Morocco, a mosaic of climates

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Situated at the crossroads of temperate climates in the north and tropical climates in the south, Morocco is a veritable crossroads where cold and hot air masses meet, and their effects change with the seasons. Thanks to its unique geographical features, between mountainous relief and oceanic influences, the country reveals a mosaic of multifaceted climates. This article invites you to explore how these natural forces, combined with the variability of climatic factors, shape a Moroccan climate that is particularly sensitive to the fluctuations and effects of climate change. Read on to discover how Morocco's geography transforms these influences to create an environment that is both fascinating and vulnerable.

1. *Geographical position of Morocco*

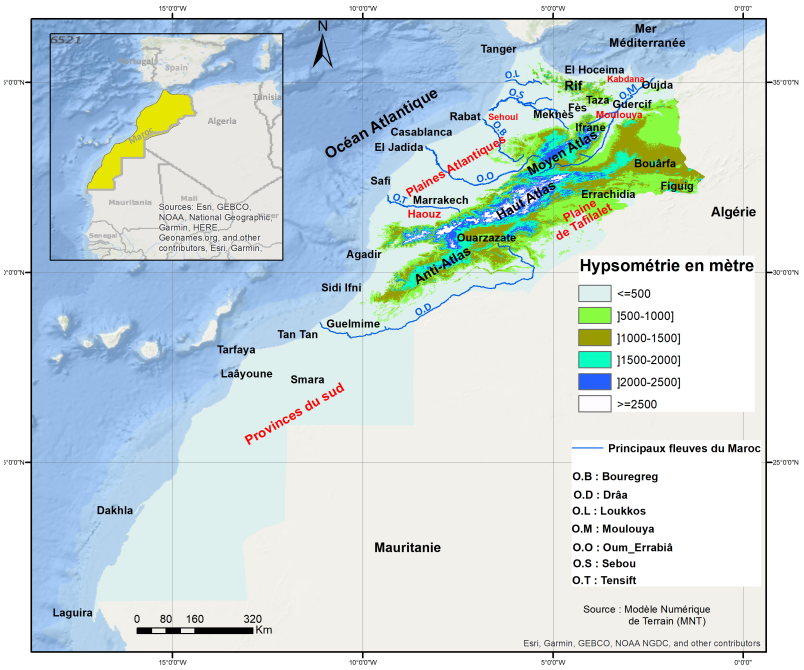

Figure 1. Geographical location of Morocco, hypsometry and position of weather stations cited in the text [Source: © Hanchane].

Located at the extreme north-west of the African continent, **Morocco's geographical position** lies between latitudes 21°N and 36°N and longitudes 1°W and 17°W (Figure 1). This position exposes it to the **atmospheric influences of a temperate climate to the north and a tropical climate to the south**. In addition, the **geographical influences specific to Morocco** - Atlantic to the west, Mediterranean to the north, Saharan to the south and mountainous to the centre, in a south-west-north-east direction - give the country a climatic mosaic which, according to Köppen's classification [1] (See Focus The Köppen's classification), is made up of **Mediterranean, Mediterranean-mountainous, arid-steppe and arid-desert climates**. The influence of altitude adds bioclimatic stages to these types of climates, ranging from hyperarid to perhumid (See Focus The Emberger index), with altitudinal thermal variations ranging from extremely cold winters to warm winters.

