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THE CURRENT PHASE OF GLOBAL WARMING:

THE CONTRIBUTION OF PHYSICAL GEOGRAPHY

TO THE DEBATE ON ITS ORIGINS

Brigitte COQUE-DELHUILLE (1), Robert MOUTARD (2), †Henri ROUGIER (3)

(1) Professor Emeritus of Geography, University of Paris VII, member of the Société de Géographie de Genève
(2) Agrégé and Doctor in Geography, University of Lyon III, member of the Société de Géographie de Genève
(3) †Professor Emeritus of Geography, University of Lyon III, member of the Société de Géographie de Genève

We dedicate this article to our friend Henri ROUGIER, who died on September 14, 2020. He worked with us to finalize the plan and write the first pages. Completing and publishing this article at the Société de Géographie de Genève is an honor for us and a tribute to him.
Brigitte Coque-Delhuille and Robert Moutard

Abstract
The origins of the current phase of global warming are still open to questions.
After an analysis of climate changes at different time scales, specially during the Holocene and since the Roman Period, this paper aims to show the physical geography contribution to this research.
The western Alps glaciers (in France and Switzerland) provide a wealth of geographical information, landforms and dated witness deposits by numerous scientific methods (14C, OSL/IRSL, dendrochonology, lichenometry, palynology, plant biology, cosmogenic isotopes).
The Walser people, who settled at high altitude in the Swiss Alps in the Middle Ages, also illustrate the medieval climatic optimum.
In tropical deserts (e.g. Sahara and Yemen), wetter and drier phases have been analyzed over the Holocene and historically.
In the relationship between natural hazards and climate change, two case studies are analyzed: French maritime Flanders and storms, then mega-fires in the USA and Australia.
The spatio-temporal side-steps represented by these case studies are the result of geography's own multi-scalar analysis. *Ultimately,* they lead us to reconsider the respective roles of natural and anthropogenic factors in the current phase of global warming.

Résumé
Les origines de la phase de réchauffement climatique actuelle posent encore question.
Après une analyse des changements climatiques à diverses échelles temporelles, plus particulièrement à l'Holocène et depuis l'époque romaine, l'essentiel de l'article s'attache à l'apport de la géographie physique à cette recherche.
Les glaciers des Alpes occidentales (France et Suisse) sont très riches d'informations géographiques (relief, modelés, dépôts) et il existe de nombreux témoins datés par des méthodes très variées (14C, ISL/ORSL, dendrochonologie, lichénométrie, palynologie, biologie végétale, isotopes cosmogéniques).
Le peuple Walser, installé en altitude dans les Alpes suisses au Moyen-Age illustre bien également la phase d'optimum climatique médiévale.
Dans les déserts tropicaux (ex. Sahara et Yémen), ont été analysées des phases plus humides et plus arides au cours de l'Holocène et à l'échelle historique.
Dans le rapport entre les dangers naturels et le changement climatique, deux études de cas sont analysées : la Flandre maritime française et les tempêtes, puis les méga-feux aux USA et en Australie.

Les pas de côté spatio-temporels que constituent ces diverses études de cas, procèdent de l'analyse multi-scalaire propre à la géographie. Ils conduisent *in fine* à reconsidérer les parts respectives des facteurs naturels et anthropiques dans le processus de réchauffement climatique actuel.

As physical geographers who specialize in Quaternary and historical paleoenvironments, as well as present-day environments, in temperate oceanic environments, in the alpine mountains, particularly in France and Switzerland, and in tropical deserts, what is the current state of play in the vast issue of global warming? Field observation forms the basis of the geographer's information, the analysis of shapes and forms, combined with sedimentological and bioclimatic data, among others.

It's also worth trying to sort out the true from the false in the vast number of publications on the subject. We also wish to provide a realistic and inclusive vision of the many parameters responsible for climate change on our planet Earth, which have always existed at different timescales. Otherwise, we would miss out on many of the perspectives offered by the complex thinking so dear to Edgar Morin. In this case, we must not allow a single causal link - anthropogenic activities dissipating thermogenic gases - to overshadow other undeniable factors, such as astrophysical mechanisms.

Admittedly, our societies and their political bodies have no way of modifying them, whereas they can regulate greenhouse gas emissions. But focusing attention on this single source of excess atmospheric heat is likely to lead to major disappointment. Indeed, if we refer to the first sentence of Epictetus' Manual, which states that "Some things depend on us, others do not depend on us", we can transpose this simple precept to the distinction between factors of human origin and those related to solar thermal radiation and the dynamics of the Earth's movements. No policy, no matter how far-reaching its scope, can control the latter. Yet these mechanisms were at work long before modern times, and have left their mark in the form of paleoclimatic fluctuation indices collected by scientists from a variety of disciplines.

THE CURRENT PHASE OF GLOBAL WARMING

The Earth and its long-term climate change

Since the Earth's origins, climates have changed profoundly over geological eras, with more or less humid tropical climates predominating in the Primary Era (although an ice age is recognized in the Sahara during the Ordovician), followed by the glacier-free Secondary Era, "This was followed by most of the Tertiary Era, but with a major signal: the formation of the Antarctic ice sheet as early as the Miocene, and even at the end of the Oligocene, marking the very beginning of a cooling trend. Finally, the Quaternary Era appears extremely original, with its well-known alternation of glacial and interglacial phases.

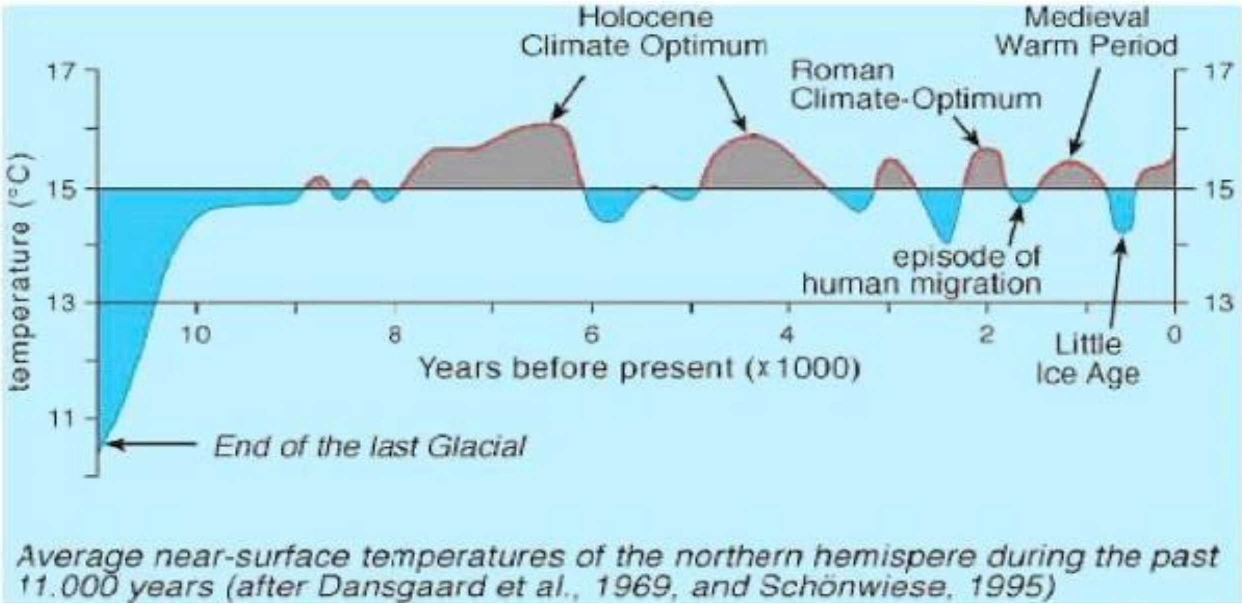
In this study, we will not go back to the ancient climates of tens or even hundreds of millions of years ago. Indeed, the distribution of land and oceans was very different, as was the composition of the atmosphere.

On the Quaternary scale, only the last 400,000 years are well known, with their alternation of glacial and interglacial periods, thanks to the study of Antarctic and Greenland ice and data from Alpine glaciers for the most recent phases.

We'll be looking at a shorter time frame, on a historical scale, from climate change in Roman antiquity to the present day, and mainly from the Middle Ages to the present day.

Climate variations since Roman times

It's impossible to think about global warming today without knowing about the climate fluctuations that have affected every historical period from Antiquity to the present day. Talking about climate change in terms of just a few years or tens of years doesn't explain anything.



Schematic diagram of near-ground temperature averages since the end of the last Glacial, the Würm, around 11,000 years BP. The warmest phases, or climatic Optima, are shown in grey, as are those of the Holocene, the Roman Optimum, the Middle Ages and the current Optimum, where temperatures are above average, and in blue the colder intermediate phases, the best-known of which is the Little Ice Age; *diagrams in Préat A., 2019, after Dansgaard et al., 1969 and Schönwiese, 1995.*

Methods used and major phases in historical variations

Knowledge of ancient historical climates is based on several types of methods and data.

- *Archaeological and sedimentological* informations: cross-referencing archaeological data with sedimentological data (analysis of deposits from before, during and after each site) enables us to pinpoint the paleoenvironments of the time and their changes (e.g. Yemen during the kingdom of Saba (1500 BC - 4th century AD) and variations in aridity).

- *Ancient texts* such as those by Eratosthene, Ptolemy and Strabo.

At first, geography was mathematical and descriptive. Then *Strabo* (64-53 BC - 21-25 AD), who took stock of the knowledge of Greek antiquity and travelled as far as the borders of Ethiopia, wrote a "Geography" in 17 books (Aujac Germaine, 1966). In it, he already developed the basic concepts of physical geography: terrestrial landforms, climate and winds, water movements and a key notion, that of the relative extension of continents and seas through the discovery of fossil marine shells far inland. The alternation of transgressions and regressions is considered, with a climatic hypothesis, the significant variation in water volumes according to the variability of the climate's humidity or drought.

- The close relationship between *history and climate provides* invaluable information on warming, cooling, humidity and drought.

E. Le Roy Ladurie, in his masterly 3-volume "*Histoire humaine et comparée du climat" , (*2004, 2006 and 2009), uses dates of harvest, grape harvest, famine and famine over the centuries, and for the present period, thermometric and pluviometric observations, breeding, tourism, and connotations relating to wine quality and vintages.

It recalls the great climatic fluctuations of the last 5000 years BC, when man played no role in the climate:
-Major Prehistoric Optimum (5000 - 3000 years BC) –
-Small Bronze Age Optimum between 1500 and 1000 years BC
-Roman Optimum (250 BC to around 400 AD)
-The Medieval Optimum from 900 to 1300 AD
-This was followed by the Little Ice Age (LIA) from 1550 to 1850 AD. -
-Finally, current global warming since 1850.
For the last 3 periods studied by the author, the precision goes down to the ten-year mark, or even to exceptional years in meteorological terms.

For the 20th and 21st centuries, we have an abundance of *weather and climate data.* In addition to traditional temperature records on all continents and oceans, we have the incomparable contribution of satellite imagery, with its numerous meteorological satellites.

- *Geomorphological data* (glaciers, erosion patterns, etc.) and data from *the global geography of physical environments* provide a wealth of useful informations for understanding climate fluctuations over historical timescales and recent decades.

The phase of global warming underway since 1850 is neither exceptional nor worrying.

Since the end of the Little Ice Age (PAG) around 1850, the Earth has entered a warming phase. It follows the PAG, as did other earlier historical periods. However, this warming is currently a little less powerful than that of the Middle Ages, when Alpine glacier tongues retreated even further (Holzhauser H. et al., 1999), and at a time when man had little influence on the climate.

