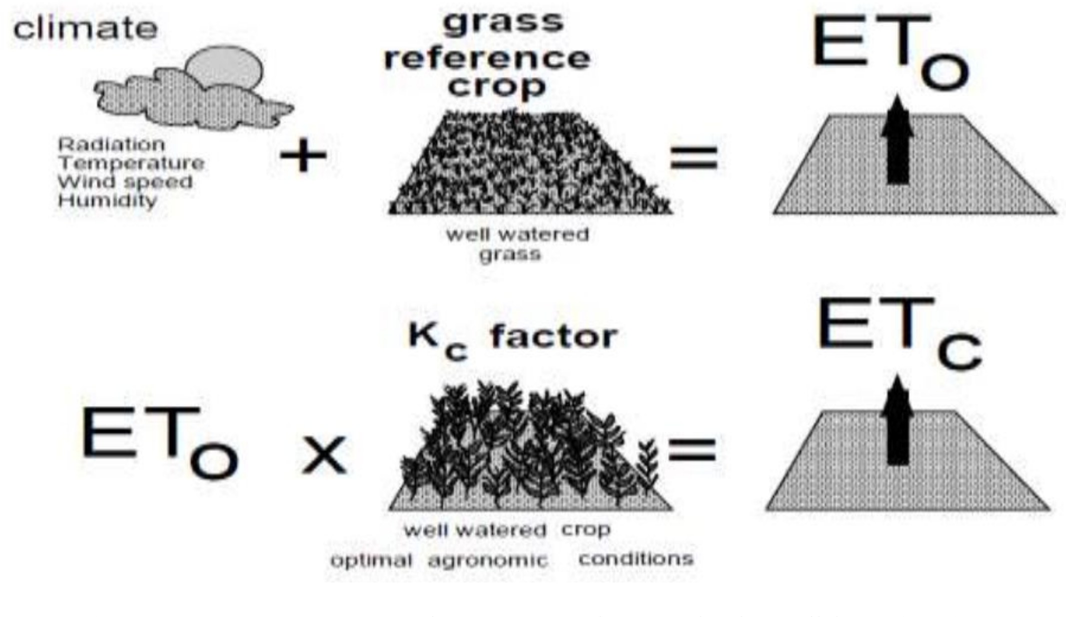


Figure 72. Reference crop ET or ET0and crop ET under standard conditions (ETc). Source FAO-56

VI.2. Estimation of Evapotranspiration

Evapotranspiration can be estimated by the water budget or heat-budget methods; many empirical formulae have been developed which are based on meteorological data. Food and Agricultural

Organization (FAO) of the United Nations has adopted the Penman-Monteith (PM) equation as the standard technique to compute reference ET (Allen et al. 1998).

FAO-56 Penman-Monteith Method for Estimation of ET

Numerous reference ET equations have been developed and are being used, depending upon the availability of weather data. These equations range in sophistication from empirical solar

radiation- or temperature-based equations to complex methods based on physical processes such as the combination method of Penman (1948). The combination approach links evaporation dynamics with the flux of net radiation and aerodynamic transport characteristics of a natural surface. Based on observations that latent heat transfer in plant stems is influenced not only by these abiotic factors, Monteith (1965) introduced a surface conductance term that accounted for the response of leaf stomata to its hydrologic environment. This modified form of the Penman equation is widely known as the Penman-Monteith (PM) equation. The PM equation is physically based, because it attempts to incorporate the physiological and aerodynamic characteristics of the reference surface. While the use of the modified Penman method (Doorenbos and Pruit, 1977) was recommended by FAO, recent studies have suggested that this method overestimates ET . FAO has now recommended the use of the PM method to compute reference ET from a grass surface and has specified a grass reference ET equation (Allen et al. 1998). Studies have shown that the reference ET computed using the PM equation yields estimates that are close to observed reference ET values. As described in the Irrigation and Drainage (Allen *et al.* 1998), the FAO has adopted the Penman-Monteith (PM) equation (named here FAO56-PM) as the standard technique to compute reference ET. The FAO56-PM can be used for hourly or daily time steps. For hourly time steps, the equation is stated as (Allen et al. 1998):

$$ET_0 = \frac{0.408\Delta(R_n - G) + \gamma \frac{37}{T_{hr} + 273} u_2 \left[e^0(T_{hr}) - e_a\right]}{\Delta + \gamma(1 + 0.34u_2)}$$

where ET0 is the grass reference ET in mm/hour, Rn is the net radiation at the grass surface in MJ per m2 per hour, G is the soil heat flux density in MJ per m2 per hour, T is the mean hourly air temperature in °C, u2 is the mean hourly wind speed at 2 m height in m/s, e0 (Thr) is the saturation vapor pressure in kPa at air temperature Thr, ea is the actual hourly vapor pressure in kPa, Δ is the slope of vapor pressure versus temperature curve in kPa per °C, and γ is the psychrometric constant in kPa per °C. Allen et al. (1998) have described the procedure and steps for the application of the PM equation for various time step sizes.

An application of the FAO56-PM equation requires data of solar radiation, wind speed, air temperature, vapor pressure, and humidity. However, all these input variables may not be easily available for a given location. In developing countries in particular, difficulties are often faced in collecting accurate data of all necessary climatic variables and this can be a serious handicap in applying FAO56-PM equation. Among the inputs needed, temperature data are routinely measured and solar radiation can be estimated with sufficient accuracy. But the other variables are mostly measured only at a few locations.

VI.2.1.Direct Methods for Estimating Evapotranspiration

Two main methods can be distinguished: **the evaporometer** and **lysimeter tanks**. These measurements are based on the **evaporation of a certain amount of water**.

- **Piche Evaporometer**
- **Lysimeter tanks**

For the second method, **ETR (Actual Evapotranspiration)** can be considered as the **residual term** of the soil water balance equation after all other components have been measured:

$$DS = P + I - (D + R + ETR)$$

Where:

- **DS** = change in soil water storage
- **P** = precipitation
- **I** = irrigation
- **D** = drainage
- **R** = runoff (lateral water exchanges) (Ibid.)

In the case where runoff is negligible and measurements begin after the soil has drained (drainage = 0), the equation simplifies to:

$$DS = P + I - ETR$$

Knowing the incident rainfall and irrigation inputs (in the case of crops), the **main difficulty** is estimating the **change in soil water storage** between two dates. A **lysimeter tank** is an outdoor container that It contains **soil covered with a certain type of vegetation** (e.g., grass) or left bare, for which the **amount of infiltrated and drained water** is evaluated in relation to the water provided by precipitation. Some lysimeters can be **weighed regularly** to determine the volume of water contained in the soil. The **depth** of a lysimeter ranges from **0.5 to 2 meters**, and its **surface area** from **0.3 to 4 m²**. A **weighing system** allows the calculation of DS. **Runoff** is eliminated by keeping the surface horizontal, and water exiting by **drainage** is collected. **Precipitation** is measured using a rain gauge.