2. *Temperature distribution in Morocco*

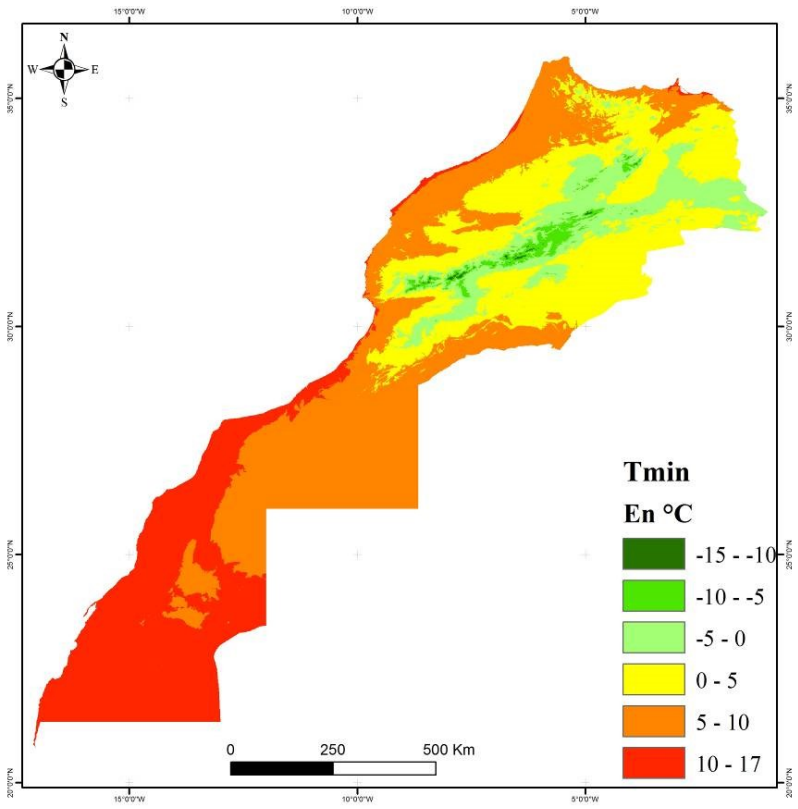

Figure 2. Average temperatures (in °C) in January. Period 1979-2013. [Data source: © CHELSA. https://chelsa-climate.org/], [see refs. 3 & 4].

The spatial distribution of mean **temperatures** in Morocco shows an **increasing latitudinal gradient from north to south and from west to east**. The first gradient more or less reflects the increasing distribution of the radiation balance, which is inversely proportional to latitude, while the second reflects the effects of continental location (or distance from the sea) and the relief of the Atlas and Rif Mountain ranges.

Average temperatures in the coldest month of January are lowest on mountain peaks and in continental areas (Figure 2) [2,3]. The thermal buffer effect of the ocean is noticeable in coastal areas, which record milder values.

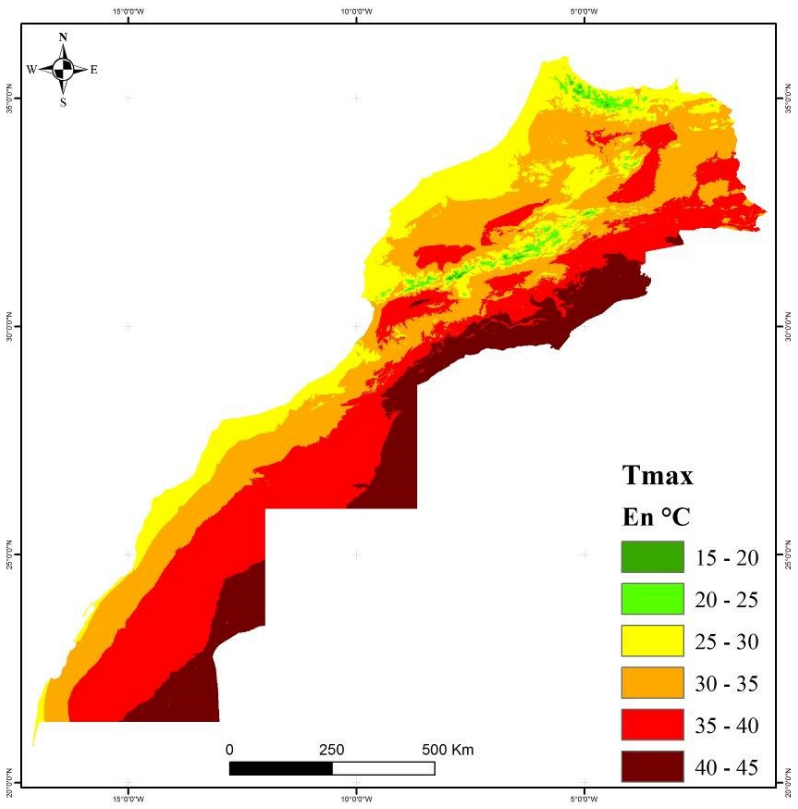

Figure 3. Average temperatures (in °C) in July. Period 1979-2013. [Data source: © CHELSA. https://chelsa-climate.org/] ; [see refs. 3 & 4].

Average temperatures for the hottest month were recorded in the south-east and extreme south of the country (Figure 3). These maximum temperatures show an increasing north-south gradient in the northern half of the country, which is attenuated by the mountainous relief where the lowest maximum temperatures are recorded. In the southern half of the country, particularly in the Moroccan Sahara, there is a stronger west-east gradient, reflecting the effect of distance from the sea. The Moroccan coast is uniform in terms of summer temperatures, which range between 22°C and 24°C. However, the average temperature for the hottest month, July, sometimes exceeds that of the humid tropical countries to the east and south-east of the country (e.g. 31°C in Ouarzazate, 31.5°C in Bouârfa and 32.3°C in Errachidia).