Temperature trends since 1850 (end of the Little Ice Age)

-Temperature rises and oscillations since the mid-1900s è
Since the end of the Little Ice Age, we have entered a new phase of global warming, over 170 years ago, and average temperatures have risen. Estimates since the middle of the 19th century are of the order of 1°C, with variations of around ten years in the rise and fall of temperatures, mainly in relation to solar parameters (see below).

-Deviations from the average measured since 1850 vary considerably, depending on whether we're talking about the world as a whole or just one country - France, for example. In the former case, the temperature rise is around one degree, and 1.3 to 1.4°C in the latter. The former values relate to an average of oceans and continents, the latter to a mid-latitude continental ensemble. Nevertheless, temperatures have been rising significantly since 1880 - 1890. However, this varies from country to country and region to region, so these data should be treated with caution. ***The average temperature for the planet as a whole is not the average temperature felt on Earth***. Numerous geographical parameters vary these temperatures: latitude, altitude, proximity to sea or ocean, or conversely, continental location, whereas measurements over oceans are less subject to

seasonal contrasts. It is essential for geographers to understand the spatial differentiation of phenomena. Climate change is no exception to this rule.

No exponential rise in temperatures since the beginning of the 20th century.

We are therefore in a phase of global warming that follows on from the PAG. However, there are no abnormal or extreme trends. Since the end of the 20th century, a more significant rise in average temperature has been observed. The 170-year trend is sinusoidal, and we are in the ascending part of an 11-year cycle, before descending again. So there's no alarmism here, and it's clear that *Mann's hockey-stick curve*, showing an exponential rise in current and future temperatures, is wrong: a sinusoid does not extend into a straight line, and the IPCC no longer supports this hypothesis.

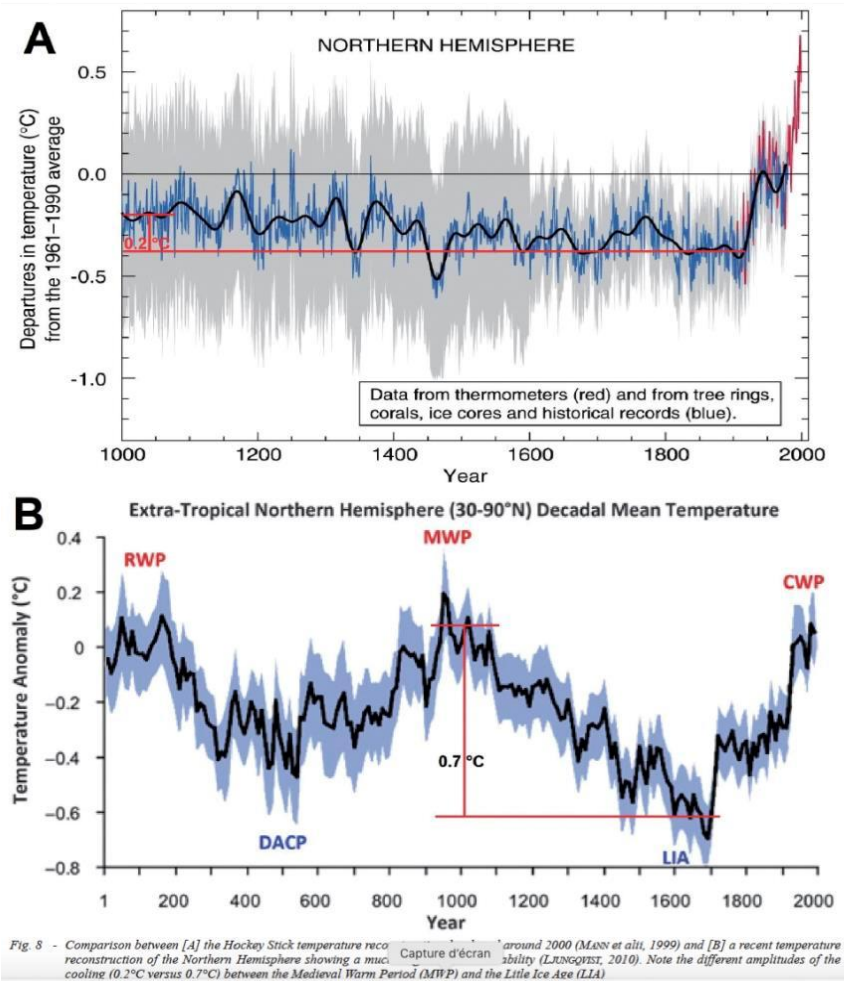


Fig.1 - Comparison of 2 temperature curves. In A, the famous hockey-stick-shaped curve of Mann et al. 1998 of the IPCC, and the variations since the year 1000 in the northern hemisphere, and in B, the temperature variations of the last century. northern hemisphere, outside tropical zones (30-90°N). Diagrams in Préat A., 2019, taken from Scafetta 2019. It is clear that IPCC figure A does not show the Medieval Optimum and the Little Ice Age at all. As for to the exponential rise in temperatures since around 1950, it is erroneous. Legend for B: RWP Roman Warm Period, DACP Dark Age Cold Period, MWP Medieval Warm Period, LIA Little Ice Age, CWP Current Warm Period.

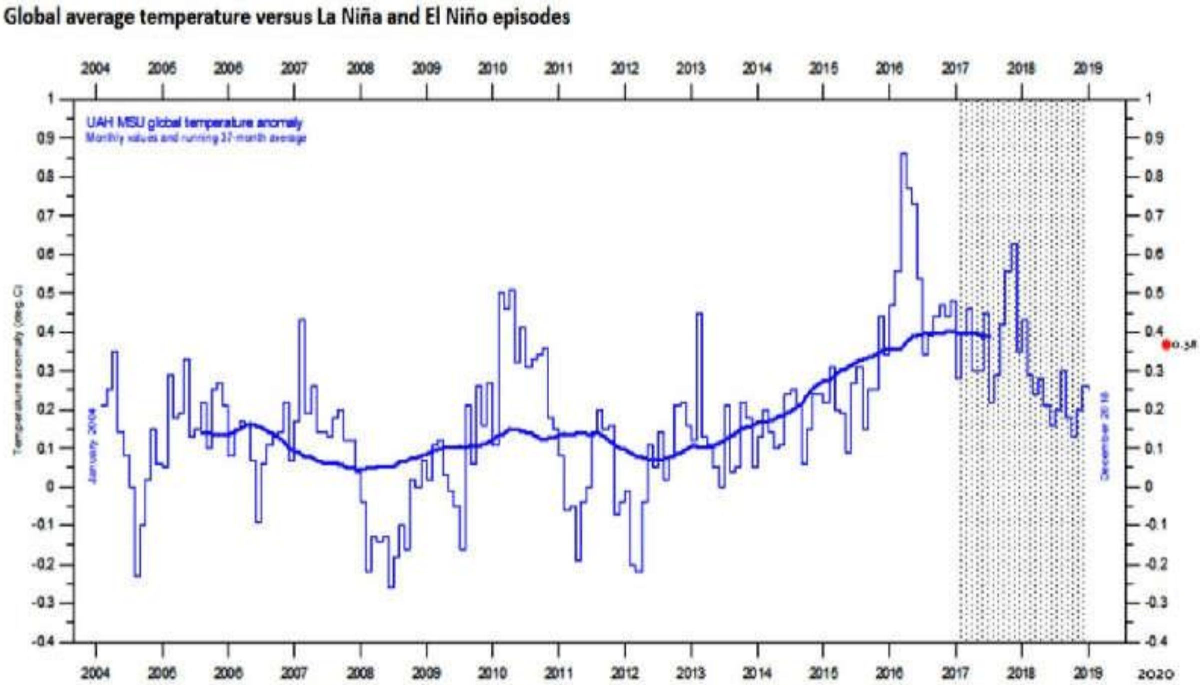


Fig.2 - The global temperature curves of the lower troposphere by satellite between 2004 and the end of 2019. This temperature is dependent, on the one hand, on the fluctuations of La Nina and El Nino. The peak of the continuous increase in temperature seems to have been interrupted since 2017. In all probability, we are, on the other hand, in a transition period which will lead to a “solar minimum”, as already evidenced by the cycles 23, 24 and the current cycle 25 (F. Ferroni, president of NIPCC-SUISSE, in debate on the German site EIKE, on the theme “alarmism is based on misleading data”, 2020).

All this goes to show that a single parameter, such as the increase in CO_2, cannot explain the rise in temperatures at any point in the Earth's history. ***The Earth system is far more complex than that, and temperature variations involve an infinite number of parameters (see below).***
The current phase of global warming is part of fluctuations of the order of 2 to 3 centuries, with internal cycles of the order of 11-12 years and more.

THE VISION OF THE PHYSICAL GEOGRAPHER

PHYSICAL GEOGRAPHY AND CLIMATE CHANGE

THE HOLOCENE IS RICH IN EQUIVALENT EPISODES OF THE CURRENT GLOBAL WARMING. TESTIMONY FROM THE ALPINE CRYOSPHERE

Glaciers in the Western Alps: witnesses to climatic oscillations

Fluctuations following those of temperatures and precipitations

Based on the work of C. Schlüchter (2004), Savoy glaciologist S. Coutterand (2019) summarizes ten episodes of climate warming covering a total of 5,400 years out of the 11,000 years of the Holocene. Details of this chronology are reproduced at the end of this article.

The advance and retraction of glacial apparatuses depend on two groups of factors. The first relates to the configuration of the landforms in which they are located: the hypsometry and longitudinal profiles of the surrounding valleys, as well as their exposure. The other variable, even more decisive as it is directly linked to climatic factors, is the balance between the accumulation and ablation of their masses. In this respect, they respond with a time lag to two key components: temperatures - essentially summer temperatures - and precipitation. The first of these factors, combined with the length of the glacier apparatus, influences the response time to ice inflow and ablation. For example, the Aletsch glacier, the longest in Europe, has a delayed response to factors affecting its mass balance, due to variations in its size. In this way, the latency of its dimensional adjustments "smoothes out" climatic oscillations. On the other hand, modest formats such as the Teppey on the flanks of the Belledonne range, show more rapid advances or retreats (Leroy, 2012; Francou et al., 2007).

