Climate change and ancient civilizations

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The history of the rise and fall of great past civilizations has often been closely linked to changing climatic conditions. This link is justified by the crucial importance at these times of regular agricultural production, which is very sensitive to climatic conditions and in particular to water availability. While archaeologists allow us, through their work, to better understand the history of these civilizations, paleoclimatology allows us to reconstruct some climatic variations in the past, and, among other things, to link changes in the water balance with environmental changes that may promote or degrade people's lives in the past. Several examples illustrate this link between the history of human settlements and the climatic events that have marked the past millennia and raise questions. How could repeated episodes of drought have pushed Sumerian and Mayan civilizations to decline? What was the impact of the Little Ice Age on some populations in Europe and Asia?

1. The emergence of the first ancient cities favoured by the climate

The great ancient cities were often at the heart of the first civilizations. Placed on a world map, most of them are located in intertropical areas (Figure 1). This geographical distribution, which does not seem to be the result of chance, reveals a hypothesis: the location of these cities is due to the need for significant agricultural production to meet the needs of their inhabitants.

Endemic agriculture has been the basis of each of these civilizations:

maize for pre-Columbian civilizations;

rice for Asian peoples;

wheat and barley for the first western and eastern cities.

Not only do these agricultures require a significant supply of water, but also a drier period. Tropical to subtropical climates offer the best hydrological conditions for such crops, with maximum rainfall in summer and a dry season in winter.

This maximum precipitation corresponds to the passage of the **Intertropical Convergence Zone** (ITCZ; Figure 1), a narrow climatic band that extends from east to west and migrates in latitude during the year (Read Jet-streams). This migration occurs between the tropics, i.e. between 20° N and 20° S, following approximately the maximum exposure. Winter is a dry season that limits the total water supply over the year and avoids flooding of crops. This alternation of highly contrasting hydrological conditions is less pronounced for temperature, although the latter could also play a decisive role on crops.

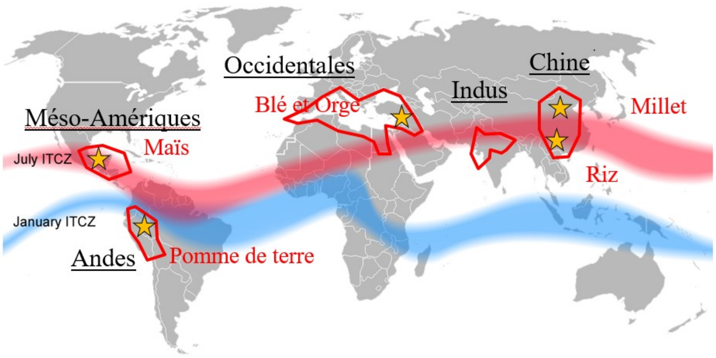

Figure 1. Distribution map of civilizations' outbreaks and meteorological zones of heavy rainfall according to seasons (ITCZ). The extension areas of the first centers of ancient civilizations are surrounded by a red line. The stars represent the privileged areas of endemic agriculture (after V. Boqueho, ref.[1]). Background map: current location of the intertropical convergence zone (ITCZ) in January (blue-coloured zone) and July (pink-coloured zone) [Source : Mats Halldin, 2006, via Wikimedia commons [Public domain]].

Vincent Boqueho in his book *Les civilisations à l'épreuve du climat* [1] underlines the importance of a **seasonal variation in temperatures**, with a period of the year below a certain threshold. According to him, low temperatures limit the development of several diseases of microbial origin, carried by parasites and promoted by high temperatures. The combination of these requirements - high water supply, alternating wet and dry conditions, colder periods - considerably reduces the geographical areas favourable to optimal crop yield. On a more regional scale, the altitude favours cooler temperatures. Figure 1, resulting from Boqueho's work, presents on the one hand the endemic agricultures that benefited from ideal climatic conditions, as well as the regions of emergence of the first great civilizations: the superposition of their distribution is striking.