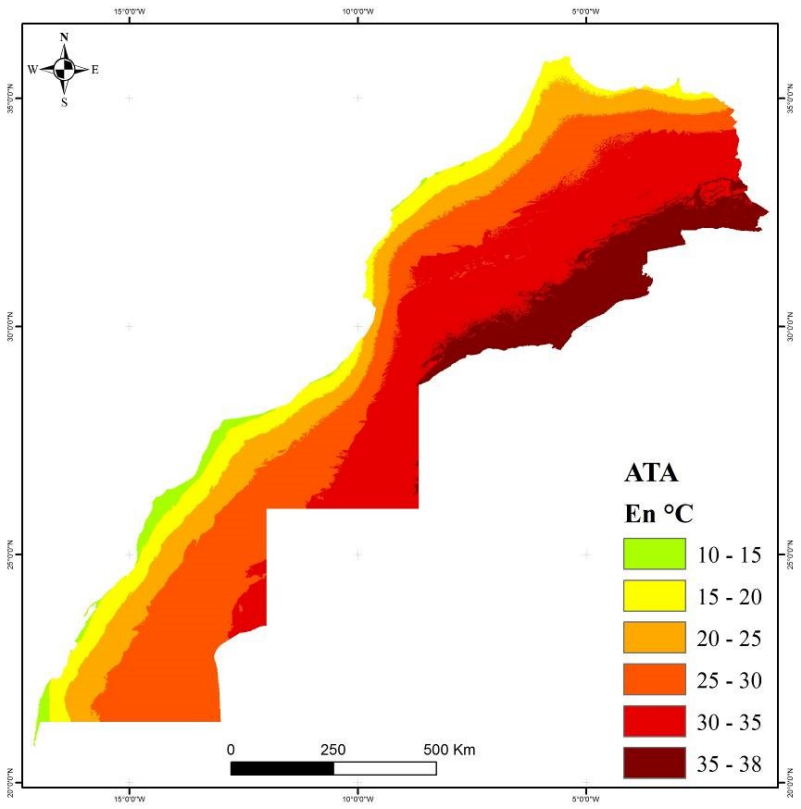

Figure 4. Annual thermal amplitude (in °C). Period 1979-2013 [Data source: © CHELSA. https://chelsa-climate.org/]; see ref. [3 & 4].

The **annual thermal amplitude** (ATA) is **highest in the southeas**t of the country (e.g. the Tafilalet and Draa plains), while it reaches minimum values at the westernmost coastal stations (Figure 4). The continental effect is again masked by the orographic effect: the Ifrane station, for example, records summer temperatures close to those of the coastal stations. The city of Essaouira is a typical example of a Moroccan city with the lowest seasonal temperature variations (annual temperature range of 5°C). This low thermal amplitude also characterises the Saharan coast (e.g. Sidi Ifni, Tarfaya, Dakhla).

3. *Rainfall variability in Morocco*

The **annual rainfall distribution** shows **considerable spatial variability** (Figure 5). The highest values are recorded on the peaks of the Rif (over 1200 mm/year), followed by the Middle Atlas (between 1200 and 1000 mm/year). Regions with favourable rainfall conditions (> 700 mm/year) cover only 7.1% of Morocco. The lowest values, below 100 mm/year, are found in the south-east and in the extreme desert south of the country. This distribution shows not only a north-south decrease in rainfall, but also a decreasing west-east gradient, which is explained by the Rif and Atlas Mountain barriers. It also highlights the low rainfall, not exceeding 200 mm/year, in the Haouz plain and the Moulouya basin. Sub-desert regions, which receive between 200 and 100 mm/year, cover 78% of the country. The rest of the country (17.9%) is covered by semi-arid and arid regions with rainfall between 200 and 600 mm.