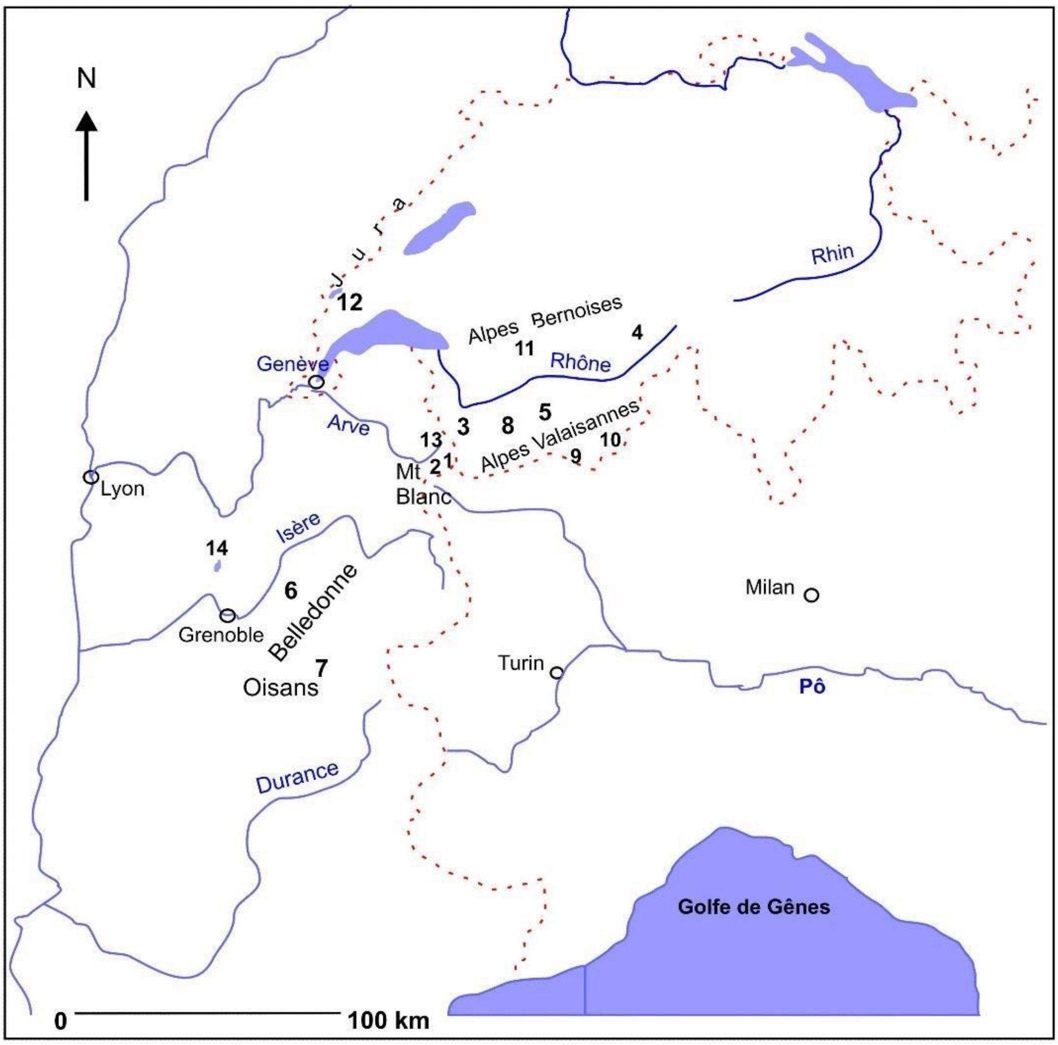
An amplification of the climate fluctuation signal

Many observers note that in mountain environments, as at high latitudes, the manifestations of recent climatic variations are generally more marked than they are in the surrounding lower-altitude areas. It's as if the signals of these phenomena are amplified.
"Mountain glaciers are one of the best indicators of climate change because of their rapid response to small variations in forcing parameters and their wide distribution over the planet. Glacial chronologies therefore represent reference records among paleo-environmental reconstructions." (Leroy, 2012).
Glacial valleys also have the advantage of being well-defined in space, thanks to their hypsometric, topographical and geomorphological attributes. This means that the phenomena they reveal can be precisely delimited in space. On the other hand, they are relatively small. Hence the importance of studying as varied a sample as possible to compensate for their heterogeneity in terms of extent, relief, and above all altitude and exposure. These last two parameters are of particular importance in glacioclimatology. M. Leroy (2012) has taken this into account in his thesis on the reconstruction of Holocene glacial fluctuations in the Western Alps, taking into account a dozen glaciers spread across the Western Alps in Switzerland and France (fig. 1).

The spectacular evolution of the Alpine cryosphere is the focus of attention not only of scientists, but also of the thousands of hikers and mountaineers who traverse the Alpine glaciers or visit their surroundings. Political leaders are also concerned, as evidenced by the French President's visit to the Mer-de-Glace at Montenvers on February 13, 2020. He was accompanied for the occasion by glaciologist Luc Moreau, a great connoisseur of the site, who provided comments for both the President and journalists (H. Rougier, 2020).
A certain kinship can be established between this media event and a new speciality that is close to geotourism, without being confused with it. This is explored in the latest issue of 2021 of the Swiss academic journal *Géo-Regards* (Bussard et al., 2021). This contribution questions the tendency to visit sites where the landscape is marked by processes of decay of the glacial apparatuses that still occupy them. The Mer-de-Glace is one of two case studies chosen to illustrate this theme.

Glacier die-off: a spectacle a priori emblematic of current global warming

Some books appeal directly to a readership sensitive to the visible degeneration of glacial apparatuses, with titles that connote pathos: "Adieu glaciers sublimes" (Funk-Salami, Wuilloud, 2013).



Sites glaciaires livrant des bois subfossiles

1 Mer de Glace
2 Les Bossons
3 Trient
4 Aletsch
5 Glacier du mont Miné
6 Teppey
7 Glaciers de l'Oisans: Le Rateau, Les Etages

Tourbières

8 Alpages de Tortin

Anciens passages en hautes altitudes

1 (id. Mer de Glace): col du Géant
9 Col de Théodule
10 Col d'Hé

Gisements d'artefacts de l'Age du bronze

11 Col de Schnidejoch

Lacs

12 Joux
13 Anterne
14 Paladru

Figure 1: Location of the main sites studied for paleoclimatic dating purposes

Seeing ahead of present time

If we were to consider only current times and fail to put them into perspective with the glacial fluctuations of previous millennia, we'd be obscuring the essence of Alpine climatic dynamics. We would then be trapped in the classic optical illusion of the "tree that hides the forest", neglecting the temporal dimension of variations in the dimensions of Alpine glacial apparatuses and what they can reveal about the climatic events to which they were linked.

To understand this warning, we first need to look at the well-documented phenomenon of the Little Ice Age, which lasted from the XV^{e} to the XIX^{e} century. Attached to this are images of glaciers in flood, venturing to the margins of the ecumene at the beginning of the XVII^{e} century, damaging hamlets close to Chamonix. These were the Argentière glacier and, above all, the Mer de Glace, still known at the time as the Glacier des Bois. The contrast between this segment of history and the glacier's accelerated retreat since the end of the XIX^{e} century is all the more striking. This fixes the representation of the glacial landscape in reference to the bygone era of its power. Painters of the XVIII^{e} and XIX^{e} centuries, as well as the first photographers who immortalized it in their images, actively worked towards this goal (photo 1).

On the other hand, there are no pictorial representations of earlier periods that might have contrasted with the Little Ice Age. For these periods, clues are harder to find. The most accessible are historical chronicles. Others require more difficult scientific notions, the most classic of which is dendrochronology. The most recent of these disciplines is astrophysics. The relative paucity of images representing the periods of climatic optima that preceded the Little Ice Age gives it an exaggerated notoriety on two counts. Firstly, because of its contrast with the present day. Secondly, by the fact that, in the minds of the general public, it eclipses the periods that preceded it. It's a case of the tree hiding the forest.

Investigation methods for reconstructing the chronology of glacial fluctuations

It is worth recalling here the methods used to date variations in the extent and altitudes of glaciated Alpine surfaces, if only to counter skeptical assertions about certain climatic optima that preceded the current warming phase. The title of one of these publications includes the Anglo-Saxon term "hoax", to equate the medieval climate optimum with "an argument put forward by climate skeptics to relativize the extent of [current] warming" (Foucart, 2015).

To shed light on this debate, we can draw on two methodological fields, which are quite different in terms of chronological scope and scientific rigor. The less well-endowed of these two areas covers historical times.

On the scale of history: passing on stories and consulting chronicles

In the classical sense of the historical sciences, we are *a priori* led to search for essentially written testimonies, which theoretically cannot cover, in absolute terms, a time span beyond six millennia. For the phenomena of interest to us in the Alpine chain, we could hardly go back further than Roman colonization, i.e. a little over two thousand years B.P. In the historical times preceding the Little Ice Age, two sequences stand in relative antithesis to this episode of climatic pejoration: the medieval and Roman climatic optima.

Evidence of the Medieval Climate Optimum in stories and chronicles

This period, originally defined by H. Lamb (1965), is marked by the first positive sinusoidal undulation in terms of temperature curves before the Little Ice Age (fig. 2).
As many authors have pointed out (Lamb, 1965; Leroy-Ladurie, 1983, 2020; Preat, 2019), it is not confined to the Alps. Although the concept of Medieval Climate Optimum is controversial in terms

of its spatial ubiquity in the Northern Hemisphere and its multi-century duration (IPCC, 2001; NOAA, 2006), it has manifested itself in Alpine glacioclimatic evolution (Leroy, 2012, Francou et al., 2007, Coutterand, 2019, Leroy, 2012).

As J. Corbel (1963) points out, there are no texts concerning the cryosphere or climate of the Chamonix valley prior to 1550. However, there are accounts of high passes that were used for pastoral transhumance and trade and are now covered in ice. They are not precisely referenced and are more akin to the transmission of traditions. Such is the case of the Col du Géant in the Mont-Blanc massif, which is chronicled as having been crossed by cows equipped for the occasion with anti-slip devices to protect them from the cold. Although glaciologist L. Moreau believes this to be possible, he views such accounts with caution.

On the other hand, references to human traffic are more numerous and better referenced. At an altitude of 3,355 meters, the Col du Géant was still a link, via the eponymous glacier, between the Doire Baltée valley leading to Courmayeur and the Arve valley, where Chamonix is located, in the 17th^{e} century. The oldest map of Upper Lombardy mentions the name of a "Col Major", which could be this passage that became impassable from the XVII^{e} century onwards, due to accumulations of ice and landslides. In this regard, R. Vivian (2005) cites testimonies collected by W. Windham, one of the "inventors" of Mont Blanc, from guides who claimed that earlier generations could reach the Aosta Valley from the Chamonix valley in just six hours. M.T. Bourrit (1773) confirms the same testimonies. Not only was there nothing exceptional about this crossing of the Col du Géant, it was also practiced by non-Alpine mountaineers. Could this be a reminiscence of the much milder times that preceded the Little Ice Age? It was this same passage that enabled Chamoniards to go to the Saint-Ours fair in the middle of winter - on January 31 - to buy farming tools. From to the present day, only experienced ice climbers or hardened high-altitude skiers use this route at this time of year.

At the end of the Middle Ages, other very high passes, such as the Valais d'Hé pass at 3462 m, were used by the Walser between Zermatt and Évolène (Röthlisberger 1976). The Saint Théodule pass (3296 m) also linked the Zermatt valley to the Valtournenche until the middle of the XVI^{e} century, before the return of the ice made it impassable in the following century. It enabled considerable trade between the two valleys. We can deduce from this that, in the Middle Ages, the populations living in these high valleys benefited from milder climatic conditions than those we know today.

H. Gams (1949) notes mentions of "the curious phenomenon of transhumance of sheep herds over passes now covered by glaciers (e.g. in the high valleys of Savoy, Engadin, Oetz and Ziller, etc.), as well as the many legends of pastures and woods buried by glaciers, or of glaciated passes once frequented, must have their origins in the Middle Ages, or even the Bronze Age.

If we go back in history to Roman times, we find another climatic optimum. The evidence for this is much rarer: there are hardly any echoes of it in chronicles or stories, as is generally the case from 5 centuries B P onwards when it comes to identifying and authenticating climatic phenomena. In such cases, it's best to resort to methods borrowed from the Earth Sciences.

Lake sedimentology

At Colletière, on the shores of Lac de Paladru in the foothills of the Isère department (fig. 1), coring of sedimentary deposits in Late Antiquity revealed bathymetric variations correlated with palaeoclimatic sequences that were warmer and drier than those that preceded and succeeded them (Brochier et al., 2007). According to the authors of this study, "(...) the low-level phase [of the lake] correlates with a phase of high solar activity". Indeed, it is hard to see any other cause than astronomical ones to explain this period of warming, at a time when human activities had not reached the importance and ubiquity they have today, to the point of being incriminated in climate evolution.

This warming period of Late Antiquity, from the IV -V^{e} centuries AD, is considered to be the most important period of our history.

Brochier et al. (2007) describe it as "the maximum of a climate warming cycle, equidistant between the cooling phases of the First Iron Age and the Little Ice Age". According to these authors, "pedogenesis was relatively short-lived" for this climatic optimum. By contrast, the pedogenesis that developed during its medieval counterpart was much more substantial, spanning three centuries from 900 to 1200 AD. However, this latter event should not be seen as one of perfect continuity. Rather, it was the sum of a succession of thermal episodes with similar trends (Brochier et al, 2007). Nevertheless, the authors of this study consider that "the optimum from X^{e} to the middle of the XI^{e} century AD appears to be a major and particular event of the Holocene".

