Climate: Recognizing True from False

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Save the Climate

Foreword

Although the part played by humans in today's global warming is acknowledged virtually unanimously within the climate science community, a number of individuals are relentlessly working to convince the public and decision makers that this is not so. Some of the climate change deniers doubt in good faith that humans can have any influence on the climate. Others voice such opinions to further their own interests: the actions that need to be undertaken to reduce, or to adapt to, global warming are disadvantageous to them.

Some of the arguments presented by those whom we call climate warming skeptics or climate warming deniers are grounded on biased data or on data sets that carefully exclude whatever might contradict their line of argumentation. Other arguments rest on calculations that are not realistic because their authors have a simplistic view of the processes at work in the climate system.

Confronted to this controversy, we do not, in this paper, aim at discussing one by one the assertions of this or that denier. This would require a large volume that might prove to be arduous reading. Our goal with this paper, rather, is to provide the reader with the tools to exercise vigilance and a critical mind when exposed to the lines of argumentation presented to her/him: observe to what extent the data presented may provide a partial view of reality that fits in with the purpose of the author and identify possible flaws or loopholes in the lines of reasoning presented.

Following an introduction on the climate system mechanisms, we explain the good usage rules that data presentations should abide by. We then detail some of the flaws that occur in simplistic representations of the climate processes, leading to erroneous conclusions on the evolution of the climate. The reader is subsequently warned against statements by scientists foreign to climate science who claim to be climate change experts. Finally, we describe some of the impacts of climate warming that deniers choose to ignore.

Introduction

The Earth receives the largest part of its energy from the sun: the energy from the core represents only 1/4000 of the energy received from the sun. Energy escapes from the Earth towards outer space, in part simply via the reflection of some of the incident sun light; the rest is emitted by the earth's surface and its atmosphere as infrared radiation. The sun light that does not return to outer space is absorbed and its energy ends up as heat. Similarly, the infrared radiation emitted by the Earth removes energy. When the amount of outgoing energy is not equal to the amount of incoming energy the following occurs: the globe cools if more energy is given off than received, and warms if more energy is received than given off. This variation of the earth's and the atmosphere's temperature persists until a new equilibrium is reached, when as much energy is given off as is received. Thus, any factor that modifies the balance of the energy exchange with space induces an alteration of the climate.

Because the Earth is spherical, a solar beam striking the Earth's surface spans a larger area with increasing distance from the equator. Thus the amount of heat received per unit area decreases from the equator to the poles. The climate system redistributes this heat at the globe's surface, reducing the latitudinal contrast. This is achieved by the two fluids surrounding the globe: the atmosphere and the ocean.

The water cycle plays an important part in this redistribution thanks to the distinctive features of water, which occurs in its 3 physical phases in our environment: solid, liquid and vapor. A transition between phases either consumes a great deal of heat (melting, evaporation) or releases the same amount of heat (freezing, condensation).

An imbalance in the globe's energy budget and the resulting change in the climate can be due to a variation of 1) the intensity of the incident sunlight (the atmosphere is largely transparent to sunlight) 2) the Earth's reflectivity for solar radiation, 3) the atmosphere's transparency to infrared radiation.

The climate can also be impacted by fluctuations within the climate system, related to the coupling of the atmosphere's and the ocean's intrinsic motion. Such fluctuations are limited to a more or less extensive region of the globe. Studies of the climates over the last million years show that the climate system sometimes experiences shifts in which the temperature rises rapidly in one hemisphere while it decreases in the other. This type of phenomenon is associated to changes in the ocean circulation. These specific climate fluctuations, however, have a limited impact on the mean global temperature both in duration and in amplitude. Indeed, a powerful El Niño may increase, for a year or so, the globe's mean surface temperature by 0.1 - 0.2 degrees Celsius.

Because meteorological variations are large (the weather changes a lot from day to day, from year to year), climate evolution can be evaluated only while considering trends over long time periods, typically 3 decades.