Only Mediterranean civilizations have developed in a much wider area, beyond the "fertile crescent". Eastern peoples probably migrated from the Middle East following the upheavals of the first Mesopotamian civilizations; it was only after a first settlement in the north of the Arabian Peninsula that these peoples moved to an area particularly favourable to economic exchanges through navigation: the Mediterranean basin.

The location of the major centers of civilization, whether eastern, western, Asian or Amerindian, was, at least in part, determined by the favourable climatic conditions of these **tropical latitudes**. These conditions are also more locally found in Mediterranean and mountain climates, in particular. However, these climatic conditions have fluctuated on a regional scale, in particular in relation to the seasonal dynamics of the ITCZ. Paleoclimatic reconstructions allow us to specify these variations in different regions of the globe. Can we relate these variations to those of human populations? We will try here to show how a natural evolution of the climate has contributed to the establishment, growth, decline, or migration of human populations, with examples from different periods and continents.

2. Migration of climate zones over the last few millennia

The establishment and development of the civilizations in question took place several millennia ago; around 5,000 to 4,000 BC for the first Asian (first intensive rice cultivation) and Eastern (Mesopotamia) outbreaks, and 3,000 to 2,000 BC for the first Mesoamerican civilizations. These settlements therefore took place between 7,000 and 4,000 years ago BP, i.e. compared to today[2].

Technically, the **dates** indicated in this text refer to the Gregorian calendar, which uses as a reference the year 'zero', and the notations 'before Christ' (B.C.) and 'Anno Domini' (A.D.) for the years before and after the year zero respectively. These years can also be expressed **in age**, defined in relation to a current reference: the B.P. ('Before Present') rating uses the year 1950 AD as a reference, and the B2K ('Before Year 2000') rating the year 2000 AD. Thus, the year 4000 BC corresponds to ages of 5,950 years BP.

How can we reconstruct climatic variations over such past periods, and what do these reconstructions teach us? The scientists who reconstruct past climates from natural archives are **paleoclimatologists**. In tropical areas, these **experts** have highlighted migrations from the famous Intertropical Convergence Zone (ITCZ) over the last few millennia at different time scales. Thus, a general southward migration of the ITCZ has first been suggested over the past 6,000 years, ref. [2].

More recently, shorter-scale migrations (up to decades) have been specified, particularly during the so-called **Early Ice Age** period [3]. These climate changes are attributed to several factors, such as variations in sunstroke, and some large volcanic eruptions, amplified by feedback mechanisms between oceanic and atmospheric circulations [4]. This turning point, since 6,000 years B.P., corresponds more or less to the **emergence of the first major centers of civilization** in the regions exposed in the introduction, where men have found ideal climatic conditions for their development. In natural archives (such as lake or marine sediments, or cave stalagmites), records of the water balance indicate significant changes that must have affected the agricultural resources that ensure human survival. What evidence shows that these civilizations have been affected by these **climate variations**?