Lac de Joux in the Swiss Jura and Lac d'Anterne in the Sixt-Passy nature reserve in Haute-Savoie (fig.1), also experienced low levels corresponding to the Medieval Climatic Optimum. In this respect, they offer "two high-resolution paleoclimatic records", particularly with regard to summer temperatures in the environment of the second site (Magny, 2009). One of these authors' stated aims was to identify the respective contributions of natural and anthropogenic factors to climate variations.

Like Lac de Paladru, Lac de Joux does not lie directly within the spatial envelope of the present-day Alpine cryosphere. However, boreholes drilled into its littoral platform provide sedimentological data testifying to biological activity requiring a mild climatic context despite the altitude. These include strata of peat, lacustrine chalk and carbonate deposits.

At a much higher altitude (2060 m), and in the immediate vicinity of the Mont-Blanc Massif, Lac d'Anterne, of glacial origin, was also sounded in its central part. The sediment cores collected show evidence of paleohydrological levels, revealing a deficit comparable to the present one, dating back to the Medieval Climatic Optimum. A qualitative analysis of the sediments, focusing in particular on the biotic elements they contain, such as *Chironomidae* larvae, enabled us to reconstruct the summer temperatures of the lake waters, of the order of 10°C, between 680 and 1350 AD. On this basis, this period is estimated to be relatively warm. This, together with the water deficit, would make this stratigraphic horizon an additional signature of the Alpine Medieval Climatic Optimum. The authors of this study point out that it is not a question of inferring from an isolated case: the data from Lake Anterne can be set against those collected at numerous other Alpine sites using different methods of investigation. For example, it corresponds to dimensional and altitudinal variations in the Aletsch glacier (Holzhauser et al., 2005), or to summer temperatures reconstructed by dendrochronology of larch trunks on a larger scale in the Swiss Alps (Büntgen et al., 2006).

The scientific contributions of plant biology

Lichenometry, palynology and palustrine paleobotany

Less widely used than dendrochronology, lichenometry is based more specifically on measuring the extension of lichens on rock surfaces in glacial wastelands. Provided that a growth curve is available for thalli covering rocky supports, it is possible to estimate the length of time that these have remained free of ice, under which lichens cannot live. However, the temporal scope of this method of investigation is rather limited, as the rock surfaces on which the thallus grows are exposed to a wide variety of mechanical stresses at altitude. This is even more the case on glacial margins, where sporadic advances of moraine-rich apparatus terminate.

It is no doubt for this reason that, based on the work of W. Karlen (1973) and J.A. Matthews (1974), R. Vivian (1975) warns that the reliability of information derived from lichenometry hardly exceeds two centuries. Referring to the work of Innes (1985) and Matthews (2005) on the late Holocene, M. Leroy (2012) concedes a longer chronological range of up to 8 centuries. With, however, significant uncertainties beyond 200 to 300 years BP. Such orders of duration are significantly shorter than those relied on by experts in dendrochronology, which has become a classic in glaciochronology.

Dendrochronology, the reference discipline for reconstructing paleoclimates

This dating method is undoubtedly the best known and most commonly used by archaeoclimatologists. Among them, J. Corbel (1963), E. Leroy-Ladurie (1967) and R. Vivian (2005) have made extensive use of dendrochronology, which involves examining the thickness and number of growth rings in subfossil tree trunks.
They can be found in a fairly good state of preservation thanks to the anoxia of the moraine clays that covered them**.**

Photo 1: Removal of a cembro pine for dendrochronological dating from a moraine on the Mer de Glace.
(Source: S. Coutterand Glaciers-climat website address :
https://www.glaciers-climat.com/gp/mer-de-glace/)

Investigative procedures within this discipline have been refined with densitometric examination of tree rings (Polge,1966) and even more so with isotopic measurement of wood components (Daux, 2013), as "Variations in the isotopic composition of cellulose (δ18O and δ13C) are robust paleoclimatic indicators, increasingly used to reconstruct various parameters (summer temperatures, precipitation, cloud cover...)" (Leroy, 2013).
In the northern French and Swiss Alps, numerous sites have yielded subfossil wood, mainly coniferous species, embedded in the moraines of proglacial margins (photo 1, and fig. 1) or appearing in positions underlying these formations. Such a configuration logically indicates that tree vegetation developed in a climatic interval favorable to its growth, before a glacial flood destroyed and covered it (fig.2). Hence the observation made by H. Gams (1949): any glacial advance largely annihilates the vegetation that developed during the climatic phase that preceded it. As a result, we often find only degraded and restricted parts of the remains to be analyzed.

Paleoclimatic sequences that allow trees to grow over several decades, or even several centuries spread over several sites, can be considered as climatic optima. However, alternating glacial retractions and floods respond - with a lag time proportional to the size of the glaciers - to the atmospheric sequences that generated them. Hence the logical extension of the concept of dendrochronology into that of glaciochronology (Leroy-Ladurie, 1967; Leroy et al, 2009).

The use of cosmogenic isotopes

We're talking about the physical sciences here.
The principle is based on the fact that cosmic rays exert secondary particle-producing spallations on the components of the atmosphere they pass through. These are transferred by precipitation to the surface of the lithosphere. Their rate of production, as well as their radiative life, is a function of time, the flow of which has been integrated into models run by computers processing samples calibrated at various sites. In his work, M. Leroy (2012) used beryllium nuclides produced in quartz by spallation of its atomic components oxygen and silica. These bodies were analyzed and measured by mass spectrometry using particle gas pedals.
The author states that "cosmogenic dating has become an essential tool for constraining glacial fluctuations on the scale of the recent Quaternary". However, he combines them with dendroglaciological methods. In so doing, M. Leroy joins other authors in identifying glacio-climatic sequences, both for phases of glacial advance and retraction.

The current regression of the Alpine cryosphere is not an unprecedented glacio-chronological episode.

On a global scale: the scope of the discussion

This is what B. Francou (2007) when he asks "(...) what if the current retreat [of glaciers] observed since the last quarter of the 20th^{e} century was merely an amplified replica of the natural fluctuations that punctuated the last millennium?".
The term "natural" is far from trivial, if we introduce it into a debate on the reverse climatoskepticism that casts doubt on or minimizes the climatic optima of historical times and the Holocene as a whole. In fact, the anthropogenic causes which, in the current dominant thinking, obscure any other origin in the warming we are experiencing, should logically not have been invoked before the Industrial Revolution, with which the massive diffusion of greenhouse gases began. This is despite the controversial theory put forward by some authors that this era was prefigured early in the Holocene, notably by the effects of land clearance following the expansion of cultivated areas (Ruddiman, 2003).

On the time scale of the entire Holocene, B. Francou (2007) asserts that "if we rely on these discoveries [results of glaciochronological investigations], and if we cumulate the times during which the glaciers of the Alps were more retreating than in our time, we can see that this represents just over half of the last ten millennia". As confirmed by S. Coutterand (2017): "The now-proven climatic optima of the Bronze Age and Roman period saw more restricted glaciers than today (...)".

Some significant spatio-temporal case studies

A look back at the **medieval** *glacio-climatic optimum*

Journalists venturing into the field of climatology believe that to hold this period as a climatic optimum would be a "hoax" on the scale of the northern hemisphere (Foucart, 2015). This somewhat provocative assertion prompts us to take a closer look at the more restricted but more precise scale of the Alpine valleys.

While historical chronicles of the Chamonix valley at this time are extremely rare, the same cannot be said for the examination of subfossil wood found on the proglacial margins of the Mer de Glace. Coniferous stands pre-existed the advanced stages of the glacier, at altitudes higher than those we know today. This is what many glaciologists and paleoclimatologists familiar with these sites report (Corbel, 1963; Vivian, 2005; Leroy et al, 2009; Leroy, 2013; Francou, 2007, 2021). These authors report true forest stands, not a few individuals that have fallen onto the glacier. The presence of soil horizons underlying the moraines or interspersed within them, in contact with which tree remains are found, attests to climatic episodes mild enough to allow the development of genuine plant ecosystems. M. Leroy (2013) dates these subfossil woods to the end of the XIII^{e} century for the upper level. They follow others from the XII^{e} century, found in an earlier level.
In Switzerland, J. Corbel (1963) reports trees dating from the late 12th^{e} century in the morainal margins of the Aletsch glacier.

The Trient glacier yielded dead Cembros Pines in the XII^{e} and XII^{e} centuries. Before that, some of them had time to become multi-centenarians, since they reached an average cambial age of 310 years - with an approximation margin of +/- 25 years (Leroy, 2013).
On the Valais alpine pastures of Tortin, in the Nandaz region, surveys of high-altitude peat bogs have authenticated the presence of abundant palustrine vegetation that thrived in the XI^{e} and XV^{e} centuries, testifying to a period of sufficient warming to allow the development of alpine pastures, accompanied by clearing, attested by the presence of charred wood, as early as the XI^{e} century. "During warmer periods, the Tortin glacier only descends to around 2700-2800 m, where it is today". (Biéler, 1978).
The author of this study does not fail to link this relative glacial retraction to that revealed by the examination of the Bunte Moor peat bog downstream of the Tyrolean Fernau glacier. It was here that E. Le Roy-Ladurie (1975) established pollen periodizations and dated peat horizons at^{14} C, completing Mayr's (1964) earlier investigations. The result is that "(...) the Grindelwald fossil forest lived on the now totally denuded sites surrounding the "glacier d'en bas" from the VII^{e} to the XIII^{e} century, i.e. at the very time when a whole series of converging clues make it possible to place the small optimum of the Middle Ages and around the year 1000" (Le Roy-Ladurie, 1975). Commenting on the dimensions of the Fernau glacier, which dominates the peat bog site, E. Le Roy-Ladurie considers them to be "even smaller, perhaps, than today's already shrunken glacier".

Interested in the Aletsch glacier for the same reasons as the Fernau glacier, E. Le Roy-Ladurie found "important medieval dating (...) of an archaeological, documentary or radioactive (carbon 14) nature". As early as 1932, Kinzl tackled the problem of the Oberriederin in Aletsch, an ancient water conduit from the early Middle Ages used to irrigate meadows located downstream of the glacier front. The route of the Oberriederin when it was in operation originated at a watering place that is still covered by the glacier today. It must therefore be admitted that "the Aletsch glacier was a little shorter during the High Middle Ages than it will be during its peaks in the XVIII^{e} century or even during the present day" (Leroy-Ladurie, 1975).