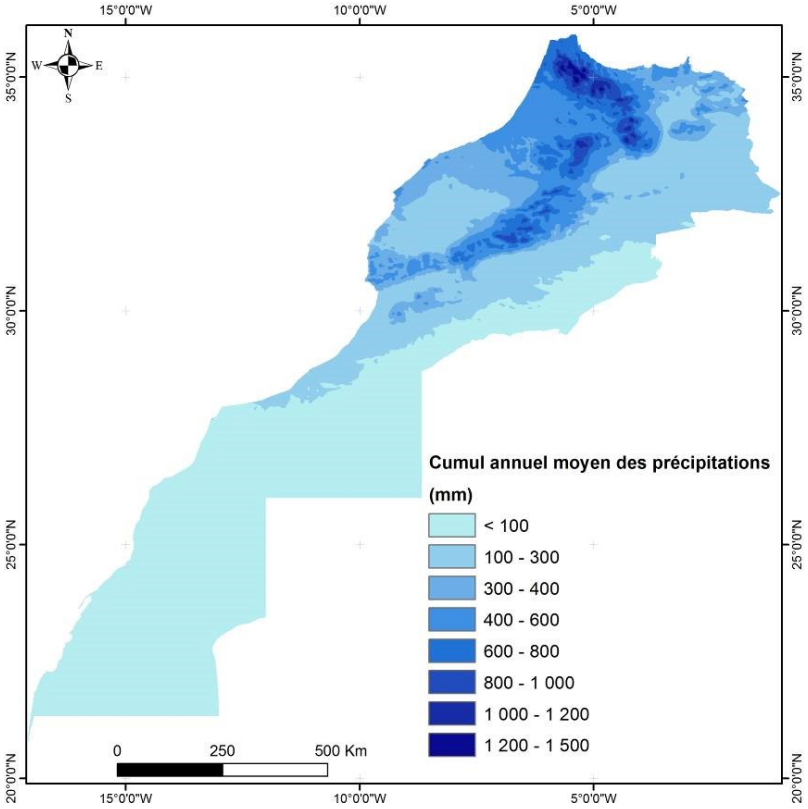

Figure 5. Average annual rainfall (mm). Period 1979-2013. [Data source: © CHELSA. https://chelsa-climate.org/]; see ref. [3 & 4]

In addition, the **very high interannual variability** is characterised by a succession of wet and dry phases. In the observed period from 1960-61 to 2015-16, there was a wet decadal period in the 1960s and 1970s, characterised by negative phases of the North Atlantic Oscillation (NAO-). This was followed by dry periods associated more with positive phases of the North Atlantic Oscillation (NAO+), which lasted until the first decade of the 21st century (see Climate variability: the example of the North Atlantic Oscillation). The long dry phase, interrupted by a short-wet phase in 2009 and 2010, has returned with a vengeance. This succession of wet and dry phases shows strong interannual variability from one winter to the next, with sudden changes: this was the case in the winters of 1994-1995 (dry)/1995-1996 (wet) and 2009-2010 (wet)/2011-2012 (dry).

On a smaller time scale (a few days), wet/dry sequences occur following the intrusion of cold polar air from higher altitudes. Westerly oceanic air, although infrequent, is considered the most favourable for the onset of rainy episodes, particularly in regions open to oceanic influences (Atlantic Morocco, Rif and Atlas Mountains). This underlines the key role played by the Atlantic Ocean in Morocco's rainfall. Air from the north contributes to rainy days in the northern half of the country (e.g. Tangier, Ifrane and Oujda).

4. *Types of climate in Morocco*

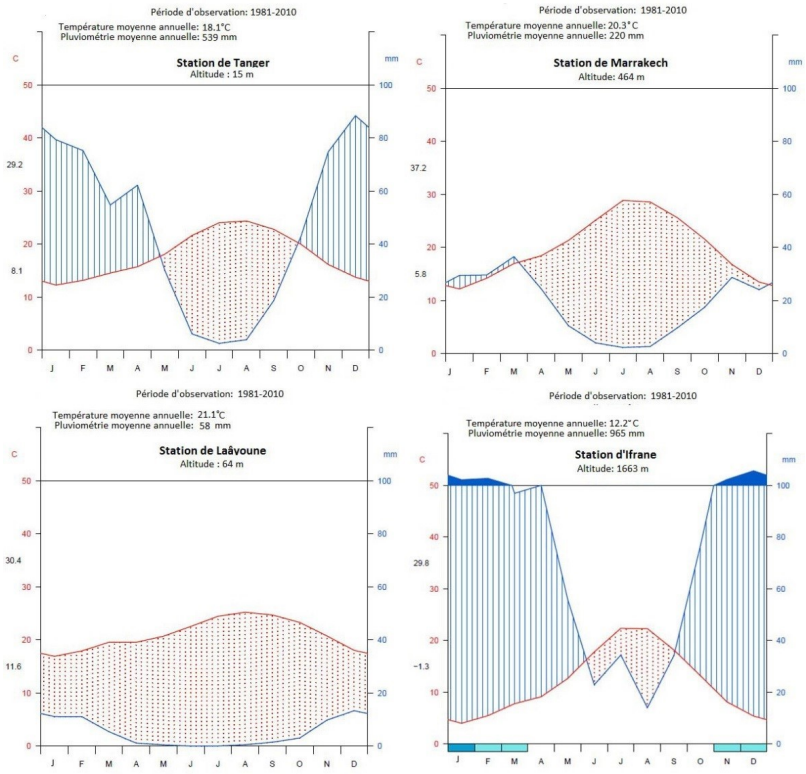

Figure 6. Umbrothermal diagrams according to the Gaussen-Bagnouls index. Stations in Tangiers (dry summer Mediterranean climate, type Cs), Marrakech (steppe climate, type BSh), Laâyoune (desert climate, type BWh) and Ifrane (Mediterranean mountain climate, type Ds). For the diagram of Ifrane, on the horizontal axis of the months, the blue boxes indicate the extreme Tmin below 0°C. (The 100 mm threshold is exceeded during the cold months). [Source : © Hanchane]4.1. Mediterranean climate Cs