ETR is then **determined by difference**. If the lysimeter tanks are maintained at **optimal soil moisture** through daily replenishment, **ETM (Potential Evapotranspiration)** is measured. If no additional water is supplied, then **ETR (Actual Evapotranspiration)** is measured.

To ensure the measurement **remains representative of natural conditions**, during periods of **severe soil water deficits**, the tank should be **as deep as possible**. Even a depth of **two meters** under a herbaceous crop can be insufficient during extreme drought. Moreover, the **representativeness of measurements** requires **minimizing adventitious exchanges** between the lysimeter and its immediate environment (guard ring). The **evaporating surface** to be considered is also delicate, particularly when vegetation grows above the edges of the tank.

Changes in **soil water storage** can also be measured using **advanced instrumentation** such as:

- **Soil moisture sensors** (neutron probes)
- **Time-domain reflectometers (TDR probes)**

Chapter VII | The Mediterranean Climate

Two relatively recent theories of Mediterranean climate variability are reviewed. Both theories shift attention from longitude-independent subsidence associated with the Hadley circulation to heating and cooling by horizontal winds as the primary determinant of Mediterranean climate and its variability. For both summer and winter, it is shown that Mediterranean wind anomalies are intimately related to North Atlantic climate variability. The Mediterranean summer aridity is attributed to the Mediterranean's location between the cool North Atlantic and the area of strong heating by the Asian Monsoon, which induces subsidence. Unusually rainy (dry) eastern Mediterranean winters are shown to arise by anomalous southerly (northerly) winds. The winter theory also displays predictive skills, which are mentioned but are rigorously demonstrated elsewhere.(Eshel, 2002)

VII.1 Mediterranean Bioclimate (Mediterranean Climate & Biome)

Mediterranean bioclimate refers to the characteristic climate and associated ecosystems found around the Mediterranean Basin and in other similar regions of the world (e.g., California, central Chile, South Africa, parts of Australia). It is defined by a distinctive seasonal rainfall pattern and temperature regime that strongly influences vegetation, water balance, and ecosystem processes.

VII.1.1. Climatic Characteristics

The Mediterranean climate is typically described by the following features:

- **Seasonal rainfall distribution:** Most annual precipitation occurs in **winter**, while **summers are dry**.
- **Temperature regime:** Warm to **hot, dry summers** and **mild, wetter winters** are common.
- **Annual precipitation:** Mean annual rainfall usually ranges from **~300 to ~1,200 mm**, with variability influenced by topography and latitude.
- **Evapotranspiration dynamics:** Dry summers often lead to high evaporative demand and soil–water deficits.

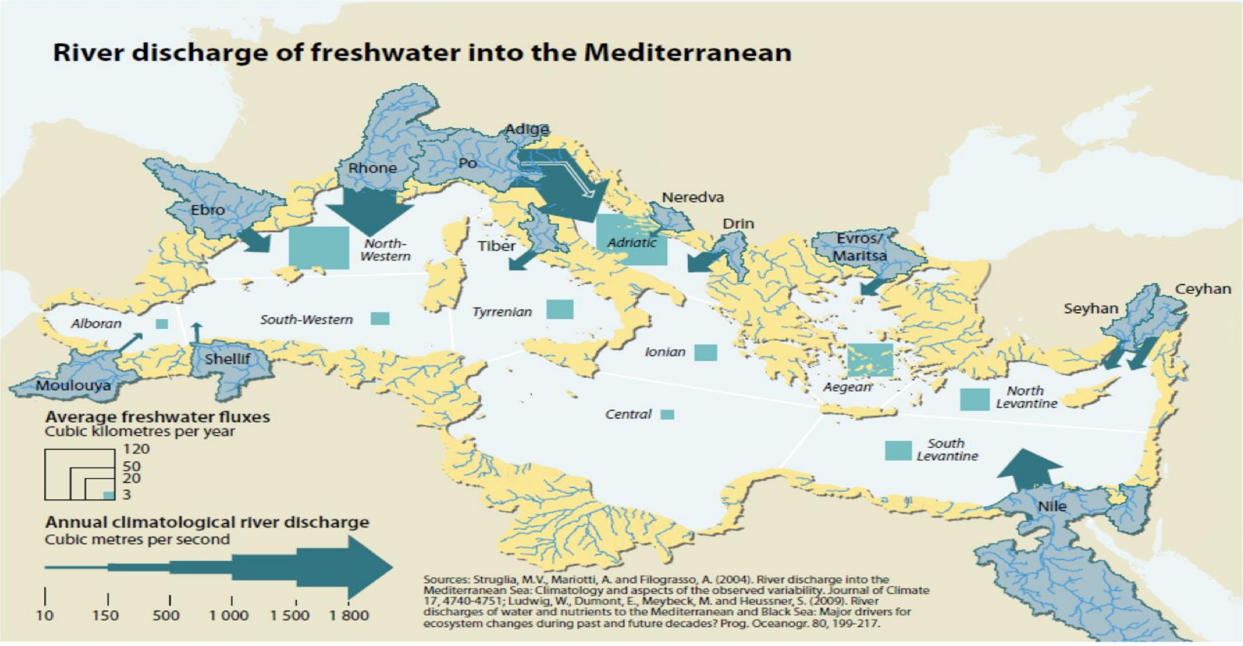
These climatic features create a pronounced **seasonal water deficit**, which strongly shapes the bioclimate and vegetation patterns.

Figure 73.Geographical characteristics of the Mediterranean region (UNEP/MAP, 2022)

VII.1.2. Hydrological and climatic setting.