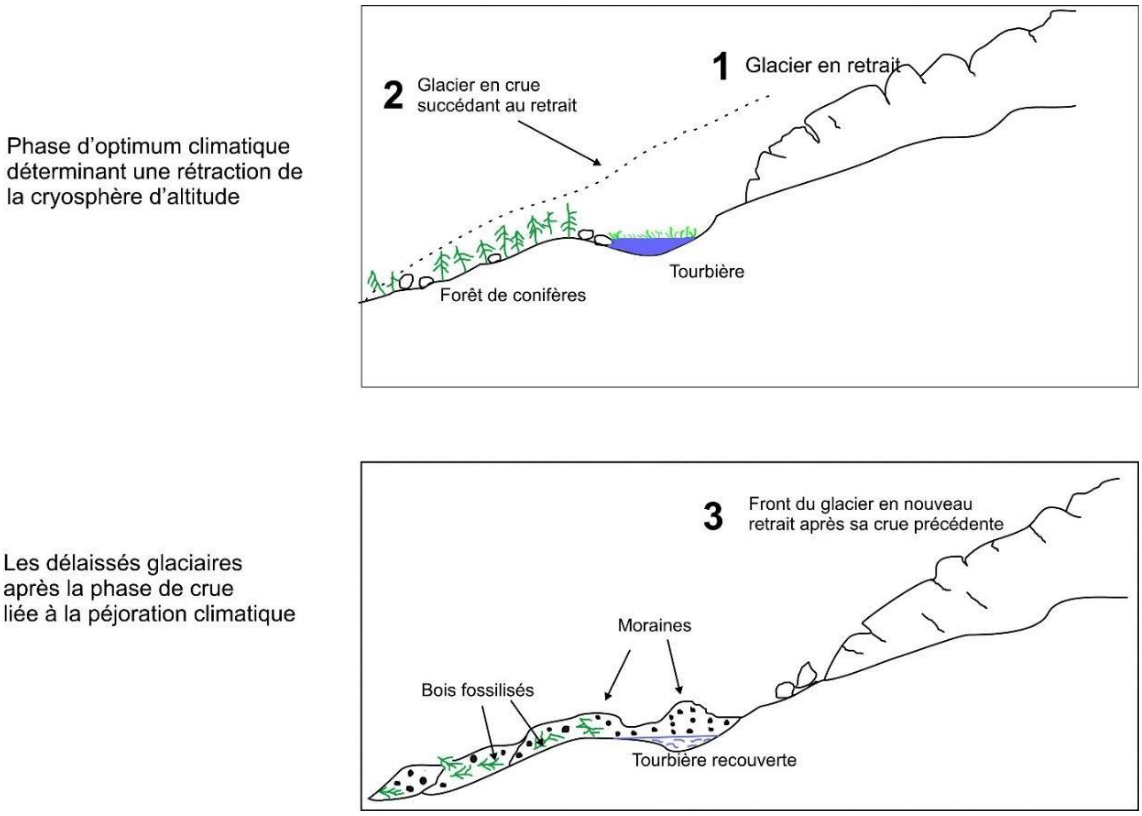


Figure 2: Phytogeographical evidence of glacial flooding and retreat (Sketch by R. Moutard)

Still on the subject of the Aletsch glacier, B. Francou and C. Vincent (2007) conclude from their investigations that (...) "the XII^{e} century and the first half of the XIII^{e} are characterized by a fine expansion of vegetation: it then extends to the limits of the glacier, which are those of 1957, without any major flooding of the glacier shaking this long period of contraction, which lasted a total of almost four centuries, from around 900 to 1300. Aletsch is therefore a record of the mild climate of the Little Medieval Optimum, a mildness that in Europe favored the clearing of land, the growth of agricultural production and, consequently, population growth.
An examination of cryospheric fluctuations in the glacial valleys of the Western Alps hardly justifies the "hoax" label that some have somewhat unwisely applied to the medieval climatic optimum.

The optimum of the* Roman *era

"The more data we accumulate on this "Little Roman Optimum", the more we realize that the glaciers of the Alps, and this is the case of Aletsch, extended over smaller areas than they do today" (Francou, 2007).
As for the medieval period, the peat bogs of Bunte Moor provide similar evidence to support the fact that in Roman times, a local climate was mild enough to allow phytogenesis, including sphagnum mosses (Leroy-Ladurie, 1975, Leroy, 2013).
In the Chamonix valleys, at the Bossons site, M. Leroy (2013) has examined subfossil wood from the IV^{e} AD century, whose presence testifies to a thermal environment that allowed the installation of a tree stand. The author considers this source of dendrochronological evidence to be highly reliable. In fact, the way they were deposited in the glacier's morainic formations rules out the

possibility that the trees studied were the result of a fall from isolated positions on the overlying slopes. They did indeed pre-exist glacial flooding.

Like its medieval counterparts, this settlement attests to climatic conditions that caused the terminal part of the glacier to retreat to altitudes higher than those at which the subfossil woods were extracted at the beginning of the 21st century. [e]

Ötzi's last trek in the Bronze Age

The man so named by archaeoanthropologists after the discovery of his naturally mummified body on September 19, 1991, at an altitude of 3,210 meters on the Italian side of the Hauslabjoch pass in South Tyrol, was not specifically equipped to walk on icy slopes. He was probably a mountain man on a hunting trip when he was killed. He was on the heights near the Similaun range 5200 years ago, in the middle of the Neolithic Bronze Age. We can deduce from this that, at that time, the summit freeze-up of the slopes overlooking the upper Senales valley was sufficiently moderate to allow the movement of men not seeking alpine exploits per se. In any case, the paleoclimate environment in which Ötzi was found was no more glaciated than when he was discovered in 1991. In fact, temperatures in the Neolithic period were 2°C higher than in the 20th[e] century (Francou, Vincent, 2007).
For a time, this discovery was considered exceptional. Since then, however, in the first decade of the 21st[e] century, other discoveries have corroborated the presence of man in sites at high altitudes that are partially glaciated today, still during the Bronze Age, and still in the Swiss Alps.
A. Hafner (2012) reports on finds of objects dating from this period at the Schnidejoch, a pass in the Wildhorn region at an altitude of 2,756 m in the western Bernese Alps. The very large number of fragments inventoried were made from leather, wood, sewn bark and fibrous fabrics, i.e. organic materials suitable for carbon isotope dating.
"These discoveries date from the Neolithic period, the early Bronze Age, the Iron Age, the Roman period and the Middle Ages, spanning 6,000 years (...). This site has uncovered the earliest evidence of human activity from the Neolithic period at high altitude in the Alps (...). This site clearly proves that human beings had access to high mountain regions as early as the fifth millennium BC. Furthermore, the chronological distribution of the finds indicates that the Schnidejoch Pass was mainly used during periods of glacial retreat". (Hafner, 2012).
M. Leroy (2013) points out that "during the fifth millennium BP a third climatic optimum has been identified. It is marked by an upper limit of high forest (Bircher, 1982; Nicolussi, 2009), and a plant recolonization of proglacial margins in the Valais (Holzhauser, 2007)."

Going back further into the Holocene

By moving away from historical times, we necessarily leave the field of anthropogenic evidence and clues useful for paleoclimatological reconstructions. We must then turn to data borrowed solely from the Life and Earth Sciences.
Research conducted on such bases leads to this synthesis: "Around ten thousand years ago, Alpine glacier fronts had already retreated to positions close to those at the end of the XX[e] Century" (Nussbaumer et al, 2012).
However, the millennia covered by this retrospective have been marked by alternating phases of glacial regression and flooding, reflecting climatic oscillations. The lag times vary according to the morphology of the glacial apparatuses and the configuration of the valleys that contain them.
Referring to the work of Nicolussi and Patzelt (2000, 2001), Hormes et al (2001) and Joerin et al (2008), Nussbaumer et al (2012) place the most marked Holocene climatic optimum between 7500

and 6500 BP and estimate that it experienced "less freeze-up than at present". This is based on dendrochronological studies carried out on subfossil wood exhumed from moraines in the Mer de Glace.
For this same Middle Holocene period, M. Leroy (2013) notes that "the upper tree line reached its highest levels". Drawing on the work of Ravazzi and Aceti (2004), Nicolussi et al, and Talon (2010), he estimates that "summer temperatures were then at the level of those at the end of the 20e century and the beginning of the 21e ". In his chronological synthesis, M. Leroy designates this interval as the second of six significant climatic optima associated with periods of shrinkage in the cryosphere of the Western Alps during the Holocene.
For the early Holocene, H. Gams (1949) estimates that "all glaciers retreated with such speed that the present limits of most forest species were reached by 5500 BC at the latest. Numerous finds of subfossil wood and, above all, pollen analyses of a large number of lake and peat deposits prove that, in the Alps, these limits were exceeded by 400 to 500 metres on two occasions, around 4000 and 1000 BC".
H. Gams also points out that during the Middle Holocene, peat bogs, some of which can be found in the Valais and Tyrol at altitudes of over 2,800 meters, took their place downstream of the upper limit of woodland. Accordingly, H. Gams estimates that spruce reached 2,400 meters in the central Alps, larch 2,600 meters, and alder 2,800 to 3,000 meters. Today, however, this species struggles to reach heights of 2,500-2,700 meters.

On the scale of the entire Holocene, many authors refer to the earliest warming phases as those covering the periods 9900-9550 and 9000-8050 BP, thus corresponding to the late Preboreal and Boreal chronozones. [1] (Vivian, 1976, Bintz, 1989, Schlüchter, 2004, Leroy et al, 2009, Leroy, 2012, Coutterand, 2017). Referring to^{14} C dating carried out by researchers at the Universities of Bern and Insbruck on subfossil wood found on present-day glacier fronts, M. Leroy et al (2009) indicate that the most pronounced sequences of glacial retreat mainly concern the first half of the Holocene. "The accumulation of these intervals even indicates that glaciers were less extensive than they are today for at least half of the Holocene (Ivy-Ochs *et al.*, 2009). The trunks found are thought to have grown during warmer periods in and/or on the edge of sedimentation basins currently under ice (...) Work carried out on this site by Joerin *et al* (2008) indicates that the altitude of the glacial equilibrium line (LEG) was more than 220 m higher than that of the reference year (1985) during the different periods when trees may have grown on this site (around 9200 cal. BP, from 7450 to 6650 cal. BP, and from 6200 to 5650 cal. BP). (...) It should also be noted that these Holocene optima reconstructed from glaciers coincide with reconstructions of an upper tree line well above the present one in the eastern Alps (Nicolussi *et al*, 2005)."
"The evolution of vegetation during the Preboreal clearly underlines the definitive improvement in climate. The appreciable rise in temperature (...) led to a marked increase in forest groups. Although any altitudinal estimate is difficult, it seems that the upper limit of the forest may have reached 1900 meters in the intra-alpine zone". (Bintz et al, 1989).
For the following period, R.Vivian (1976) considers that "the presence of trunks at the altitude of present-day glacier fronts suggests that 8,000 years ago, i.e. during the boreal period, the glaciers were smaller than today, since the local climate was mild enough to allow the growth of trees whose stumps and trunks show that they were then able to reach a respectable size".
This comment invites us to take stock of the Holocene paleoclimatic overview we have just completed. It gives the impression of a "trampling" of glacial advances and retreats in the Alpine valleys. This term is borrowed from P. Veyret, the former Dean of Grenoble University, when he summarized the contents of R. Vivian's thesis (1976), which he co-directed with E. Leroy-Ladurie.

[1] We base ourselves here on the periodization established by P. Bintz et al in their study specifically dedicated to the Holocene in the Northern Alps (1989).

Outline of a synthesis of the chronological variations of Alpine glaciers during the Holocene

The investigative methods used by the authors of this study could not be more diverse, ranging from the use of historical chronicles for the most recent periods, to scientific techniques derived from the Life and Earth Sciences, when human evidence is lacking for the earliest periods. Among these scientific disciplines, palynology and especially dendrochronology still occupy a central place. However, they are increasingly complemented by the contributions of lake sedimentology and nuclear physics. This scientific spectrum gives the authors who use it greater reliability in the results they derive from their studies.
Looking back over the millennia of the Holocene, the image of recurring glacial floods tends to overshadow that of the retreat of the high-altitude cryosphere, the traces of which they destroyed (fig.2). It should be noted, however, that these traces are now accessible - particularly in the case of subfossil tree remains - thanks to the current melting of the ice that once covered them. This means that today's glacial fronts, although affected by marked warming, were at even higher altitudes in the past, since they covered the wooded areas as they descended.