According to Köppen's classification (see Focus on Köppen's classification), four types of climate have been identified in Morocco:

Mediterranean climate (Cs: temperate climate with dry summers, corresponding to the Mediterranean climate),

Arid steppe climate (BSh: steppe climate with hot, dry summers),

Arid desert climate (BWh: desert climate with hot, dry summers),

Mediterranean mountain climate (Ds: snowy climate with dry summers, found only on the high mountain peaks of the country).

Figure 6 shows the umbrothermal diagrams (according to the Gaussen-Bagnouls index [4]) for various stations representative of the different types of climates in Morocco.

This classification places **Morocco** in the **global climate zones: temperate in the north (type C) and arid in the south (type B**). However, considering the specific biogeographical features of the eastern part of the country, the term arid desert (type BW) corresponds to arid bioclimates with temperate to cool winters, according to the Emberger classification (see Focus The Emberger classification). Along the Mediterranean coast, from Kebdana to El Hoceima, the bioclimate is semi-arid with temperate winters. The Saharan bioclimate and its desert equivalent, according to Köppen, only appear from Figuig and Bouârfa stations onwards.

4.1. Mediterranean climate (Cs)

The **Mediterranean climate zone** is located on the **western side of the continents between 30° and 40° latitude**. By definition, the Mediterranean climate (Cs) is characterised by a dry season. It lies between the temperate climate in the north and the dry subtropical desert climate in the south. Another characteristic is the relatively **strong increase in solar radiation towards the south**.

Figure 7. The Sehoul area, north of Rabat-Salé, with a Cs-type climate (Photo taken in December 2017). The landscape illustrates the impact of drought at the height of the winter season. [Source: © El Kassioui Jaafar]

The different variations of the Mediterranean climate can be observed from the Atlantic coast to the Algerian border in the east, from the Mediterranean to the Sahara and from sea level to high altitudes (Figure 7). The **dry season**, as defined by the Gaussen-Bagnauls index, **intensifies towards the south and the regions behind the Atlas barrier**; the effect of the orographic altitude reduces the duration of this dry season, even shortening it compared to that of the coastal plains (e.g. Ifrane station) (see Figure 6).

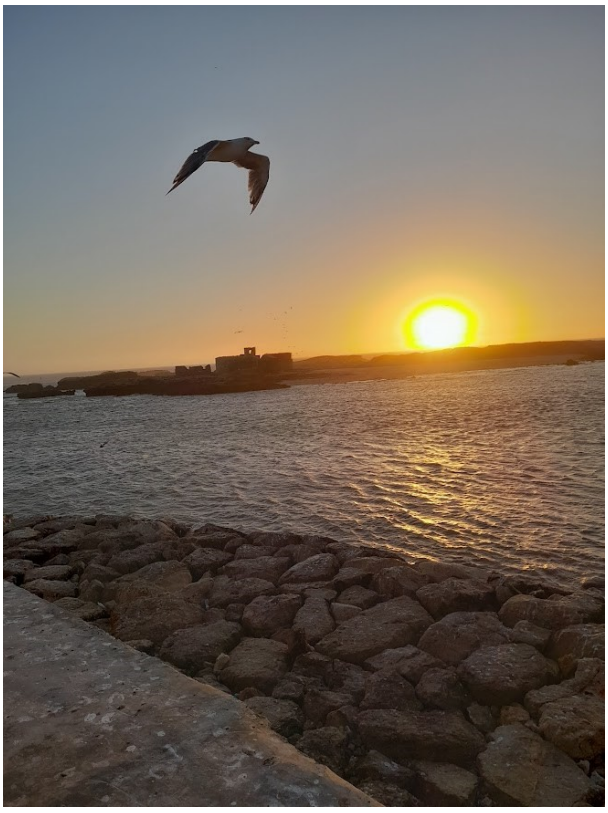

Figure 8. Port of Essaouira (Cs), a city with a semi-arid climate, benefits from the influence of the Canary Current and the upwelling of cold water, which gives it mild temperatures in winter and summer, with a low annual temperature range. (Photo taken in August 2024) [Source: © Hanchane Mohamed].

Along the **Moroccan coast**, the **rainy season** lasts from **October to May** and extends as far as Rabat. From Casablanca to El Jadida, the season is shortened to seven months (October to April). For Safi, it lasts from October to March, for Essaouira (Figure 8) from November to March and for Agadir from November to February. **Rainfall peaks in November-December** and lasts until April in Ifrane and Fez. Rainfall in March tends to decrease from Essaouira onwards.