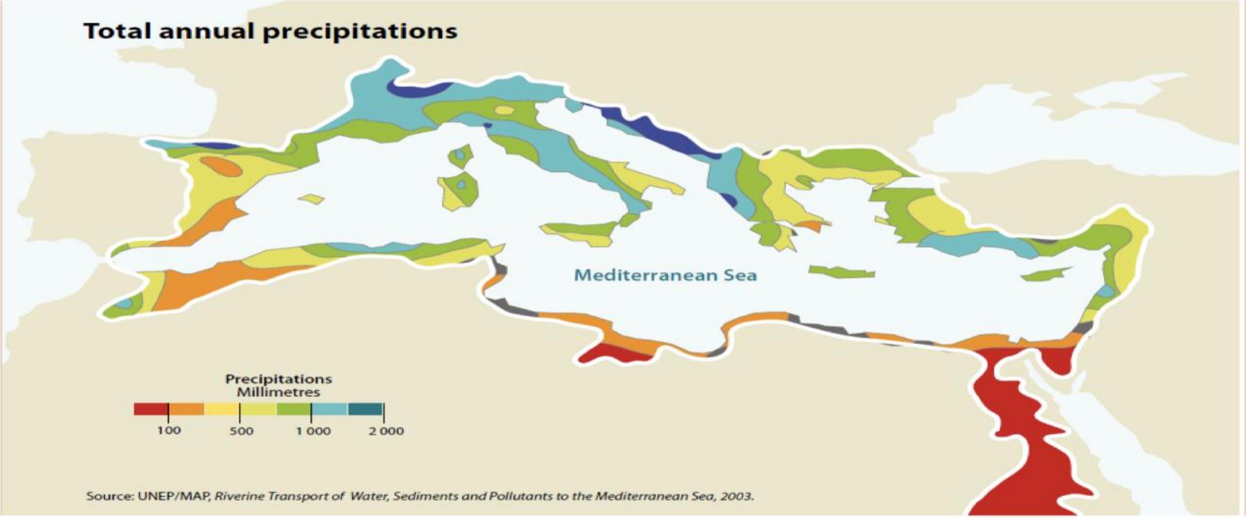
The Mediterranean region is characterized by winter dominated rainfall and hot dry summers. Even though large spatial climate variability and diversity exist within the Mediterranean basins, many areas can be classified as arid or semiarid. The Mediterranean is an area of transition between a temperate Europe with relatively abundant and consistent water resources, and the arid African and Arabian deserts that are very short of water. The Mediterranean region is experiencing a large stress on its water resources due to a combination of effects ranging from climate change to anthropogenic pressures due to an increasing water demand for domestic and industrial use, expansion of irrigated areas, and tourism activities. More than half of the water-poor population of the world is concentrated in the Mediterranean basin, which holds only 3% of the world's fresh water resources. These resources are unevenly distributed over space. Half are located in Italy and Greece and 25% in catchments in France and Turkey. Catchments on the southern and eastern rims provide, respectively, only 4% and 2% of Mediterranean water resources (Milano *et al.*, 2013).

Water resource availability in the Mediterranean has already been affected by environmental change, and is seriously jeopardized in future environmental, economic, and demographic scenarios (Garcia-Ruiz *et al.*, 2011). Most global hydrological models are based on expected trends in precipitation and temperature. However, a number of studies have demonstrated the influence of land cover on river discharge and water resources. Climate and land cover change (artificial and natural reforestation, deforestation, expansion of farming areas) are likely to amplify water stress in the Mediterranean region, caused by a combination of decreased water resource availability (lower precipitation and increased evapotranspiration) and increased water use pressure resulting from economic growth and urban expansion. Special attention to mountain areas is required, as they are the most important sites for water resource generation worldwide, and particularly in temperate and semi-arid areas including the Mediterranean basin. However, mountain areas are facing increasing hydrological stress caused by a combination of i) increasing temperature and decreasing precipitation, exceeding that in the lowlands; ii) land use change, including natural and deliberate reforestation of abandoned farmland, thus increasing evapotranspiration and water consumption; and, (iii) increasing pressures on surface and groundwater resources, thus reducing river discharge and lowering the depth of the water table in groundwater-dependent areas.



Sources: Struglia, M.V., Mariotti, A. and Filograsso, A. (2004). River discharge into the Mediterranean Sea: Climatology and aspects of the observed variability. Journal of Climate 17, 4740-4751; Ludwig, W., Dumont, E., Meybeck, M. and Heussner, S. (2009). River discharges of water and nutrients to the Mediterranean and Black Sea: Major drivers for ecosystem changes during past and future decades? Prog. Oceanogr. 80, 199-217.

Figure 74. River discharge into the Mediterranean (UNEP/MAP, 2022)



Source: UNEP/MAP, *Riverine Transport of Water, Sediments and Pollutants to the Mediterranean Sea, 2003.*

Figure 75. Total Annual Precipitation (UNEP/MAP, 2022)

The amount and distribution of rainfall in Mediterranean localities is variable and unpredictable. Along the North African coast from Gabès in Tunisia to Egypt, more than 10 inches (250 mm) of rainfall per year is rare, whereas on the Dalmatian coast of Croatia there are places that receive 100 inches (2,500 mm). Maximum precipitation is found in mountainous coastal areas (Figure 74.75). The climate in the region is characterized by hot, dry summers and cool, humid winters. The annual mean sea surface temperature shows a high seasonality and important gradients from west to east and north to south.

Coastal aquifers provide another source of freshwater discharge to the Mediterranean. The submarine groundwater discharge from the coastal aquifers, estimated at 2.200 m3/s, accounts for almost one-fifth of the total freshwater inflow into the Mediterranean, with more than one-third of this discharge entering from the sea's European shores. Seepage inflows are prevalent on the eastern coast of the Adriatic, dominated by karstic aquifer systems, as well as on the eastern and southern Mediterranean coast with semi-arid and arid conditions, limited precipitation and runoff, and limited surface watercourses and discharge points.

Coastal seepage and submarine discharges are critical to the water balance and seawater quality in the marine sub-basins. They also support wetlands and brackish water habitats, important to biodiversity, and fishery nursery areas. The coastal aquifers are threatened by over-exploitation and consequent seawater intrusion and water and land salinisation, which will add to the deficit in recharge of the Mediterranean. Submarine groundwater discharge is also a significant source of nutrient input in some regions and could provide pathways for pollutants to disperse into the sea (UNEP/MAP, 2012, and UNEP/MAP, UNESCO, 2022).

VII.1.3. Biodiversity.

The Mediterranean is one of the world's 34 hot spots for biodiversity. Its highly diverse marine ecosystem hosts around 4 to 18% of the world's marine. The Mediterranean provides vital areas for the reproduction of pelagic species: the Atlantic bluefin tuna's main spawning areas, the great white shark's unique breeding areas and sea turtles, such as the green and loggerhead turtles, nesting areas along its eastern coast. These high oceanic productivity areas host a particularly rich marine mammal fauna and the eastern part of the basin is one of the last shelters for the threatened Mediterranean monk seal. The shallow coastal waters are home to key species and sensitive ecosystems such as seagrass beds and coralligenous assemblages, whilst the deep waters host a unique and fragile fauna. Many of these species are rare and / or threatened and are globally or regionally classified by IUCN as threatened or endangered.