Since the 1970s, observations have shown that the globe's mean surface temperature is increasing. A lot of information circulates on this matter; it is often contradictory making it difficult for the layperson to evaluate the credibility of the information. In what follows, we detail some of the specifics that make a statement plausible or, on the contrary, should lead to questioning or even rejecting it. We also discuss a set of theories that are incompatible with the physics of the climate system. Finally, we will see to what extent those who play down the impact of global warming really consider the facts.

Some Do's and Don'ts for the Presentation of Data

Time-Related Coverage

Because of the intrinsic fluctuations of the climate and because of meteorological variability, it is important to consider time periods that are not too short. Well distributed meteorological observations covering a large portion of the globe date from 1880. A pronounced warming has been observed from the 1970s on. Over time, measurements have become more numerous and precise. If a document displays a set of data that does not cover the entire time period during which the data are available, one should always wonder why not. Indeed, oftentimes, to put forward a biased view, some authors choose to show a limited subset of a temporal series in order to mask a trend that would have been manifest had they shown the data over a longer time period. Showing a limited time coverage can be justified, however, if the data presented are taken in full from a duly referenced scientific publication; and provided that the publication cited has not been contradicted by a more recent one.

Spatial Coverage

A phenomenon can be considered global only if it impacts the different regions of the globe simultaneously. Nevertheless, a phenomenon may have very different intensities from one place to another. Indeed, the latitude, the position of the continents, the presence of mountains, the wind patterns, the ocean circulation,... all these factors condition the way in which an evolution is distributed on the globe's surface. The observation of the same phenomenon in various locations on the globe allows it to be qualified as global only if these observations are concurrent. Satellite observations, when available, contribute valuable information towards the evaluation of a phenomenon's global character.

Yet, a phenomenon may display disconcerting effects, or even contradictory aspects. For example, the Gulf Stream slow down due to global warming may induce North Atlantic cooling that will locally counterbalance the general warming trend. Thus, some local anomalies in the global climate evolution are, in fact, consequences of the said evolution. In such cases the local anomaly can be traced to known physical processes linked to the global evolution.

What Data

A climate trend can be identified only over a long time period. Meteorology fluctuates, the weather changes considerably from day to day, week to week, month to month, year to year. Plotting the monthly mean global temperature yields a strongly fluctuating curve (gray curve in Figure 1), with month to month variations that largely exceed inter-annual variations as well as the general trend. In order to dampen the meteorological noise, average values are used. The annual mean (blue curve) is still pretty noisy. Because of this, most authors active in climate science prefer a 5 year running mean that yields a much smoother curve (red curve). Finally, to remove the modulation due to the solar activity cycle (11 years), some use an 11 year running mean (black curve).

Climate models must be capable of reproducing the chaotic character of climate physics and, as a consequence, the amplitude of the monthly or annual variations; these variations, though, have obviously no reason to be synchronous with those of the observed climate. Thus, when comparing climate model results to observations, either the chaotic fluctuations have to be smoothed out thanks to appropriate time averages, or the fluctuations must be taken into account when evaluating model to observation discrepancies.

A comparison of observations to the findings from a climate evolution model will make much more sense if it is done on filtered data where the rapid weather fluctuations and the fluctuations due to the solar cycle have been smoothed out. Of course, a (dissenting) model that claims to reproduce observations would very easily fit in with the gray zone in the figure while it would poorly approach the black curve.