Moving **southwards**, the **Mediterranean climate** (Cs) **degrades towards semi-arid and arid bioclimates** (or steppe-BSh) and **hyperarid bioclimates** (or desert-BWh). These qualifiers of steppe and desert, retained in the Köppen classification, evoke the desert degradation of Mediterranean climates with winter rain (Cs), which is difficult to define its southern limit because of the layout of the Atlas Mountains [5].

4.2. Steppe climate with hot summer (BSh)

Figure 9. Panoramic view of the Oued Melloulou (Province of Guercif-Eastern Morocco), the main tributary of the Oued Moulouya, highlighting the development of irrigated agriculture along its watercourse, in eastern Morocco with an arid steppe-type climate (BSh) (Photo taken in March 2020) [Source: © Hanchane Mohamed].

The **Mediterranean climate** with semi-arid to arid degradation always has the same **single winter maximum**, except for the eastern basin of the Moulouya (Figure 9). In this region of the Kingdom, where the interannual variability of rainfall reaches its maximum compared to the whole of the Maghreb, the seasonal rainfall pattern is marked by a spring maximum (Moulouyen regime according to Delannoy and Lecompte [6]). During this season, these continental lands heat up rapidly, and convective rains develop east of the Atlas. Also, desertification is a real threat to the East, in addition to the extreme stormy rains of short duration during the autumn and spring months. This steppe climate is also found in the region of Haouz; the resort of Marrakech (BSh) is marked by a very short wet season (January-March) (see Figure 6).

4.3. Desert climate with hot summer (BWh)

Figure 10. Merzouga (Errachidia Province, BWh), a wonder in the heart of the Sahara with its vast sand dunes and breathtaking desert landscape. (Photo taken in May 2018) [Source: © El Kassioui Jaafar].

In the **south** and **south-east** of the country, **aridity reaches its peak**; all months of the year are dry (Figure 10). In the Saharan provinces, the maximum temperatures of November and December remain visible for the hyperarid stations (*e.g.* Guelmime and Tan Tan). Moving even further south, especially in Laayoune, this maximum moves towards the month of January. From the latitude of Dakhla, a new maximum appears in September, thus revealing the importance of the marginal influence of the monsoon on the climate of the southern Moroccan provinces.

Figure 11. Illustration of the association of crops in tree, shrub and herbaceous levels in the oasis of Tafilalet (Province of Errachidia) (BWh). Photo taken on 02/09/2021 [Source: © Sadiki Abderrazzak].

Amid the hyperaridity of the climate, **oasis environments constitute unique ecosystems**, built and maintained by indigenous peoples for generations through rigorous management of water resources. They extend from Figuig in the east of the country to the Guelmim region on the Atlantic coast in the west. They are characterised by low rainfall (sometimes less than 50 mm per year in hyperarid areas) and a high daily temperature range exceeding 30°C, accompanied by night-time temperatures of around 0°C depending on the season. They contribute to the formation of a microclimate through the "Oasis effect" within the desert, which is created by the combination of crops on three levels, often composed of date palm, fruit trees and vegetable or fodder crops (Figure 11). Humidity, produced by evapotranspiration (see Plants water needs), heat and light are favourable conditions for the development of crop and livestock systems in a hyper-arid environment where fertile land is scarce. The sustainability of the waters of the oases is ensured by rainfall and snow inputs from the High Atlas and Anti-Atlas Mountains, which limit them to the north and northwest.

4.4. Mountain climates and snowfall in Morocco (Ds)

Figure 12. The Atlas Cedar tree: majestic tree of the Ifrane National Park (type D climate). (Photo taken on December 20, 2021) [Source: © Hanchane Mohamed].

The **mountainous relief** and its **complexity**, due to the exposure of the slopes to insolation and winds, **give rise** to a **multitude of local climatic particularitie**s, topoclimates and microclimates [7] in the steep-sided valleys, depressions, etc. However, the specificities of the Mediterranean impose their rhythm on the climates of the Moroccan mountains. This Mediterranean climate footprint, well-illustrated at the Ifrane station (see Figure 6), shows the persistence of the winter rainfall maximum and the dry but shortened season (Figure 12). Moreover, the Moroccan mountains preserve, compared to the plains, the same distribution of rainfall sequences as well as their violence. Admittedly, the volume of precipitation in the mountains is more abundant, but there are still a low number of rainy days, which often correspond to very short showers. For example, the Rif can receive 1000 to 2000 mm of rain in a few weeks, which can exceed, in some humid places, half of the average annual volume.