3. The Sumerian civilization

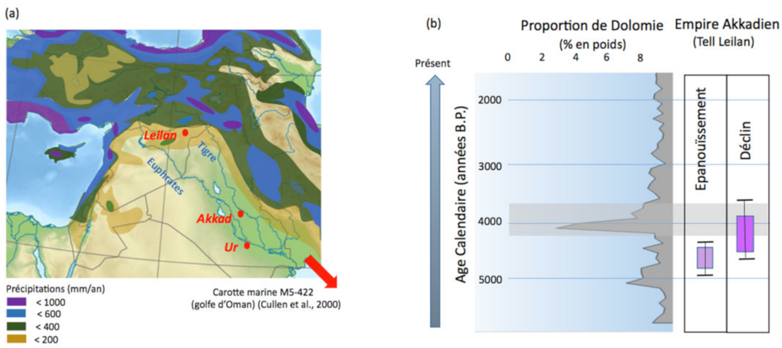

Figure 2. (a) Map of current rainfall distribution in the Near East, and location of some ancient cities. (b) Left: variations in the dolomite content of sediments in the M5-422 marine core from the Gulf of Oman. The presence of this mineral attests to a dry period (grey band) on the continent. Right: chronology of the Akkadian Empire deduced from the excavation results of the city of Tell Leilan (Syria). [Source: Left, adapted from Geyer and Sauvage, background map Викмор B [CC BY-SA 2.0 (https://creativecommons.org/licenses/by-sa/2.0)]; Right, adapted from Cullen et al., 2000, ref. 5]

A first example is provided by the Sumerian civilization, which flourished in Mesopotamia, between the banks of the region's two rivers, the Tigris and the Euphrates (Figure 2a). People occupied this region as early as the 7th millennium BC, long before the Sumerians flourished around 3500 BC. This civilization brings significant progress, such as the invention of the wheel, the cuneiform writing, and develops monumental cities like Uruk (Figure 2a).

In order to feed the inhabitants of its cities, the State must ensure significant agricultural production: it relies on writing, which allows better management of resources such as crops, places, plants and animals' accounting), but also on river exploitation, which guarantees the necessary water supply. These large rivers are fed by the Transcaucasian mountain range in the northern part of the Fertile Crescent, east of Anatolia (Figure 2a). Currently, these mountains receive between 0.6 and 1m of precipitation per year, which is sufficient to create large rivers (Figure 2a) [5]. Such climatic conditions, if they were identical more than 5,500 years ago, must have contributed to **the proper development of agriculture**, and therefore to the development of Sumerian civilization.

This civilization was at a turning point around 2,334 BC, with the influence of a new ruler, King Sargon, who brought together the various cities under the hegemony of a new capital, Akkad, to found the Akkadian empire. However, it seems that a major setback struck this empire a century after its emergence, that is, about 4,100 years ago. The term collapse of the Akkadian empire is often used to describe the loss of political influence of these large cities throughout the region, also corresponding to major armed conflicts and the exile of a significant part of the urban population. As often, it is not a real collapse since traces of occupation are still found in the region 300 years later.

What do the climate archives tell us about this period? Geological records show significant dust deposits, on the one hand in the area of the city of Tell Leilan in present-day Syria [6], and on the other hand in marine sediments in the Gulf of Oman, ref[5]. Marine deposits are dated at approximately 4,025 years B.P. with an uncertainty of 125 years (Figure 2b). These deposits indicate a **rapid shift to much drier climatic conditions**. Some writings report much more difficult agricultural conditions at that time, suggesting that significant climate change has had a drastic impact on agriculture, and consequently on the cohesion of the Akkadian empire. From a climatic point of view, the aridification of Mesopotamia would be **linked to the cooling of surface waters** in the North Atlantic, as such an atmospheric link has been demonstrated for the current climate. Paleoclimatic records show a drop in temperatures in the North Atlantic Ocean of about 1 to 2°C 4,100 years ago B.P. [7].

The climate cause is certainly not the only one to explain the fall of the Akkadian empire. Nevertheless, these significant climate changes have inevitably had impacts on agriculture and caused difficulties in meeting the needs of the population. These difficulties have undoubtedly contributed to conflicts between cities and a destabilization of political power.

This climatic event seems to have affected the entire tropical zone, probably in two phases, one around 4,200 years old and the other around 3,900 years B.P. [8], causing drought events in some geographical areas and heavy rainfall events in other regions. The magnitude of this climatic event is such that it is now used as a stratigraphic reference point for the definition of the most recent Holocene period sub-story, under the name of **Meghalayan** [9]