This natural heritage has profoundly influenced the development of populations, transforming this basin into a rich and heterogeneous mosaic of cultures. It is defined as "under siege" due to historical and current impacts of multiple stressors. Among them, fishing practices, habitat loss and degradation, eutrophication, and more recently, the introduction of alien species and climate change effects. Since the intensity of these stressors is increasing throughout most of the Mediterranean basin, temporal analyses are increasingly needed to inform effective current and future marine policies and management actions.

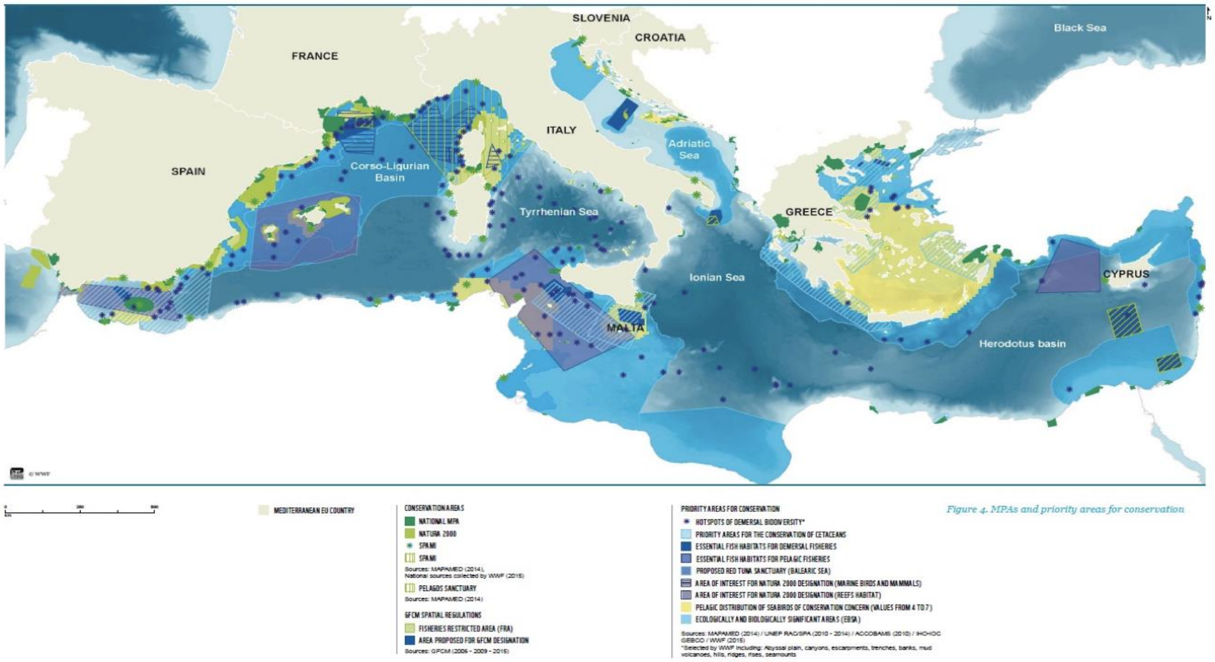


Figure 76. Marine protected Areas and protected areas for conservation (Piante, C., Ody, D.,2015)

Almost 86 000 km² of the Mediterranean is classified Marine Protected Areas (MPAs) or Natura 2000 site (Figure. 76). In 2016, only 3 % of the Mediterranean Sea is protected. The target of 10% protection of the CBD convention is far from being achieved. New Marine Protected Areas must be created in high and deep sea, which are not represented in the current network.

Chapter VIII | Adaptation of plants and animals to climatic conditions

In 1903, Danish botanist Christen Raunkiær published a system t o classify plant life forms based on their adaptation to the unfavourable season. He categorized plants according to the position of their perennating parts, i.e. buds or shoot apices.

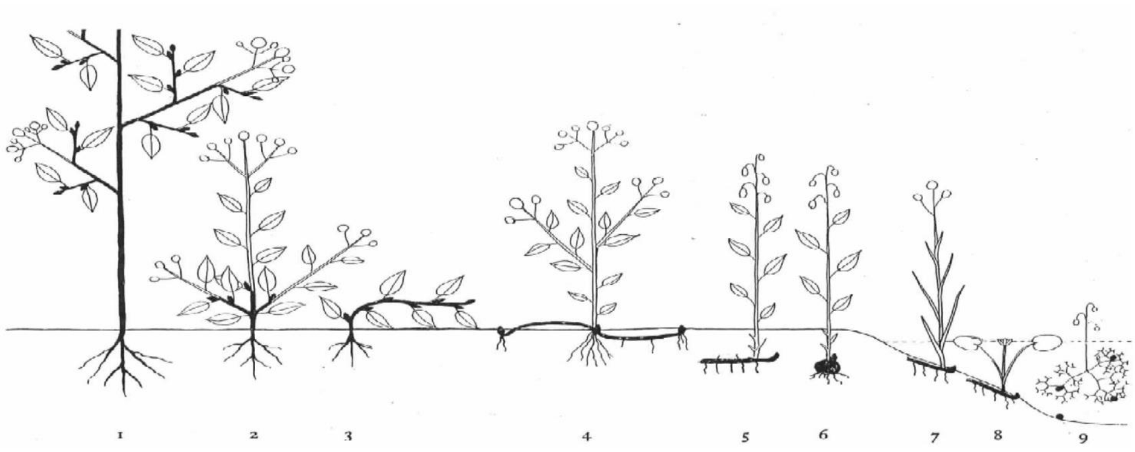


Figure 77. Schematic illustration of Raunkiær's life forms.

1: Phanerophyte 2,3: Chamaephytes 4: Hemicryptophyte 6-9: Cryptophytes .(Moser, 2019)

The problem of climate change is unavoidably accompanied by climate variabilities, such as high temperature, varying patterns of rainfall, and other environmental factors (including biotic factors), and causes an adverse impact on plant development and global food security. The effect of climate change on vegetation may be from cellular to the molecular level. Consequently, the existing literature on the plant's response to different environmental factors is varied. In view of the future impacts of climate change, understanding the response of plants becomes critical in developing strategies to cope with the threats to plant growth and development.