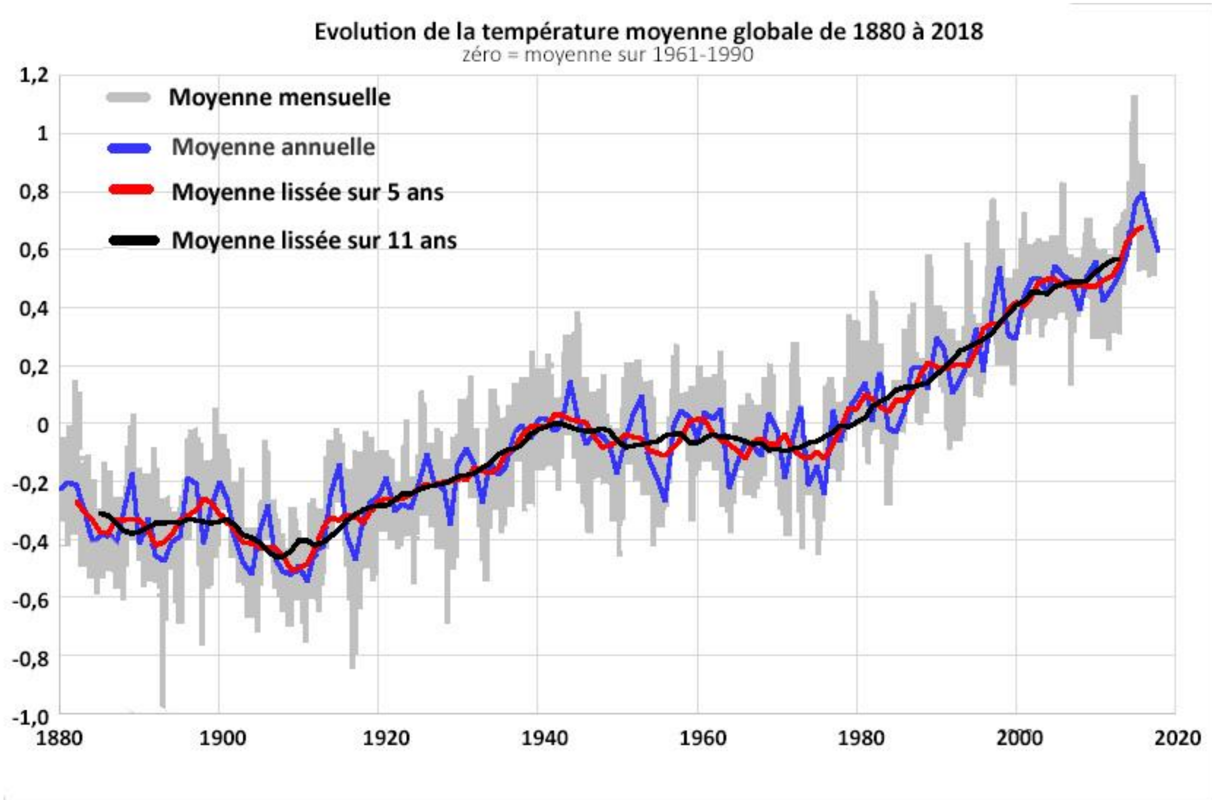

Figure 1: Time evolution of the mean global temperature (HADCRUT4 data https://crudata.uea.ac.uk/cru/data/temperature/). Gray curve, monthly mean; blue curve, 12 month mean; red curve, 5 year running mean; black curve, 11 year running mean. The ordinate scale shows the difference relative to the 1961-1990 mean (temperature anomaly).

Correlations

Some authors present a correlation between an environmental parameter and a parameter linked to the climate or to meteorological conditions as a proof of the influence of said environmental parameter on the climate. One must not forget that correlations are never, on their own, the proof of a causal link. A large number of examples can be found of purely accidental coincidences. See, for example, Jean-Pierre Delahaye's paper in *Pour la Science* N° 481, November 2017 issue; some of the curves in this article are shown in Figure 2. A causal link is plausible only if the process by which the cause can produce precisely the effect considered can be stated and quantitatively validated.

Figure 2: Correlations do not necessarily imply a causal link. The examples (all from the US) in this figure are a good illustration of this.

Data Sources

Whenever data or figures are put forward in science, their origin must be referenced. With this information, the reader, or the publisher, can refer to the original data to find out more as well as evaluate the associated uncertainties. Although citing one's sources does not guarantee authenticity (the reference is sometimes wrong or the data can have been manipulated or truncated for the presentation) the absence of source referencing should induce caution.

Theories that Disregard the Physical Processes Involved

Some individuals, possibly in good faith, claim that they can show that humans are not responsible for the recent changes in the climate. To this end, they elaborate theories and engage in calculations that they believe convincing. Yet, their misconceptions of the phenomena involved in climate dynamics lead them to elaborate theories that do not apply to the reality of the climate system. We give some examples below.