4. The Mayan civilization

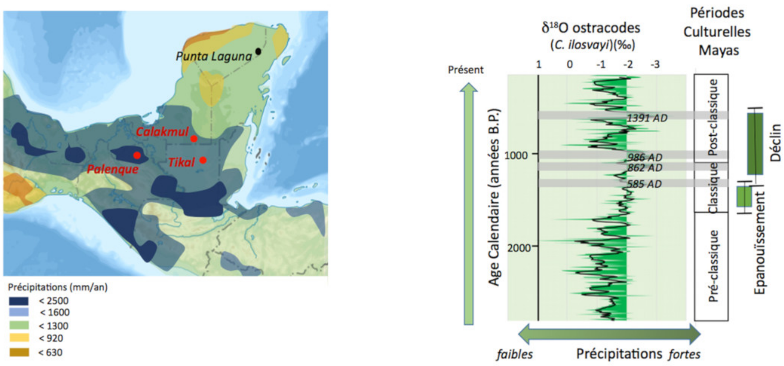

Figure 3. (a) Current rainfall distribution map over the Yucatán peninsula, largely in Mexico, at latitudes of about 15-20º N, and location of some ancient sites. (b) Isotopic composition of Ostracod shells from Lake Punta Laguna in Yucatán: positive values correspond to drought episodes highlighted by the grey bands. Right: chronology of cultural periods of the Mayan settlement in the Yucatán peninsula. [Source: On the left, adapted from Lachniet et al. 2013, background map by Addicted04; On the right, adapted from Curtis et al. 1996[10])

The American continent has hosted many great civilizations that have relayed over time, with very different geographical occupations. The Mayan civilization colonized much of southern Mexico, the entire Yucatán Peninsula (Figure 3a). Historians identify three phases in the evolution of this civilization (Figure 3b):

A preclassical period, which extends from 2000 BC to 250 AD;

A classic period, during which this civilization reached its peak, between 250 and 900 AD;

and finally a post-classical period, where large cities have declined and emptied themselves of their inhabitants, and where small communities have regrouped in scattered villages. This weakening leaves the field open for the arrival of new peoples from the north, such as the Toltecs, who are bringing new cities to the north of the peninsula.

During the pre-Classical period, the Mayans settled in small villages and began to **modify their environment**, clearing the jungle in order to establish the first crops, especially corn. This development is, as for the Sumerian and Akkadian civilizations, supported by a precise writing system and calendar, making it possible to manage agricultural holdings as well as possible.

The establishment of a powerful political and religious power, centralized around a "king-divine", sees the emergence of several city-states, such as Tikal (Figure 4), Calakmul or Palenque, which will try to extend their perimeter of domination over different areas of the peninsula (Figure 3a). A subtle interplay of wars and alliances then began between these cities, leading to the construction of ever more monumental temples and pyramids, around which more and more inhabitants came to find protection [11]. This increase in urban density leads to **increased exploitation of crop areas.** It seems obvious that accelerated deforestation occurred during the classical period.

Figure 4. Mayan site of Tikal (Guatemala), during the celebration of the solstice. [Source: Bjørn Christian Tørrissen[CC BY-SA 3.0 (https://creativecommons.org/licenses/by-sa/3.0)]

This deforestation has exposed the geological substrate of the peninsula: it is a karst limestone plateau, very permeable to rainwater, except where soil formed by a large plant cover retains rainwater. In addition, the amount of precipitation over this region of Central America depends directly on the geographical position of the intertropical convergence zone (ITCZ) presented in the introduction. Only the seasonal swaying of this ITCZ provides rainfall during the summer season (rainy season), and a water deficit during the winter season (dry season) (see Figures 1 and 3). For Mayan agriculture, the return of the rainy season each year, combined with the presence of substantial soil, guaranteed a water reserve necessary for the maximum exploitation of agricultural land.