VIII.1 Drought-adapted plants (xerophytes)

Plants living in dry and desert regions have had to develop mechanisms and strategies to manage this sometimes very scarce natural resource: water. Different strategies exist:

1. **Adaptation of the growth cycle to the rainy season:** Annual plants that survive as seeds during the dry season or enter dormancy during summer.
2. **Storage of water and nutrients** (mainly carbohydrates) for long periods in underground stems or deep, thick roots. The root system can correspond to about ten times the mass of the aerial parts. *Harpagophytum*, growing in the Kalahari Desert, is a good example, with its tuberous secondary root being used therapeutically.
3. **Reduction of evapotranspiration through various mechanisms:**

a. Decreasing the number of stomata (responsible for photosynthesis and water release) and concentrating them on the lower leaf surface, which is less exposed to sunlight. b. Covering leaves with long, woolly hairs (trichomes) that reflect light, reduce heating, and conserve moisture (e.g., lavenders, sages, or thymes).c. Reducing leaf size, as in heather, astragalus, or asparagus.d. Rolling the leaf to varying degrees depending on its hydration state (e.g., rosemary).e. Epidermis covered with a water-impermeable layer (e.g., olive, strawberry tree, pistachio, or succulents that store water in their leaves, such as plants from the Crassulaceae family, including *Rhodiola rosea* and houseleeks).

VIII.2 Cold- and altitude-adapted plants

Mountain plants and those living in the tundra have developed several strategies to cope with environments where snow persists for long periods, the growing season is short, drought and wind are strong, and temperature fluctuations are large. Among the adaptations developed to avoid cold and limit its effects, the following can be cited:

- **Reduction in size** to benefit from the warmth of the soil and to gain protection from the wind under the snow cover.

- **Horizontal growth of certain trees** rather than vertical, as seen in birch or willow in the tundra.

- **Cushion-like growth form**, which reduces evaporation and traps the heat from sunlight.

- **Presence of small, thick, waxy leaves** that prevent water loss from drying winds.

- **Presence of a rapid reproductive cycle.**

VIII.3 Light-adapted plants

VIII.3.1 Light requirements of sciophytes and heliophytes

The light requirements of young plants are highly variable, and solar radiation affects the morphogenesis and growth of the individual through its **intensity, quality, and duration**. Its duration also influences flowering processes and constitutes an important factor in the development of the organism. Most plants have reproductive and nutritional cycles that depend on the intensity of light and darkness, or on seasonal changes caused by planetary movement.

Since the light requirements of green plants vary, **Wiesner** distinguished three groups of species based on their light needs:

- **Obligate heliophytes:** These species are found exclusively in exposed and sunny habitats and require 100% light. They include plants of deserts, tundras, high mountains, and steppes.
- **Facultative sciophytes:** These species can live under 100% daylight but can also tolerate some shade. At this limit, etiolated individuals may flower or become sterile. This group includes many "weeds," such as *Matricaria discoides* (100–50%), *Sedum acre* (100–48%), etc.
- **Obligate sciophytes:** These species are never exposed to direct daylight in nature. Their optimal light intensity is lower than for the previous groups, though the optimum cannot be extremely low, while the minimum can be very low. Examples include *Corydalis cava* (50–25%) and *Anemone nemorosa* (40–20%).

Green plants can only flower if they receive a sufficient amount of light energy, called the **trophic minimum of light** or **minimum illumination**. This corresponds to the minimum duration of light required for the plant to carry out enough photosynthesis to support vegetative growth and reach flowering maturity. Thus, differences in flowering or leafing are exclusively related to **day length and light intensity** at different times of the year.

In the Northern Hemisphere, these values range between a **maximum** (summer solstice) and a **minimum** (winter solstice).

A. Adaptation of shade-loving plants to low light

The adaptation of **sciophytes** (shade-loving plants) to low light involves **avoidance mechanisms** or **compensation mechanisms** for reduced light energy. Under limiting light conditions, the capacity for energy absorption can be increased by:

- **Reducing leaf reflectivity** (thin cuticle, absence of wax layer or hairs).
- **Presence of chloroplasts in epidermal cells.**
- **Increasing chlorophyll or other pigment content**, which allows absorption of energy from different wavelengths of radiation.
- **Increasing leaf surface area** to compensate for low photosynthetic activity (due to low light); this increase is, however, compatible with transpiration.

This plasticity of leaf surface involves a reduction of the palisade tissue to a single layer in shaded leaves (instead of 2–3 layers).

The arrangement and spacing of individual leaves along the stem are regulated to allow **maximum light exposure** and **maximum CO_2 absorption**: leaves may alternate along the stem, be opposite in pairs, emerge gradually in a spiral, or form **flat rosettes** (for prostrate plants on the ground).

B. Adaptation of sun-loving plants to high light

a. Morphological adaptations

Plants developed under high light differ from those grown in the shade by having **shorter stature, creeping growth habit, leaves arranged in rosettes or cushions, more branched stems with shorter internodes, larger underground organs, thicker and smaller leaves with less intense coloration**. Peripheral protections (epidermis, cuticle, hairs) are more developed, palisade parenchyma is more pronounced, flowering and fruiting are generally more abundant and earlier, and leaves are larger with more intense colors.

b. Harmful effects of intense light

High levels of infrared radiation accompanying intense sunlight cause **wilting** and abnormal increases in organ temperature. Excess light can cause **two types of damage**, direct or indirect. Direct damage affects membrane enzymes (involved in active transport), which undergo **photo-oxidation damage**.

Unlike sciophytes, the **deep tissues of heliophytes** are protected from direct irradiation by many peripheral defenses: membranes, wax or suberin layers, hairs, and the presence of anthocyanins in epidermal cells, which prevent excessive heating of underlying tissues.

c. Physiological adaptations

Heliophytes develop protections against the direct effects of UV radiation: inhibition of respiration in some algae, destruction of cytochrome A, yeast cytochrome oxidase, and mitochondrial cytochrome A3. These protections also produce **flavonoid pigments**, which absorb UV and minimize damage.

On the other hand, **three functions are sensitive to light intensity**: respiration, photosynthesis, and transpiration. Profound physiological modifications then influence the growth and morphogenesis of the individual, leading to **biological types perfectly adapted to their environment**.

The evolution of the photosynthetic activity of a chlorophyllous plant is closely linked to the amount of light energy received. Photosynthetic activity can be measured by the amount of CO_2 absorbed. However, due to the simultaneity of respiratory and photosynthetic processes, it is necessary to distinguish:

- **Gross photosynthesis**, which corresponds to the total reduction of CO_2.
- **Net photosynthesis**, which corresponds to the CO_2 gain, taking into account losses from (photo)respiration and various carboxylation processes independent of photosynthesis (PEPCase).

For a given light intensity, the amount of CO_2 fixed may equal the amount of CO_2 produced by respiration. In this case, **apparent photosynthesis is zero**, as gas exchanges from respiration and photosynthesis balance each other; this is called the **compensation point**.