The Atmosphere Acting As a Window Pane

A number of calculations rest on the implicit hypothesis that the atmosphere behaves like a window pane, i.e. like a thin sheet transparent to sunlight. The thermal radiation from Earth to outer space is presumed emitted by the earth's surface. If one supposes that the "window pane" is opaque to this type of radiation, then the radiation is absorbed and none of it escapes to outer space.

This hypothesis is implicit in arguments that claim that as almost everything is absorbed within the first few meters of the atmosphere, a doubling of the CO_2 concentration cannot significantly increase the absorption: it is already nearly complete. The same implicit hypothesis underlies the arguments according to which CO_2 plays practically no role because the radiation is already stopped by water vapor, the main natural greenhouse gas, and much more abundant than CO_2 in the atmosphere.

In truth, such arguments break the energy conservation principle. They disregard one of the laws of infrared radiation emission, Kirchhoff's law of thermal radiation: any material body capable of absorbing a radiation is, itself, a radiation emitter, at the same wavelengths. Thus, if CO_2 or water vapor absorb infrared radiation, they also emit radiation, in the same wavelength range. The radiation that escapes Earth, then, will be emitted essentially by the atmosphere, and not by the earth's surface. It will escape from the atmosphere when the amount of absorbing gas above the emission point is not sufficient to absorb the radiation. When the greenhouse gas concentration increases, the altitude where the radiation emitted can escape the atmosphere increases. Since the temperature decreases with the elevation in the troposphere, the intensity of the radiation emitted at the altitude such that it can escape from the atmosphere decreases, as long as the climate has not adapted: the intensity of the radiation emitted varies as the 4th power of the absolute temperature. The energy carried off by the radiation is thus smaller than that brought in by the sun. Heat accumulation ensues and, as a result, a warming of the atmosphere. This, in turn, increases the intensity of the escaping radiation and a new state of equilibrium is reached where the energy input from the incoming solar radiation is balanced by an outgoing infrared radiation that has increased thanks to the temperature increase. This is illustrated in Figure 3.