As a result - and this is the essential point of the present study - the climatic optima within which the retraction of Alpine glaciers took place can be used to relativize, without minimizing, the much-publicized presentation of the current melting and warming phase. It is not without many precedents. Certainly, the fact that "Alpine glaciers were less extensive than they are now for more than half of the last ten millennia" (Coutterand, 2017) does not detract from the fact that the present situation is felt to be worrying.
However, a retrospective of alpine climate warming episodes should provide grounds for relativizing the concerns raised by the current state of affairs. In this sense, we can rely on a chronological review drawn up by S. Coutterand (2017a), who builds on the work of C. Shlüchter (2004). This review, presented in the following table, concerns Holocene periods during which glacier melting was explained by temperatures 1 to 1.5°C higher than those of the present.

Calendar years before 1950	Duration
9900 - 9550	350
9000 - 8050	950
7700 - 7500	200
7350 - 6500	850
6150 - 6000	150
5700 - 5500	200
5200 - 3400	1800
2800-2700	100
2300 - 1800	500
1450 - 1150	300
TOTAL	5400

But, until the end of the 19th[e] century, the shrinkage of the Alpine cryosphere owed nothing to the anthropogenic causes that are unambiguously incriminated today. The successive climatic optima of the Holocene were due to astrophysical factors. It should be noted that, for the present era, their relative contribution to global warming compared to anthropogenic causes is neither precisely quantified nor readily published. The current dominant media trend tends to conceal them by referring only to greenhouse gas emissions.

Paradoxically, ignoring the fluctuations in solar activity to which the Earth is constantly exposed can have undesirable effects on our conduct in the context of the global warming we are experiencing. Global warming is governed by two groups of actors. The first is the set of forces exogenous to our planet. Only the second, which is endogenous, is man-made. The world's population can only control the latter.
However, if in all probability the former is decisive when we focus on GHG emissions alone, we run the risk of inevitable disappointment if we expect a decisive effect from measures that human populations alone are in a position to implement. This is not to suggest that such actions are useless. On the contrary, the aim is to prevent massive disappointment, which would eventually lead to discouragement and demobilization, both in terms of policies and of the behaviour of citizens committed to eliminating or reducing the factors contributing to atmospheric warming. Such discouragement cannot be ruled out. It could stem from a disproportion between the results obtained by a policy of measures breaking with the old energy paradigms, and the excessive expectations invested in such a program.

The Walser people in the Swiss Alps in the Middle Ages

The Walser people, studied by Henri Rougier (2022, Editions LEP, Mont-sur- Lausanne), perfectly illustrates the role of climatic variations on their settlement at altitude in the Middle Ages.

The word Walser comes from the contraction of the German word *Walliser*, which designates the Valaisans. Originally settled in the upper Rhône valley, Val de Conches, in the German-speaking Valais region since the 8th century, these mountain herders benefited from a warmer climate than the one we know today.
The *Petit Optimum Médiéval* (around the 8th to 13th centuries) provided many favorable conditions: higher temperatures, glaciers retreating to higher altitudes than today's regression, vegetation limits higher than today's, cereal crops that could even be grown at altitudes of over 2000m, and even higher alpine pastures. The space available for livestock farming was therefore considerable and was gradually filled in this area.
But the rapid increase in the Walser population, due to overcrowded families, led to the need to migrate. It was mainly in the 13th and 14th centuries that the great migrations of this mountain people took place, the largest in the history of the Alps. As the valleys with their good soils were already occupied, all that remained were virgin areas upstream, where topographical conditions were difficult, and the slightest flat was occupied. But climatic conditions remained favorable. They moved eastwards, into the Rheinwald, the Ticino and the Davos region, as well as the highest valleys in the canton of Graubünden.

However, with the onset of the *Little Ice Age* around the middle of the 16th century, the Walsers had to contend with harsher, colder climatic conditions. This had a detrimental effect on them: they abandoned the highest plots of land, reduced yields from hay meadows and food crops, and shortened the growing season. As a result, the population had to move to slightly less harsh locations at somewhat lower altitudes.

The Walser people thus perfectly evoke the relationship between climate change in the Middle Ages and during the Little Ice Age, and their adaptations to these fluctuations (Rougier H., 2002, 2013 and 2022).

Sloping ledge occupied by the Walsers at Sparru (1800 m), near Jungu (*photo Henri Rougier, 2010*)

Wetter and drier Holocene phases in deserts (e.g. Sahara and Yemen).

Far from the Alpine mountains, tropical deserts such as the Sahara and the Arabian-Yemeni desert also underwent more humid and more arid Holocene and historical phases. These climatic variations had consequences for human occupation in the Sahara and for flood irrigation in arid Yemen.

The extent of arid environments has varied considerably over the Quaternary, including the Holocene. In temperate mountainous areas, alternating glacial and interglacial periods were followed by a succession of wetter and drier phases in the deserts. The lacustrine limestones found in the ***Sahara*** bear witness to the presence of ancient lakes around which life flourished, and where archaeological remains can be found. Rock engravings of animals such as elephants and giraffes reveal a fauna that today is only found in the savannahs.
A remarkable example is the Taoudenni basin (Mali), located on the Tropic of Cancer (22-24°N), where the climate is currently hyperarid (only about 10 mm of precipitation per year). During the Holocene climatic optimum, also known as the humid Holocene, between 8500 and 6500 years BP, large lakes developed and were not drained until around 4500 years BP, just 2500 years before our era (Petit-Maire N., 2012). This region, well known for the salt accumulated by the evaporation of certain lakes, is still exploited by the last great caravan that regularly criss-crosses the Sahara.
On a historical scale, since Antiquity, data is more disparate and still incomplete.

In the ***interior desert of Yemen,*** on the other hand, the archaeological and geoarchaeological research carried out there (over the decade from the 1990s to around 2000), including geomorphological and sedimentological studies and absolute dating of flood irrigation silts, has enabled us to clarify the paleoclimatic context during the South Arabian Antiquity of the kingdoms of Saba, Qataban, Awsan and Hadramawt.

The arid inland Yemen studied, facing the Arabian desert (Rub al Khali), lies between 14°30'-15° North and 45°40'-46°30' East. It is framed by the Tertiary volcanic highlands (2000-3700m) to the west, the Hadramawt plateau (1300-1400m) to the east and the South Arabian basement mountains

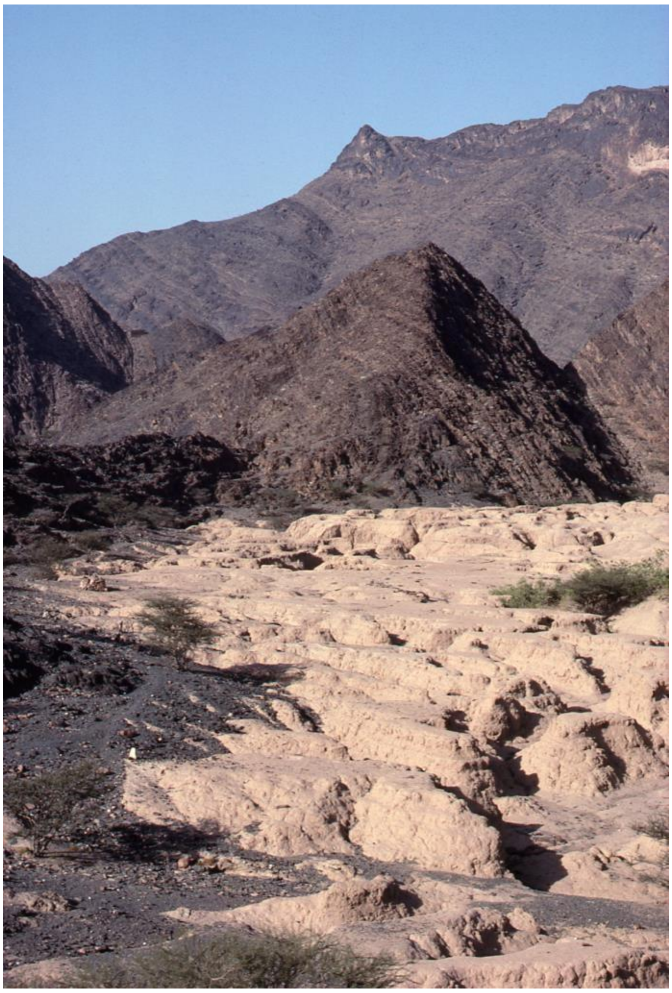
to the south, ranging in altitude from 1500-1800m in the Bayhân region to almost 2600m south of the Dura' and Abadan wâdîs.
Wide valleys, with an average altitude of 1000-1150m at the mouth of the gorges, are oriented SSW-NNE. They are set in granitic and metamorphic bedrock and feature powerful plio-quaternary alluvial fillings. Flood flows are lost in the Ramlat As-Sabat'Ayn desert, making this an endoreic region. These valleys have a highly arid climate, bordering on hyperaridity (P/ETP index around 0.03 to 0.04). On the other hand, their vast, high mountainous impluvium, with steep slopes in impermeable, vegetation-free rock, generates allogenic floods resulting from monsoon-type rainfall in March-April and July-August.

As early as the South Arabian Antiquity, these floods were controlled by means of ingenious stone hydraulic structures (deflectors, partitions, sluices...), enabling the construction of silty irrigation perimeters and the cultivation of portions of valleys where no soil existed. In this way, over the centuries, man-made terraces were built up, the tops of which correspond to the last ancient fields (Coque-Delhuille B. et al., 1994). These deposits are up to 15m thick at Al-Hinwa in the Dura' wâdî.

Al-Hinwa ancient irrigation perimeter (wâdî Dura'). The irrigation silts here are 15m thick *(photo Brigitte Coque-Delhuille*).

These have been dated for the first time using the OSL-IRSL optical luminescence method, with the oldest dating back to 3500 years BP. The ages obtained at Al-Hinwa place the start of irrigation at around 3400 **+/-** 400 years BP and the end at around 1500 +/-200 years BP (Balescu S. et al., 1998).

Downstream, irrigation remains are more degraded and covered with sand on the edge of the erg Sabatayn'. The dates obtained to date show that irrigation stopped earlier downstream, and that crops must have been progressively retracted upstream, due to less and less powerful floods around the beginning of our era ("Common Era"). The end of the Sudarabic kingdoms was thus accompanied by a climate shift towards more arid conditions.



Ancient irrigation perimeter upstream of the Dura' wâdî. Since the abandonment of the ancient fields, around 1555 +/-150 years BP, the silty deposits were eroded by runoff and the sands of the ancient canals by wind erosion. Since then, only scree from the dominant slopes has partially covered the ancient deposits (*photo Brigitte Coque-Delhuille*).

Today, the climate in the valleys remains very arid, as it was at the beginning of our era. However, agriculture is no longer dependent on flooding, as wells and motorized pumps enable water to be drawn from the water table. This ensures that the needs of a growing population are met, especially since Yemeni workers were driven out of Saudi Arabia during the 1ère Gulf War (1990-1991). But this easier access to water is rapidly lowering the water table, by around a metre a year. Ever deeper wells are needed, and many very poor Yemenis cannot afford the high costs involved.

NATURAL HAZARDS AND CLIMATE CHANGE

Are coastal storms more frequent today ? The example of maritime Flanders since the beginning of our era.

Maritime Flanders in the Dunkirk region is a flat plain situated between +2 and -2m above sea level. Much of it lies below sea level.

With the major rise of the sea (over 100m) following the Würmian deglaciation, the Flandrian transgression deposited a sandy base. The post-Flandrian regression, during the Roman Empire,

led to the development of a freshwater peat layer. A new "Dunkirkian" transgression, beginning in the 2nd century B.C., deposited clays, sandy clays and then sands in several episodes until the 11th century.
It was at this time that the new dune belts were built and so, they protect part of the coastline. At the same time, the first coastal dammings were built to protect the plain.
From the 13th century onwards, a network of watergangs, small drainage channels criss-crossing the plain, was built. The water flows into an outlet canal and is evacuated at low tide by opening a sluice communicating with the sea, which prevents sea water from invading the plain at high tide. The maritime plain has thus become *a polder*, thanks to human development (Coque-Delhuille B., 1972).