Two groups of plants have been defined among the **Gramineae** (grasses), where this phenomenon is related to leaf anatomical structure:

- In **Poaceae** (e.g., wheat), where carbon assimilation produces a C3 molecule (3-phosphoglyceraldehyde), the phenomenon of **light saturation** is particularly clear.
- In other grasses (maize, sorghum, sugarcane of the Panicoideae), where the carbon assimilation cycle involves C4 molecules, **light saturation is hardly detectable**.

The distinction between C3 and C4 plants is not absolute, as intermediate types exist. For example, in *Atriplex*, there are both C3 and C4 species, and hybridization can produce intermediate types.

There is also another type of metabolism, **CAM metabolism** (Crassulaceae and cacti), which behaves like C3 plants during the day and like C4 plants at night (CO_2 is fixed at night and released during the day for photosynthesis).

From an ecological point of view, **C4 and CAM plants** appear particularly well adapted to sunny climates and low latitudes. These represent an evolutionary adaptation, as such metabolic pathways are absent in algae and lower plants.

VIII.3.2. Light requirements for different species

Light requirements determine species distribution: **heliophilous species** avoid shady areas, while **sciophilous species** prefer understory habitats. In nature, **multi-layered plant communities** form, generally with a tree layer and an herbaceous or shrub layer.

The tree layer intercepts a portion of energy and acts as a **filter**, selecting light radiation and modifying the **quantity and quality of light** reaching the understory. The herbaceous layer responds in various ways to changes in light intensity.

In deciduous forests, a first group of species completes its development **before the tree layer leafs out**: these are **spring-leafing species**. These plants develop in a **very sunny understory**; they are typically They are **normal heliophytes**, with a short development cycle allowing growth **before the understory becomes shaded**.

For the tree layer, **heliophilous plants** capture direct solar radiation. When these species are densely packed, light availability determines **rapid growth**: tall, slender trunks and natural pruning of branches, as the plants do not receive the desired amount of light.

Renewal of this layer occurs through seeds; seedlings from these seeds experience **herbaceous layer light conditions**, which may lead to **selection of species whose seedlings are more shade-tolerant**.

VIII.3.3. Action of light on development: photoperiodism

The **ratio of day to night duration** is a key factor in the formation of floral primordia. This effect was discovered by Garner and Allard on a tobacco variety: in summer, the plant grows without flowering, and if it does flower, it is very late (autumn).

When cultivated in winter at the same temperature as in summer, flowering occurs rapidly after reduced growth. In a greenhouse, if a lamp is kept on continuously or for several hours, flowering does not occur. Conversely, in summer, if the plant is kept in darkness for part of the day, **flowering and seed formation occur normally**.

Photoperiodism thus refers to the set of reactions of living organisms to a defined pattern of alternating light and darkness.

The **photoperiod** consists of two regularly alternating phases: a light period (**hemeroperiod**) and a dark period (**nyctiperiod**). Under natural conditions, the photoperiodic cycle is 24 hours, with variable durations for the hemeroperiod and nyctiperiod. Near the tropics, these durations are approximately equal, though modifications can occur depending on light or darkness exposure.

A. Plant responses to photoperiodism

From a photoperiodism perspective, **three main categories of plants** are distinguished:

- **Day-neutral plants (indifferent plants):** These can form floral primordia from a seed or tuber **regardless of the relative duration of light and dark periods**, as long as the minimum trophic light requirement is met. These plants generally have substantial reserves and can survive long periods without photosynthesis, e.g., peanut (*Arachis*; floral primordia appear even in seedlings), potato (etiolated shoots sometimes form floral primordia), and daffodil (large bulbs can produce flowering plants even in darkness).
- **Long-day plants (hemeroperiodic plants):** Flowering of **absolute hemeroperiodic plants** (e.g., *Anagallis arvensis*) occurs earlier as daily light duration increases. Flowering is fastest under **continuous light**. However, flowering becomes impossible if light duration is **shorter than the critical photoperiod** (critical hemeroperiod).
- **Short-day plants (nyctiperiodic plants):** Similar to long-day plants, they can be either **preferential or absolute**. Absolute short-day plants **never form floral primordia below a certain critical nyctiperiod**, as long as the minimum trophic light requirement is satisfied.

Absolute short-day plants (e.g., *Nicotiana tabacum* 'Maryland Mammoth') **cannot flower if the daily light duration exceeds the critical photoperiod**.

B. Role of photoperiodism in species distribution

The photoperiodic response of plant species is a **genetically determined trait**, always adapted to the environmental conditions of the species' native habitat. Photoperiodic characteristics therefore play an important role in **species distribution**. In particular, the natural latitudinal range of flowering plants with photoperiodic requirements is often **strictly limited by the seasonal day-length regime**.

The flora of **mid-latitude regions (temperate zones)** includes many day-neutral plants, but their development is sensitive to temperature (**vernalization**). Many are annual species that flower during the favorable season when temperatures are particularly suitable. Alongside these, there are numerous **long-day plants**, which are induced to flower in spring by increasing day length; their flowering may continue until autumn or occur only then, either because their floral state persists or because flowering requires a very large number of long days.

In **low-latitude regions (tropical and especially equatorial countries)**, there are also some day-neutral plants; these are often **perennial and woody**, and their flowering mainly depends on minor meteorological events (small alternations of temperature, rainfall, or drought). However, the bulk of the flora consists of **short-day species**.

The photoperiodic requirements of plant species have numerous practical implications. For example, when **beet** is moved to higher latitudes, its developmental cycle changes; a biennial plant may become annual, significantly reducing its yield. Such modifications are sometimes intentionally sought in agronomy.

VIII 3.4. Photoreception

Plants do not have a **distinct organ of perception (eye)**, but they exhibit **directional growth responses** (tropism, tactism, or taxis). One of the most characteristic plant responses is **positive phototropism**, which is the tendency of a plant to grow toward a directional light source.

VIII 3.5.Salt-adapted plants (halophytes)

Among the best-known **halophytes** are **sea lavender** along maritime coasts and **glasswort** in salt marshes. Also notable is the **mangrove**, found in tropical regions. These plants face **two main challenges**:

1. Salt interferes with their **water uptake**.
2. They must **regulate their internal salt content**, which cannot exceed a toxic threshold.