Figure 5. A cenote, a natural water reservoir in the Yucatan Peninsula "Cenote de los Sacrificios" in Chichén Itzá, Mexico. [Source: Ekehnel (Emil Kehnel) [CC BY 3.0 (https://creativecommons.org/licenses/by/3.0)]

To reconstruct the evolution of this water balance, lake sedimentary archives have been collected at numerous sites in the northern part of the Yucatán peninsula [12],[13] and in the centre [14],[15], as well as some marine sedimentary archives from northern Venezuela [16]. These records reveal **several periods of droughts** that have lasted from several years to decades, well identified and dated between 800 and 900 AD (Figure 3b). These climatic events are explained by a southward migration of the ITCZ, which prevented the return of summer rains to the north and the irrigation of Mayan lands. These hydrological deficits have probably affected crop yields, despite an extremely well developed system of water retention at the surface, through engineering work, and in natural reservoirs called cenotes (Figure 5). Indeed, it was at the same time that historians noticed an increase in political tensions between the various "city-states", and a massive exodus of urban populations. The disappearance of the hegemony of the great cities in the central territory of Yucatán marks the end of the classical period, often referred to as the "collapse" of Mayan civilization. Once again, this term "collapse" is undoubtedly abusive, since the Mayan people and culture have remained, either integrated into a new culture, as in the north of the peninsula, or by surviving in small isolated communities.

In a context very different from the previous example, and if climate variations are certainly not the only causes of the destabilization of a civilization, the temporal conjunction of the two events (climate change and cultural upheavals) has probably

accelerated the process of radical changes in the functioning of a human society, calling into question its sustainability.

5. Impacts of the Little Ice Age

Figure 6. The Frozen Thames, London (1677) by Abraham Hondius, London Museum [public domain]. This image is emblematic of the Little Ice Age in 17th century England.

Other civilizations on other continents have also suffered significant setbacks, such as a loss of political power, ongoing armed conflicts and a flight of part of their population to other regions. The review of environmental records has identified major contemporary climate changes in response to these setbacks. We can mention the Vikings settlement in Greenland, or the Khmer civilization in Cambodia, with one of their flagship cities hosting the majestic temples of Angkor: in both cases these peoples brutally abandoned these places around the 13th century. In both cases, the economic problems encountered, at the source of political instability or simply survival, could also be explained by significant environmental changes linked to climate change during the so-called "Little Ice Age" period.

The Little Ice Age (Figure 6) is a period that extends approximately from the 14th to the 19th century, during which the lower activity of the sun, but also the occurrence of strong volcanic eruptions, has **affected the global climate** in a sustainable way, including through cooling [17]. This decline in solar activity, in successive waves in the 14th, 15th, 17th and 18th centuries, to which volcanic eruptions were added, caused a significant drop in temperatures in the North Atlantic Ocean, but also modified the general atmospheric circulation, with a southward migration of the ITCZ described by several climate archives [18].

5.1. Cooler conditions in Greenland

Figure 7. Ruins of Viking installations in Brattahlid (Greenland). [Source: Gordontour via Flickr (CC BY-NC-ND 2.0)]

Viking populations settled in Greenland during the so-called medieval Optimum period, around the year 1000, with favourable climatic conditions, following political events on their original territory (Eric the Red's exile). These favourable conditions had allowed the establishment of villages, with sheep and cattle farms (Figure 7).

During the Lesser Ice Age, a **progressive advance of glaciers**, associated with a **drop in** atmospheric and ocean **temperatures**, has been documented in environmental records, including ice sheets and marine sediments off Iceland and Greenland. These changes have forced the Vikings into the dilemma of either **adapting**, by changing their lifestyles and diets, or setting out on the **open sea** to find more lenient living conditions. After trying the first option by turning to an economy based on fishing and marine resources [19], they definitively fled these lands that had become hostile to return to Scandinavia or colonize the northern coasts of the American continent. The last Viking burials found on Greenland land are dated around 1430 A.D., ref [18].