Even if the monthly minimum of minimum temperatures can reach critical values of -5.3°C in February in Ifrane (the record value is -24°C in February 1935), it makes no sense to exclude the mountainous climate of the Mediterranean climatic domain. It is the Atlas Mountains that have the most typically Mediterranean characteristics, because they are marked by a summer drought and because they are the only ones where we find the entire bioclimatic range of the Emberger climagram, from the hyperarid to the perhumid, with all the altitudinal thermal variants, from hot to extremely cold. This climatic diversity gives the Moroccan mountains a richness in terms of plant formations and a remarkable biodiversity on the scale of the Mediterranean climatic domain.

Risks of thunderstorms during the **hot season** can occur suddenly in mountain regions. This is the example of the torrential rains of 1995 and 1999 in the Ourika valley (Marrakech) which were responsible for deadly floods. Summer rains in mountainous regions can be accompanied by hailstorms that have a detrimental impact on rosaceae. The hailstorm of more than 5 mm, which occurred on June 6, 2020, in the Fez-Meknes region, was strongly perceived by the population, especially since it affected not only the mountainous regions of the Middle Atlas, but also neighboring cities such as Fez, Meknes and Taza.

Figure 13. Panorama of the Central High Atlas from Agouyim (Ouerzazate Province): Contrasts between the arid climate BWh and the mountain climate Ds. (Photo taken on February 8, 2023) [Source: © Kessabi Ridouane].

Mountain **snow** plays a **crucial role** in the **availability of water resources** in Morocco's arid and semi-arid climate. The importance of snowfall in Morocco at the level of the mountain peaks which are located in a continental climate context marked by aridity is highlighted (Figure 13). The duration of the snow cover is of paramount importance for the lives of the populations and their water resources: feeding the herds, producing crops, supplies, etc. Its relatively long presence on the northern slopes is highly dependent on insolation and wind action. In addition, it is important to remember the role of snowfall on the peaks of the High Atlas for the sustainability of water in the oases of Tafilalet and Drâa. On the other hand, we emphasize the significant contribution of snowfall in the Eastern Middle Atlas (the peaks of Bouiblane) for the maintenance of olive irrigation in the middle of the arid plain of Guercif (Eastern Morocco). However, the contribution of snowfall to water resources is not always well known in the country. In addition, the decrease in snowfall and the shortening of the duration of its presence on mountain peaks are increasingly perceived by the populations of the Middle Atlas Mountains, thus threatening the rangelands and watering of livestock [8].

4.5. Atlantic coastal climate and the role of the Canary Islands Ocean current

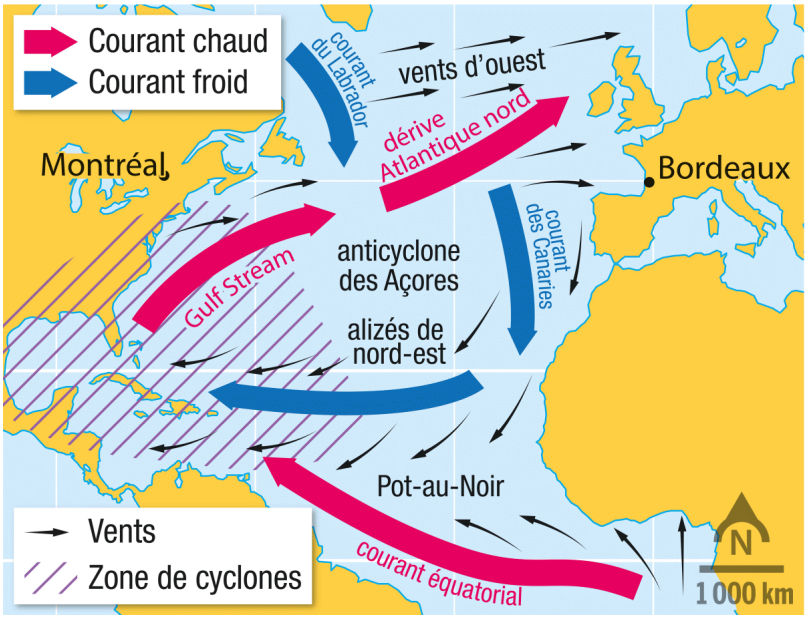

Figure 14. Surface ocean currents over the Atlantic Ocean of the Northern Hemisphere illustrating the Canary Current and the Trade Wind Winds. [Source: © 2024 Arvik EcoTravel: https://ecoarvik.com/ecosse-dou-viennent-les-dechets-sur-les-plages-bilan-de-nos-observations/]

In the tropical latitudes of the northern hemisphere and close to the country, the Canary Current is a cold current that runs along the Moroccan coast to the vicinity of Cap Blanc in summer and to the Senegalese coast in winter. This northwest current is accelerated when the winds blow from the north (Figure 14).