For water to be absorbed by a plant's roots, its cells must have a **higher solute concentration than the external environment**, so that water naturally moves from the more dilute medium to the more concentrated one in minerals and organic solutes (this is known as **osmosis**). Accordingly, plants have **anatomical and physiological adaptations** to manage excess salts and conserve water:

1. **Reduction of transpiration:** Decrease in the size of the aerial parts, leaves often modified into **needles or scales**, and a thick cuticle covered with a waxy layer.
2. **Water storage:** Aerial organs often **succulent or fleshy**, similar to plants living in arid environments.
3. **Control of salt entry:** Selective membrane permeability, presence of **epidermal glands** that excrete salts (especially sodium chloride), storage of salts in **vacuoles**, or loss of salt-loaded organs.

VIII.3.6 Aquatic plants (hydrophytes)

All the **vegetative organs of hydrophytes** are in contact with water. Since the concentration of oxygen in water differs from that in air, these plants have developed **special acquisition strategies**. Among other features, they possess **parenchymatous tissue with large intercellular air spaces**, which transport oxygen from above-water parts to submerged parts. In addition, these plants **absorb water directly from their environment** through leaves that are **little or not cutinized**.

VIII .4.Studies of different models or approaches under the future climate change

The following seven papers studies using different models or approaches under the future climate change scenario. Simulation of differential impact on winter wheat (*Triticum aestivum* L.) by future projections of climate change (2025 and 2050),

especially under increasing temperature was done using CSM-CERES-Wheat model coupled with different Representative Concentration Pathways (RCPs) and two Global Circulation Models (GCMs)(Yengoh et al .,2020). The study indicated that the production of wheat in Guanzhong plain will increase (positive) under future climate change using crop simulation modeling. However, the negative impact will depend upon the climate change projections as GCMs showed both increase and decrease in the grain yield. The study also emphasized proper use of irrigation management as rainfed wheat is very sensitive to climate change.

In a study, a scaling approach was used to measure the variation of scaling factors and their correlation at large scales in the estimation of actual transpiration of three boreal species in a forest . The authors demonstrated that the scaled canopy transpiration signified a considerable fraction of forest evapotranspiration (>70%) and recommend the approach for the proper estimation of actual transpiration in the areas having low tree diversity.

Mendoza et al. emphasized the use of the Climate Data Science (CDS) Toolbox Species Distribution Model (SDM) in evaluating the appropriate areas of grapevine (*Vitis vinifera* L.) under the present and future climate conditions in France. The study proved different possible effects of future climate change on the spatial distribution of proper areas for grapevine crops. The maximum entropy modeling approach was utilized to foresee future habitat distribution of the susceptible *Prunus Africana* under the effect of climate change in Tanzania . The results showed reductions in appropriate habitats for *P. Africana* under all imminent representative concentration pathways' scenarios as compared to present distributions.

Various statistical methods were used to study the variations in the seasonality of Ethiopian highlands' climate, consequences for crop development, assessment of variations in the annual cycle, and long-term trends. .

Coupled Model Intercomparison Project (CMIP5) Hadley2 data assimilated by the Inter-Sectoral Impact Model Intercomparison Project (ISIMIP) hydrological models used in the study provided understandings on the unimodal annual cycle of soil moisture in past and future eras. The study concluded that evaporation is increasing and might put stress on different land and water resources due to seasonal variations. An empirical hazard model was used to get the pattern of the global spread of Black Sigatoka Leaf Disease (*Mycosphaerella fijiensis*), an important pathogen on banana . The results showed that agricultural trade might play a significant role in spreading the disease across countries and highlights the threat and prospective cost of relying on just a few varieties with genetic similarity to produce a particular crop globally. Climate change is negatively affecting the health of populations around the world, especially in low-income countries like East Africa. A Wet Bulb Globe Temperature (WBGT) approach, a common index, was used to evaluate the heat stress in occupational health in East Africa . The results showed that heat stress is already influencing the areas of East Africa. (Strobl *et al.,* 2020)

The analysis of two terms of the agricultural calendar suggests that Kenya and Tanzania face substantial portions of their national landmass influenced by high WBGT values; a neighboring country (Uganda) is comparatively less affected.

The goal of this Special Issue is to present research with a broad perspective to understand the effects of climate change on vegetation, involving applied research and studies with different types of modeling approaches, and the 13 papers in this Special Issue achieve this goal. I thank the authors for their significant contributions and hope that this issue triggers some ideas and collaboration or serve as a resource to move ahead in a rapidly changing climate.

VIII.5. Animal adaptation

Animals have some amazing adaptations that help them live in even the most hostile environments. Consider camels, for instance. They can thrive in some of the hottest and driest places on Earth. Their legs don't get burned when they kneel on hot sand due to thick leathery patches on their knees. They can survive for an entire week without water but, at the same time, they can drink 32 gallons of water at once. Their body temperature ranges from 93 °F to 107 °F, so they don't need to sweat very often and can conserve water this way. The spongy bones in their noses absorb any excess moisture to keep every drop of water in, so the air they breathe out is dry air. In addition to camels, other animals' adaptations are equally remarkable. How do they do it?

VIII.5.1. Adaptations of animals to cold

Warm-blooded or cold-blooded? The most important adaptation is how animals regulate their body temperature. Animals can be either warm-blooded or cold-blooded. Warm-blooded animals, which are mostly birds and mammals, need to maintain a relatively constant body temperature. The body temperature of most mammals ranges from 97 °F to 103 °F, while birds have an average body temperature of 105 °F. For humans, the commonly accepted average body temperature is 98.6 °F (even though it may vary among individuals). Cold-blooded animals do not maintain a constant body temperature.

They get their heat from the outside environment, so their body temperature fluctuates, based on external temperature. If it is 50 °F outside, their body temperature will eventually drop to 50 °F, as well. If it rises to 100 °F, their body temperature will reach 100 °F. In most instances, the size and shape of an organism dictate whether it will be warm-blooded or cold-blooded. Think about some large animals—elephants, whales, and walruses. Their volume is so large that relying on the outside environment to heat them up would be inefficient and would slow their response times, putting their survival at risk. For that reason, nearly all large animals are warm-blooded. What about all the birds and mammals that are not large, such as mice and sparrows? The other factor—body shape—comes into play here. Small warm-blooded animals tend to have a rounded shape, which ensures that the interior of an organism stays warm the longest time possible. Most cold-blooded organisms have either an elongated or a flat shape. If you look at a typical fish, their bodies tend to be flat when viewed head-on from the front. Snakes, lizards, and worms tend to be long and slender. These shapes ensure they can heat up and cool down rapidly.(Streever,2013)

volume of an object decreases, the ratio of its surface area to its volume increases. In other words, the smaller an animal is, the higher the surface area-to-volume ratio. These animals lose heat relatively quickly and cool down faster, so they are more likely to be found in warmer climates. Larger animals, on the other hand, have lower surface area-to-volume ratios and lose heat more slowly, so they are more likely to be found in colder climates.