5.2. Dryer conditions in Southeast Asia

In a completely different context, in the countries of South-East Asia, the Khmer civilization has spread over Cambodian territory and has built a first-rate architectural complex on the Angkor site. The first buildings date back to the 9th century, and the expansion of the site accelerated with the construction of Angkor Wat (Figure 8) and Angkor Thom in the 12th century, thanks to climate stability. The regular alternation of dry and wet seasons allowed sufficient rainfall to be provided, if stored, to feed crops and feed the ever-growing population. As can be observed for other civilizations (see the Mayas in Part 4), the **hydraulic engineering** work developed at that time is remarkable: several retention basins of more than 50 km^2 were associated with a network of canals and dikes extending over several hundred kilometres.

At its peak, the Khmer empire spread over a large part of the countries of Southeast Asia until the 14th century. Around the 15th century, historians pointed to a drastic reduction in this power, until the Angkor temples were abandoned. This period of decline corresponds approximately to the Early Ice Age period.

Figure 8. Aerial view of the Angkor Wat temple complex surrounded by basins. [Source: Steve Jurvetson from Menlo Park, USA [CC BY 2.0]

In Southeast Asian countries, climate change has occurred through the monsoon regime, due to the southward migration of the ITCZ. In particular, the chemical study of several stalagmites in China, or the detailed study of a sedimentary sequence from one of the Angkor retention basins, showed a significant drop in the amount of precipitation in the 13th, 16th and 17th centuries [20],[21]. This **succession of** major **droughts**, sometimes interspersed with very heavy rainfall, could have severely damaged the hydraulic network, built on soft ground and therefore very sensitive to these hydrological changes. The major consequences on agricultural production and food supply may have led to a massive exodus from the Angkor urban area and the fall of the political and religious power in place. The concomitance of these climate changes and the evolution of the Khmer empire is in any case remarkable.

It can be seen that climate changes in the Early Ice Age have had different expressions depending on the geographical areas: lower temperatures in countries around the North Atlantic Ocean, lower precipitation in countries in South-East Asia. In the Pacific, a marked advance of glaciers in the valleys of New Zealand [22], heavy rainfall on the island of Tahiti [23] and on the Galapagos archipelago [24] have been reported. The Little Ice Age has therefore had **contrasting climatic impacts** in different parts of the world.

6. Messages to remember

Adaptation to the environment has often been the **key to sedentarization**. This adaptation is all the easier when the environment is favourable.

The development of several large cities through the ages, ancient or more recent, is closely linked to the availability and management of natural resources, and in particular fresh water. For tropical regions, this availability results from the seasonal balancing of the maximum precipitation zone (ITCZ), which supplies these regions with water stored from one year to the next.

Climate records show that the extent of this balancing has varied over time, with significant hydrological impacts. The hydraulic engineering of the peoples has made it possible to build reservoirs, retention basins or irrigation canals: these installations have proved extremely effective in dealing with short or moderate climatic hazards, as has been shown for the Mayan cities of Palenque, Tikal, and the Khmer city of Angkor.

When climate change has proved too great, these ingenious adaptations have not been sufficient. Most people then migrated to find new conditions elsewhere that were favourable to their development.

The climate changes expected over the next century will not be homogeneous across the globe. Each region can expect more or less significant changes in temperature or water balance, as well as impacts related to rising sea levels on coastal regions and deltas. People will then have several possibilities: adaptation, migration or disappearance.

For developed countries, some agricultural adaptations are already underway or at least under consideration, for example the adaptation of grape varieties to wine-growing regions. On the other hand, the costs of these adaptations may not be borne by all. Other sensible savings policies could then emerge. The peoples who preceded us have put in place adaptation strategies, sometimes successful, sometimes doomed to failure. If a certain resilience can undoubtedly be achieved on a regional or even national scale, what about the global level?

Notes and references

Cover image. Illustration of the Mayan civilization at the height of its splendour. Pyramid of Kukulkán, also known as El Castillo, Mayan archaeological site of Chichén Itzá, Yucatan, Mexico. [Source: © B. Malaizé, 2010]

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