The **Canary Reef Current** is one of the four main eastern boundary currents of the oceans that are affected by the phenomenon of coastal *upwelling* [9], which corresponds to the upwelling of deep cold water on the continental shelf compensating for the drift of surface waters out to sea, under the combined actions of a favourable trade wind and the rotation of the Earth. The **Moroccan Atlantic coast** is exclusively **crossed by this current**, which is **accompanied by upwelling of cold water**, which varies over time. The **surface waters**, **carried by** the **trade winds**, are **replaced** by **deep cold water** which makes the Canary Current even colder. This cold current **trigger** a **thermal inversion** at the base of the atmosphere that is observed from the city of Casablanca, thus promoting the condensation of the lower atmospheric layers in contact with the sea [10,11]. A cool, moist sea breeze blows towards the mainland, sucked in by the updrafts over the warming continent. But this inversion blocks the lifts, prevents rainfall and promotes fog that occurs quite frequently in the Casablanca hinterland.

Figure 15. Sidi Ifni (BWh climate): A haven of freshness thanks to the fog on the Moroccan desert coast. (Photo taken in summer 2020) [Source: © Hanchane Mohamed].

In the southern provinces, the impact of the sea is clearly reflected in the relative humidity of the atmosphere and the frequent fogs; Tarfaya records 24 days of dew per year, Dakhla 33, but Smara only 2. The Moroccan desert coastline is an exception to the hygrometric regime of the great desert (Figure 15). In addition to the high humidity along the coastline, the cold waters of the Atlantic Ocean promote condensation that gives rise to fog. The latter dissipate quickly and do not invade the warmer continent, because they vaporize immediately on contact with it. Water supplies from fogs are essential for the southern provinces. For example, the arid climate of Sidi Ifni is characterized by an annual rainfall of about 100 mm. In addition, 120 mm of rain came from the frequent fogs that covered the coastline over a width of 5 to 10 km. Upwelling regions are also places of high biological activity and high fish production.

5. Messages to remember

Morocco's geographical position, between tropical latitudes in the south and temperate latitudes in the north, makes it dependent on atmospheric conditions both at altitude and at the surface.

Local geographical conditions, such as the orographic effect, continentality, the western basin of the Mediterranean Sea, the cold Canary Current and the upwelling of cold deep waters off the Moroccan Atlantic coasts (or Upwellings), play a decisive role in modulating Morocco's climate.

The northern half of the country has a Mediterranean climate, which gradually gives way to an arid desert climate to the south and an arid steppe climate to the east. The Rif and Atlas Mountain ranges give the country unique Mediterranean climatic conditions, where all bioclimatic variants can be found. The Moroccan mountains, the country's water tower, play an essential role in the formation of solid precipitation, such as snow, which feeds both the water tables and the flow of surface water. Rainfall on the Atlas Peaks ensures the sustainability of water resources and crops in the oases, generating a unique microclimate that promotes their prosperity.

Under the influence of the trade winds, the cold ocean current of the Canary Islands exerts a marked influence on the climate of the Moroccan Saharan coast, bringing cooler temperatures and moderating the intense heat specific to the southern desert region. Accompanied by the upwelling of cold water, this phenomenon mitigates the impact of the desert heat, creating a more temperate climate along the coast. In addition, this mass of cold water promotes the formation of sea fogs and generates specific microclimates, which play a key role in increasing humidity and maintaining vegetation in coastal areas, especially south of Sidi Ifni.

In the face of climate variability and the potential effects of climate change, the entire country is increasingly threatened by longer and more recurrent drought crises that are accentuated by rising day and night temperatures and longer and longer heat waves. These effects, felt over the past decade, are now reflected in a nationwide water security crisis. Thus, drastic water management and saving measures have become a national priority for adaptation and resilience to climate change, because without sustainable management of this vital resource, our future will inevitably be compromised.

Notes & references

Image de couverture. *Weather and climate monitoring satellite image showing a cloud system precipitating off the Atlantic coast while Morocco is experiencing stable atmospheric conditions and winter drought. Image taken on 18 December 2024. [Source © EUMETSAT, 2024]. (https://pics.eumetsat.int/viewer/index.html).*

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[7] Due to a lack of means of observation, these climatic aspects of a reduced spatial scale have not yet been elucidated by research in Moroccan climatology.

[8] Train survey that we conducted in June 2023 as part of a national project funded by the CNRST (National Center for Scientific and Technical Research).

[9] Eastern Boundary Upwelling Ecosystems (EBUEs) are among the most productive ecosystems in the world. They cover a small ocean area (<1%) but contribute to 20% of the world's fish catch.

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