- Some animals remain active: The fox develops a thicker fur coat. Swallows, storks, gray geese… escape the cold by migrating to warmer regions where food is more abundant.
- Others slow down their activity: Some mammals (warm-blooded animals) such as the hedgehog and the marmot enter a deep sleep and their internal temperature drops; this is called hibernation. Animals with variable body temperature spend the winter in a dormant state in a shelter (snakes, frogs, etc.); this is called winter dormancy.

VIII.5.2. Animal Adaptation to High Temperatures and Drought

Different strategies are used by the animal kingdom to survive during drought: behavioral adaptations, morphological adaptations, and physiological adaptations.

A.Behavioral adaptations

The first and most obvious method to cope with heat is a change in behavior. Some species avoid high temperatures by hiding underground or in burrows during the day, such as gerbils. The temperature inside these burrows can drop by 10°C compared to the outside temperature. These animals are nocturnal and thus avoid the daytime heat.

B.Morphological adaptations

Others have a morphology adapted to withstand heat. Scorpions have a hard, waterproof exoskeleton. Some never drink water and obtain the necessary moisture from the seeds and plants they consume, such as kangaroo rats or gerbils. These animals also have tufts of hair or pads on their feet that provide insulation. Fennec foxes have developed elongated ears to dissipate heat, as well as fur coloration that provides camouflage. Many small desert dwellers cool the air they exhale in their nostrils, condensing the water it contains before releasing it. The thorny devil, or moloch, has a remarkable strategy to collect moisture from the soil. Channels between the scales on its skin allow water to be transported by capillarity to its mouth. In short, it can “drink” through its feet.

C.Physiological adaptations

The moloch also has a fat hump at the back of its head, similar to a camel, which serves as a water reserve during long droughts. The oryx can minimize water loss by allowing its body temperature to rise above the ambient temperature. To compensate for water loss through sweating, respiration, and urine excretion, desert animals have adapted in various ways. Most desert animals, such as insects, reptiles, and birds, produce highly concentrated waste in the form of solid uric acid, which helps reduce water loss through urine.

Conclusion

Bioclimatology constitutes a fundamental scientific discipline for understanding the complex interactions between climate and living organisms. Through the study of atmospheric factors such as temperature, precipitation, humidity, solar radiation, and wind, it provides essential knowledge for interpreting the functioning of ecosystems and the spatial distribution of plant, animal, and human communities. This document has highlighted the major principles of climatology and their direct relationship with ecological systems, emphasizing the importance of climatic parameters in shaping environments at global, regional, and local scales.

The course demonstrated that climate is not merely a static description of atmospheric conditions but rather a dynamic system involving continuous interactions between the atmosphere, hydrosphere, cryosphere, biosphere, and lithosphere. These interactions regulate the Earth’s energy balance, hydrological cycle, and ecological equilibrium. Understanding these processes is crucial for explaining climatic variability, weather phenomena, and the mechanisms governing global and regional climate systems.

Special attention was given to climatological data and meteorological measurements, which form the basis for climate analysis and environmental monitoring. The use of conventional stations, automatic weather systems, satellite observations, and climatic indices allows scientists to quantify atmospheric processes and evaluate environmental changes. Parameters such as precipitation, temperature, atmospheric pressure, humidity, sunshine duration, and wind are indispensable for understanding climatic dynamics and for predicting extreme events such as droughts, storms, floods, and heat waves.

The study of atmospheric circulation and the structure of the atmosphere revealed how large-scale and local climatic mechanisms influence weather conditions and ecological processes. Trade winds, cyclones, anticyclones, jet streams, and air masses determine the distribution of heat and moisture across the planet. Similarly, the different atmospheric layers, especially the troposphere and stratosphere, play essential roles in regulating weather, climate, and radiative balance. These processes directly affect ecosystems, agriculture, water resources, and biodiversity.

This document also emphasized the importance of solar radiation and the Earth’s radiative balance in controlling climate conditions. Solar energy is the primary driving force of atmospheric and biological processes, while greenhouse gases regulate the retention of heat within the atmosphere. However, human activities have intensified the greenhouse effect through increasing emissions of carbon dioxide, methane, and other greenhouse gases, leading to global warming and climate change. These anthropogenic disturbances are now recognized as major threats to environmental stability, ecosystem resilience, and sustainable development worldwide.

Aridity and desertification were identified as critical environmental challenges, particularly in arid and semi-arid regions such as Algeria. The analysis of aridity indices and evapotranspiration processes demonstrated the close relationship between climate, water availability, and ecosystem productivity. In Algeria, climatic contrasts between the humid Mediterranean north and the hyper-arid Sahara create diverse bioclimatic zones, each characterized by specific ecological conditions and biological adaptations. Nevertheless, increasing temperatures, irregular rainfall, prolonged droughts, and land degradation are accelerating desertification processes and threatening natural resources and biodiversity.

The Mediterranean climate, with its seasonal rainfall regime and ecological richness, represents a particularly sensitive environment to climate variability. The biodiversity associated with Mediterranean ecosystems is highly adapted to drought and seasonal contrasts, yet it remains vulnerable to climate change, wildfires, water scarcity, and anthropogenic pressures. Consequently, sustainable management of ecosystems, conservation of biodiversity, and rational use of natural resources have become essential priorities for maintaining ecological balance and ensuring resilience against future climatic disturbances.

The course further illustrated how plants and animals have developed remarkable physiological, morphological, and behavioral adaptations to survive under different climatic conditions. Xerophytes, halophytes, hydrophytes, and cold-adapted species provide examples of the close relationship between living organisms and their climatic environment. These adaptations reflect the evolutionary capacity of organisms to cope with environmental stress; however, the rapid pace of current climate change may exceed the adaptive potential of many species, leading to ecosystem degradation and biodiversity loss.

In conclusion, bioclimatology provides indispensable tools for understanding environmental processes and addressing the major ecological challenges of the 21st century. It contributes not only to scientific knowledge but also to practical applications in agriculture, forestry, hydrology, biodiversity conservation, urban planning, and climate adaptation strategies. In the context of accelerating global climate change, the integration of bioclimatic approaches into environmental management and sustainable development policies is more necessary than ever. Strengthening research, improving climatic monitoring systems, promoting ecosystem conservation, and developing adaptation measures are essential steps to ensure environmental sustainability, food security, and the resilience of both natural ecosystems and human societies for future generations.

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