Nevertheless, in the Middle Ages, very severe storms caused major human and material disasters (Gantois T., 2000). On the night of November 22, 1334, for example, a powerful storm swept away the dammings, causing immense damage in French and Belgian Flanders, Holland and Friesland. Many villages disappeared beneath the waves and sand. Similarly, in 1421, a devastating cataclysm (submergence storm) affected coasts from French Flanders to Holland. 72 towns and almost 100,000 people were swallowed up by the waves. In Zuydcoote, after several major storms in the Middle Ages, the one on New Year's Eve 1776 was very violent, causing the dunes to shift and the sand to cover part of the village; torrential rain also undermined the houses.
Could these major, destructive storms be linked to the warmer climate of the Middle Ages? Current knowledge is too fragmentary to confirm this. However, the fact that these severe storms occurred more frequently argues in favor of a warmer climate during the Middle Ages.

Today, the coastline evolves locally under the sole influence of marine erosion processes. Elsewhere, as in Dunkirk with its major port extensions, erosion is considerably affected by human activities. These major constructions are modifying the littoral drift, with a deepening to the west and a thinning to the east. To limit the effects, new dikes, riprap and groynes have been built...

The former DIREN Nord-Pas-de-Calais, now the DREAL, launched a long investigation and research project entitled : « *Determination of the marine submersion hazard integrating the consequences of climate change in the Nord - Pas-de-Calais region"* (Kerambrun G., 2013). Thanks to the breakwaters installed between 1978 and 1984, the coastline of the Malo-les-Bains beach has been stabilized.
As a result, sediment transport has resumed further east, as far as the Belgian border. In this sector, with its extensive dune belts, the coastline is retreating only slightly. One area is even prograding. Only a powerful storm event could cause the coastline to retreat by up to 20m.

This coastline along the North Sea is well protected by solid edifices (dammings, riprap, etc.) and a dune cordon vegetated with 8 to 10 m-high oyats. If we look at the downward re-evaluation of the eustatic rise in sea level for the 21st century (IPCC, 2007), it would only be 28 to 43cm. According to DREAL calculations, this would result in a coastline retreat of 6 to 9m over a 100-year period.

Any talk of the Dunkirk region being completely under water by 2100, as recently published in certain media, is therefore nothing more than an unfounded scenario, in line with the prevailing doom and gloom.
As for storm frequency, Emmanuel Garnier (2012), who studied storms between 1500 and 2000, shows that there were slightly more storms of force 10 and above in the 18th century than in the 20th century. Similarly, in the case of flooding storms on both the Atlantic and North Sea coasts, the 18th century was also the most affected, well ahead of the 20th and 19th centuries.


Watergang in the Moëres region near Dunkirk (photo CAUE Nord).

Mega-Fires: specific physical environments and human actions

In recent years, mega-fires have regularly made headlines in many media. What are mega-fires? The term "megafire" is used to describe fires of unprecedented scale, affecting large areas of forest and having major consequences for wildlife and populations, with casualties and damage sometimes incommensurable.

These mega-fires are most often uniquely linked to global warming. But what is the reality? We can only understand such a phenomenon if we take into account all the parameters that can explain these types of fires and the origins of their outbreak: study in what types of specific physical environments they are triggered (climate, topography, biogeography etc.) and what anthropogenic actions come into play (Yang J. et al., 2014).

We'll take 3 recent examples: the fires in central California (2017), the Marshall fire in Colorado in December 2021 and those affecting eastern Australia in 2019.

The case of California

Mass and Owens (2019) have shown that the October 2017 fires in ***Central California***, close to the coast, are only a very small part of general global warming. Summers are hot and dry enough to dry out vegetation, particularly herbaceous plants. In autumn, strong winds from the coast accentuate the drought and allow fires to spread. The increase in fire frequency is due to a number of factors: highly flammable herbaceous vegetation, primary trees destroyed to the tune of 95% during the gold rush, then replaced by coniferous trees that are more sensitive to fire, and above all the gigantic expansion of suburbs into forested areas, in certain valleys and on slopes. As a result, people and their property are increasingly living in environments where the risk of fire is high.

The vast majority of fire starts are of human, involuntary or criminal origin. Yet the frequency of fires has declined over the past 1400 years (studies cited by Mass and Owens (2019). But their intensity and extent are major. Amerindian populations used to practise slash-and-burn to enrich the soil, control the destruction of the herbaceous stratum and destroy dead branches by fire. Today, this practice has become obsolete and the undergrowth is no longer maintained.

The same associated factors were responsible for the ***gigantic Paradise fire*** (California, USA) in November 2018, resulting in the deaths of 85 residents and the annihilation of 19,000 homes and buildings.

Photo of a neighborhood in the town of Paradise after the fire. Homes are razed to the ground, and their location in the heart of a wooded area can be seen (*City News photo, AP Photo, Noah Berger, 2018*).

The Marshall Fire in Colorado in December 2021

This mega-fire affected the town of Superior, located between Denver and Boulder in ***Colorado***, at the foot of the Rocky Mountains. It was started by a human-caused brush fire, and under the effect of very powerful winds of over 160 km/h, it rapidly moved towards populated areas. Two people were killed, and 1,000 homes and commercial buildings were destroyed.
An article published in January 2022 by Cliff Mass: « *The Colorado Wildfire and Global Warning: Is there a Connection »,* shows that no link can be established between this event and global warming :

1- The fire was caused by people and not by lightning;
2- It was driven by very strong winds on the eastern flank of the Rocky Mountain range. This is known locally as the *foehn* or *Chinook.* It accentuates the dryness of the eastern slopes with its downslope winds, based on the principle of dry adiabatic conditions. In December 2021, these winds reached between 161 and 185 km/h, which is already considerable but a far cry from the historical records of 230 km/h in 1972 and 225 km/h in 1982*;*
3- This fire was fuelled by very dry grass from the vast meadows to the west of Superior. Relative humidity was only 23% on the day of the storm, making these grasses highly flammable*;*
4- The enormous increase in population in this area over the last fifty years has considerably increased the possibility of accidental fires.

Between 1950 and 2020, no upward or downward trend in temperatures has been observed, and the drought index shows no significant trend either.

Among the factors responsible for this mega-fire are the exponential expansion of a dense habitat following the consequent increase in population, its location close to dry prairies from late summer to early winter, in a geomorphological environment subject to violent foehn winds that descend along the eastern flank of the *Colorado front range*.

Devastating mega-fires in eastern Australia in 2019

These mega-fires killed around 30 people, between 500 million and one billion animals perished in the forests and bush, at least 1,500 homes were destroyed and 10 million hectares of bush and forest were burnt.

These fires mainly affected the ***south-east of Australia,*** in New South Wales, in the most populated areas of the eastern sector of the Blue Mountains.

As Alexis Metzger (2021) rightly points out, "*In Australia, for example, the major forest fires of 2019, which destroyed over 5 million hectares of forest, are linked to a combination of* factors." Indeed, neither global warming (temperatures in Australia have risen by around 1°C over the past century, according to the Australian Bureau of Meteorology), nor any other single factor can explain this disaster.
Australia's climatic characteristics must be taken into account. Straddling the Tropic of Capricorn, this island-continent comprises mainly arid and semi-arid zones, with very high temperatures. The northeast is tropical and humid around Cairns and Darwin, while the central east and southeast have subtropical climates, with Mediterranean conditions in the southern parts. So, with the exception of the far north, we're in a context of warm to hot temperate climates with significant periods of drought.

Mega-fires in eastern Australia seen from satellite, with huge plumes of smoke over coastlines and the Pacific Ocean. This image also clearly shows the multitude of fires starting in the forest or in cleared areas (*Google Earth photo*)

These Australian megafires are triggered by several factors:

1- The climatic conditions mentioned above are conducive to *bush* fires. For a long time, these fires were started and controlled by the aboriginal populations, who practised "ecobuage". Today, natural areas are protected and these practices have ceased. As a result, the bush burns in places every year, uncontrolled, and the fire spreads to the *eucalyptus forests*, a *pyrophyte plant* whose essence is particularly flammable. Add to this the lack of maintenance of these forests, particularly the undergrowth.
2- Waves of increased heat and drought are recurrent in Australia. Recorded since 1851, the one in 1896 was also very intense. In the 20th century, we can cite the 1939 heatwave in the southeast, and the 1960 heatwave with a record temperature of 50.7°C in Oodnadatta, a hamlet located in the north of South Australia, at around 27°N.

3- The large population increase in the eastern part of Australia, where the major cities are located. Their suburbs, notably Sydney, are growing right up to the foot of the Blue Mountains, named after the color of the dominant tree species, the highly flammable eucalyptus. The country's population has quintupled in a century, with an even higher percentage in these eastern regions. The number of fires in these areas is increasing due to human action, whether unintentional or criminal.
   The Google Earth photo above clearly shows that there are many fire starts, both in cleared areas and in the forest itself.

So it's clear that these mega-fires are the result of multiple factors converging to make them much more dangerous than before, in terms of human lives, property destroyed by the flames, and biodiversity also greatly affected.
One extra degree in a century does not make the current phase of global warming responsible for these mega-fires.

All in all, while mankind bears a major responsibility for today's " Natural" disasters, global warming plays only a secondary role.

So what are the parameters that modify climate?

FACTORS BEHIND THE CURRENT PHASE OF GLOBAL WARMING

Recurring natural factors in climatic variations

Climatic variations have always characterized the Earth, whatever the time scale considered: long-term, Quaternary, historical and even in the current warming phase. In the history of our planet, mankind has only recently appeared on the scene, yet climatic variations have always occurred outside of his potential influence.
Fundamental, recurring natural parameters are mainly responsible for these changes, including astronomical and solar factors.

Astronomical parameters and Milankovitch cycles

Three astronomical parameters, the Milutin Milankovitch parameters (1941), define climate cycles on different time scales.

Terrestrial eccentricity.
The Earth's orbit forms an ellipse that is eccentric by around 18 million km with a periodicity of 100,000 years (M. Tabeaud, 2014). This characteristic leads to major climatic variations, such as the great ice ages of the Quaternary.

Earth's *obliquity*
The Earth's obliquity corresponds to the inclination of the pole axis with the perpendicular to the ecliptic plane. While it currently forms an angle of 23°27', this can vary between 22.1° and 24.5°. The "solar constant" therefore undergoes variations, and its effects are greatest at the poles (longer or shorter nights, depending on this range of inclination, with a heat balance that fluctuates more than at other latitudes).

The precession of the equinoxes
The Earth rotates on its own axis, not like a balloon, but like a spinning top (Société d'Astronomie de Rennes). This axis describes a cone around the perpendicular to the ecliptic plane "according to a main cycle of around 23,000 years and another of 19,000 years" (M.Tabeaud, 2014). This precession results from the fact that the attractions of the Sun and Moon are not uniform on Earth. This movement leads to a precession of the equinoxes and a drift of the seasons over time.

All in all, ***these astronomical parameters combine to create complex movements of the Earth and changes in its climate over variable time periods***, with the 100,000-year cycle corresponding to that of the Quaternary ice ages. But there are others of around 40,000 and 20,000 years, and even fluctuations with a very short period of 18.6 years. The latter are the result of the *nutation* phenomenon linked to the disruption of precession by the attraction of the Moon and Sun.

Variations in solar activity

Sunspots and solar flares
Solar activity is not constant but variable, depending on the number of sunspots on the Sun. These correspond to darker, less hot regions of the Sun (4200 K instead of 5800 K). Here, gigantic explosions known as *solar flares* are produced. The flow of energy radiated by the Sun, or *irradiance*, therefore varies. As a result, the "*solar constant"* varies a little, even if only slightly (0.1%), (Delaigue Gilles, 2021). During periods of high solar activity, the ozone layer expands and heat is retained in the atmosphere, leading to higher temperatures. The opposite occurs during periods of low solar activity, with a drop in terrestrial temperatures (Bard E. 2011; Zharkova V., 2020).

Solar cycles and their influence on climate change
Sunspot activity varies according to an 11-year cycle, but also according to a longer cycle of 200-300 years (Tabeaud Martine, 2014). These cycles correspond to major historical phases of warming (Middle Ages) or cooling (Little Ice Age). The latter saw a sharp drop in the number of sunspots, particularly between 1790 and 1830.

Natural external factors thus play a role in the Earth's climate as a whole, but also in the Earth's climates, which form a mosaic with multiple elements (Connolly et al., 2021).
For the latter, we must also take into account the essential role played by latitude, altitude, the distribution of continents/oceans, thermohaline circulation and volcanism, among others.

Anthropogenic factors in the current global warming phase and the role of CO2

The greenhouse effect

Definition The term atmospheric greenhouse *effect* comes from a comparison with the horticulturist's greenhouse. In both cases, it involves the trapping of infrared radiation. The glass walls of a gardener's greenhouse, like planetary atmospheres, have the property of letting visible solar radiation through and partially blocking the infrared radiation emitted by room-temperature objects inside the greenhouse. In the case of the Earth, however, this would be an upward-opening greenhouse, so the comparison is only an approximation.

The greenhouse effect is first and foremost a *natural phenomenon* that protects the Earth from excessive temperatures. Without its influence, the average temperature of the Earth's surface would be around -18°C, making life impossible. Thanks to the greenhouse effect, the temperature of the lower atmosphere remains around +15°C on average, i.e. 33 degrees warmer, making all forms of life possible on Earth. This confirms the **benefits of the natural greenhouse effect on Earth**.

The gases involved in the greenhouse effect are *very much in the minority in the atmosphere*, generally accounting for less than 1% of the total, with the exception of water vapour, the most represented GHG, whose percentage averages around 1% (at 15°C and at sea level). The much-criticized CO2 has an atmospheric concentration of just 0.04%. NO2, nitrous oxide, 0.00005%, CH4, methane, 0.0365%, ozone O3, a very rare gas (around 0.000001%) and chlorofluorocarbons (aerosols, refrigerant gases): 0.0002041%.
The role of these greenhouse gases also depends on their *capacity to absorb infrared radiation* emitted by the Earth. Thus, their global warming power (GWP) is established as follows for the main GHGs. Expressed in C02 equivalent and given a value of 1, we obtain 8 for water vapor H2O, 23 for methane CH4, and 120 to 12,000 for chlorofluorocarbons (HFCs). CO2 is therefore far from having the highest GWP, and representing just 0.04% by volume.
The anthropogenic share of these GHGs generates **an additional greenhouse effect** whose role in the global warming phase is debatable.

Anthropogenic actions and the additional greenhouse effect

What human actions are responsible for these additional greenhouse gases?
Water vapour (H2O) is by far the most important greenhouse gas. However, it is essentially of natural origin (evaporation from oceans and lakes) and very secondarily of anthropogenic origin (irrigation, water reservoirs), so this major greenhouse gas is rarely mentioned by the IPCC.
Carbon dioxide (CO2) comes from plant biomass and the combustion of fossil fuels (coal, oil, natural gas). Conversely, plants absorb carbon through photosynthesis, and since CO2 is soluble in water, the oceans absorb large quantities of it. Since the beginning of the industrial era, the share of carbon has certainly increased, but the anthropogenic share would only be 0.4ppm out of a total CO2 of 390ppm. Calculations by F. Gervais (2013), inspired by atmospheric specialists, give a temperature rise of 0.0005°C per year, or 0.05°C per century, due to the anthropogenic effect. The situation is therefore not alarmist.
Anthropogenic *methane (CH4)* comes from anaerobic fermentation by livestock and agriculture (ruminants and rice), but also from fossil fuel combustion, biomass fires (forest fires for deforestation, as in Amazonia) and microbial activity in landfills. Methane's GWP is fairly high, but its percentage in the atmosphere is only 0.0365%.
Nitrous oxide (N2O), ozone (O3) and CFCs (chlorofluorocarbons) play only an extremely limited role in anthropogenic warming.

It thus appears that anthropogenic CO2 only has a secondary impact on the greenhouse effect.

The IPCC

The Intergovernmental Panel on Climate Change (IPCC) was set up in 1988, jointly by the World Meteorological Organization (WMO) and the United Nations Environment Programme (UNEP). The aim was to gather information on current climate change from scientific articles and publish a summary. But this was to lead to a "*consensus"* of all participating countries*, which was* difficult to establish and could not respond to the scientific diversity of approaches to climate fluctuations (synthesis reports, 2014 and 2021).
The four main ideas of this UN body are as follows:

-there is significant global warming, which is dangerous for the planet
-it results from the greenhouse effect
-CO2 is the determining factor
-This GHG is the result of human activities since the beginning of the industrial era.

Any scientist who disagrees with these assertions is considered a *"climate skeptic".* The IPCC's position fails to take into account, for example, the complexity of the phenomena involved in climate change, with the result that decisions have been taken to counteract them, but whose effects on the climate are doubtful.

A scientist has a duty to doubt single causes and to look for all the parameters responsible for the current warming, which is in no way alarmist, but is part of a normal phase of rising temperatures following the cold period of the Little Ice Age (PAG). Moreover, this rise in temperature is not as excessive as we are led to believe (up to +6°C by the end of this century).
In fact, temperature variations of 10, 20 or 30 years can be observed, and these have not increased since 1998, or only slightly, as confirmed by the famous specialist institutes GISS (NASA's Goddard Institute for Space Studies), UAH (University of Alabama at Hunstville), HadCRUT (Hanley Center, UK), RSS (NASA Remote Sensing System), NOAA (National Oceanic and Atmospheric Administration), already cited in 2013 by François Gervais, with current solar cycles showing fewer and fewer sunspots (cycles 21,22,23,24 and cycle 25 underway). This augurs a return of the cold, perhaps as intense as during the PAG, in a few decades' time, with a gradual descent in temperatures. Numerous scientists have shown that the *current,* post-GWP *global warming is fundamentally natural* (orbital and solar factors) and not caused by C02 produced by anthropogenic actions, or only to an extremely minor extent.

For their part, Kauppinen and Malmi (2019) show that the IPCC does not take into account the role of clouds and that, over the last hundred years, temperatures have risen by only 0.1°C due to global CO2, or only 0.01°C due to anthropogenic CO2. *Low clouds are the main temperature controllers.*

Scientists demonstrate the minor role of anthropogenic CO2

François Gervais' remarkable book (2013) clearly shows that *CO2 is not responsible for global warming, or only to a very small extent*. He estimates warming *at* 0.0005°C per year, or 0.05°C per century (p. 142-143). For his part, Jean-Marc Bonnamy (2018), with a very fine scientific demonstration, provides proof that CO2 is "innocent", as he puts it. Indeed, the clearly demonstrated phenomenon of *CO2 saturation in the atmosphere* confirms that current warming "*cannot be attributed to carbon dioxide".*

Vahrenholt F. (2012), German scientist, environmental activist, member of the SPD with environmentalist functions and entrepreneur in renewable energies, was also a member of the IPCC of which he was the reviewer of the AR 3 report in 2007, but left following the factual errors and biased conclusions he found there. From this experience, he wrote a book entitled *Die Kalte Sonne*, 2012, *le soleil froid,* available only in German. In it, he questions the thesis that global warming is caused by man-made CO2. He concludes that "*the way carbon has been instrumentalized in climate studies is a scientific and human scandal".* As a result, billions of dollars are being spent to achieve, perhaps, totally decarbonized energy, which will make no difference to global warming.

Above all, we now know that ***the rise in the amount of CO2 in the atmosphere follows global warming, and not the other way round.*** This is an essential fact.

The curves of climatic variations and atmospheric CO_2 concentration for the last 400,000 years, obtained from the analysis of air bubbles contained in Antarctic ice, show an apparent coincidence between their rises during interglacial phases. However, on the scale of the graph, this is not the case. In fact, at a smaller time step, a 1,000-year lag has been demonstrated, with the increase in C02 systematically following that of temperature (Harde H. et al. 2019, Deheuvels P., 2020). When the oceans warm up, the CO_2 they contain is released to a greater extent through degassing.

All these aspects, highlighted by scientists, demonstrate that there is *no climate emergency*. Remember that CO_2 is necessary for the planet, and in particular for the biosphere, thanks to photosynthesis (Gervais F., 2018 and 2020, Gérondeau C., 2019).

Mathematical models and future climates

The many mathematical models that attempt to determine future climates come up with proposals that are as diverse as they are aberrant, ranging from 1.5°C to 6°C temperature rises by 2100. Bear in mind that at mid-latitudes, there is only a 10°C difference between an ice age and an interglacial phase.

The discrepancies between models are enormous. In fact, models only take into account a limited number of parameters that influence climate change. In fact, as we have seen, there are an extremely large number of factors involved in climate change, which are difficult to integrate into an equation or algorithm. As a result, there is an inevitable simplification of reality, and we cannot prejudge a continuous rise over a century or more, using only a few decades' worth of data. Variations over time steps of 10 and 100-200 years are not taken into account. These projections are therefore inherently unreliable.
Numerical simulation models for the future are therefore far from being able to provide credible information. We'll need to be able to integrate many more parameters of the highly complex climate system once we have a much better understanding of its overall workings.

REVIEW AND OUTLOOK

-No single parameter can explain current climate change, and even less so anthropogenic CO_2, as scientists from different specialties have demonstrated. It's a simple idea that makes man feel guilty.
To think that the latter would have such powers on our Earth, which is subject to an enormous number of interactions within the solar system, is unfounded.

-Multidisciplinary studies are needed to understand how the Earth system works: we need to give SCIENCE its rightful place.

-There isn't just one general climate, but many different climates on Earth, all interlocking at different spatial scales: large bioclimatic environments, regional climates, local climates and microclimates.

-**Importance of the time scales considered**

We can't talk about the current global warming phase without knowing about those of historical times (Roman optimum, Medieval optimum), at a time when man had no role whatsoever in C02 production.

-Global warming and pollution are not the same thing.
Pollution, unlike climate, is entirely man-made. There is an intense battle to be waged against urban and rural pollution, plastic waste in the oceans and so on.

The global vision of the physical geographer thus provides concrete, comparative knowledge of climate change, in a spatio-temporal perspective, based on the terrain, surface formations providing information on erosion systems and their changes, and dating using an ever-increasing number of methods (14C, ISL/ORSL, dendrochonology, lichenometry, palynology, plant biology, cosmogenic isotopes**).** It also makes it possible to determine the anthropogenic factor in the development of natural disasters, depending on occupation sites (major beds, avalanche corridors), irresponsible deforestation in humid tropical environments, where soils are thin, abandonment of crop terraces in Mediterranean environments exacerbating water erosion, risky behavior responsible for forest fires where undergrowth is poorly managed, amplified by the presence of easily flammable species (e.g. eucalyptus in Australia).

The knowledge of the past that alarmists of climate change lack, enables physical geographers to consider the question of current global warming realistically and in all the complexity of the Earth system. Nor are we climate sceptics, since global warming since the Little Ice Age is a fact, but we are climate realists, since man's contribution to this warming is very small. Science will gradually provide a better understanding of these multifactorial phenomena, and mankind will continue to adapt to climate variations as it has always done. The current climate is not "*deregulated*", it has always fluctuated and always will.

So let's not be afraid of tomorrow's climate.

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Author contact details :
Brigitte Coque-Delhuille: hrbc.mcda@gmail.com
Robert Moutard: robert-moutard@orange.fr