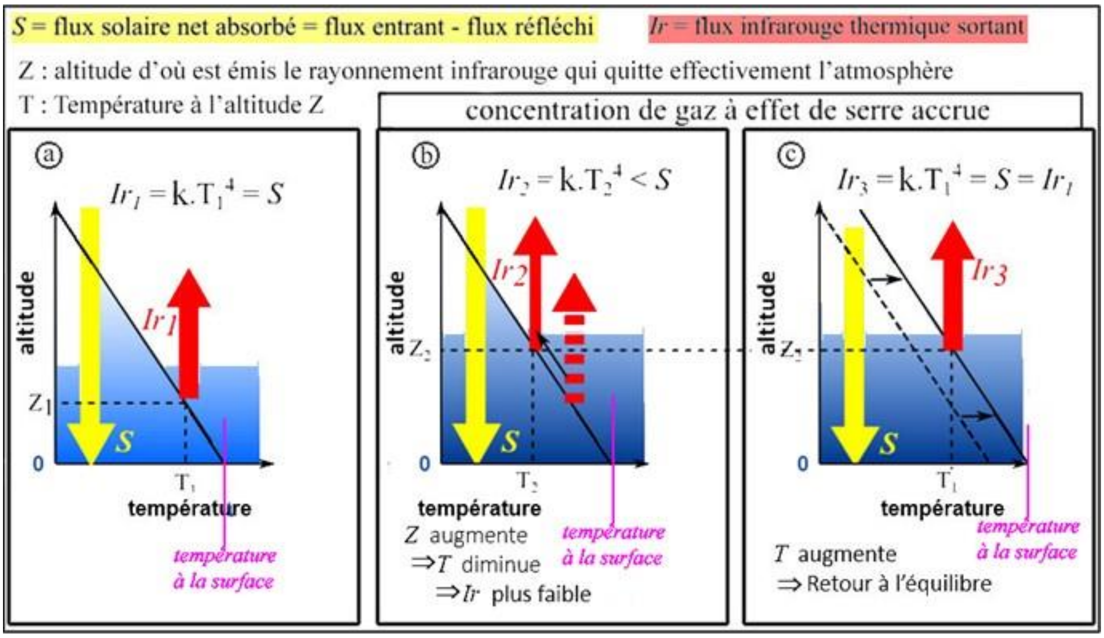

Figure 3: Increased greenhouse gas concentration in the atmosphere causes a temperature increase. In figure a, the system is in its initial state, where the outgoing energy balances the incoming energy. The oblique line sketches the temperature's vertical profile in the troposphere; its slope is determined by thermodynamics. With increased greenhouse gas concentration (figure b), the infrared radiation that can escape the atmosphere no longer removes enough energy. The atmosphere's temperature has to increase before the system can reach a new equilibrium (figure c) and, since the slope of the vertical temperature profile does not change, the surface temperature increases concurrently. A more detailed explanation is given in a paper by Jean-Louis Dufresne and Jacques Treiner published in "La Météorologie" February 2011 issue.

CO_2 is distributed uniformly in the atmosphere. On the contrary, when the temperature decreases, the air's ability to contain water vapor that does not condense decreases significantly. Thus, the water vapor concentration in the air decreases with increasing altitude. While concentrations of a few percent are possible close to the globe's surface, they are necessarily smaller at altitudes of a few kilometers, where the processes that control the Earth's radiated energy balance occur. Thus, water vapor plays a minor role as compared to CO_2 in the current evolution of the climate.

Atmospheric CO_2

Without the perturbations introduced by humans, the atmosphere exchanges considerable amounts of CO_2 with the environment, the total exchange being balanced. About 250 billion metric tons are emitted and absorbed each year in the course of exchanges between the atmosphere and the oceans. In addition, roughly 420 billion metric tons are emitted and absorbed by the continents (vegetation). These two global annual exchanges are balanced: for each molecule emitted, a molecule is absorbed.

Isotopic Composition

Carbon in nature occurs as three different isotopic species (the atomic nucleus contains 6 protons but the number of neutrons differs). Almost 99% of natural carbon is carbon 12 (6 neutrons), another 1% is carbon 13 (7 neutrons) and the rest, in very small traces (10^{-12}), is carbon 14 (8 neutrons). The latter is produced by nuclear reactions between cosmic radiation and nitrogen in the atmosphere. Carbon 14 is radioactive, its half-life is 5730 years (it takes 5730 years for half of the carbon 14 atoms to disintegrate back to nitrogen

14). Since the carbon in fossil fuels has not interacted with the atmosphere for hundreds of million years, they obviously no longer contain any carbon 14. In addition, these fuels contain little carbon 13 owing to their biological origin (carbon assimilation in biological reactions favors carbon 12 which, being lighter, is more mobile). Thus measuring isotopic proportions provides a means to monitor the effects of coal, oil and gas combustion on the atmosphere's carbon composition. The abnormally low carbon 14 and carbon 13 concentrations observed in the 1950s were evidence that fossil fuels are at the origin of part of the carbon in the atmosphere.

The average time a CO_2 molecule spends in the atmosphere can be estimated by monitoring the isotopic composition of the atmosphere. This time is found to be short: a few years only. Climatologists estimate that the disturbance of the CO_2 concentration in our atmosphere lasts several centuries. Arguing that a CO_2 molecule's residence in the atmosphere is short, some conclude that man cannot contribute significantly to increasing the CO_2 concentration in the atmosphere. But this line of reasoning ignores the carbon exchanges with the environment and their importance in the relative concentration of the different carbon isotopes. The dynamics that control the fate of a molecule do not determine the dynamics that describe large systems. For example in a closed enclosure containing liquid water and water vapor and at constant temperature, the volumes and the masses of liquid water and of water vapor remain constant while water molecules are constantly crossing the surface, traveling from one medium to the other. Back to CO_2; in the course of a year, the CO_2 that the ocean and the vegetation exchange with the atmosphere represents more than ten times the amount injected in the atmosphere by humanity over the same period. This means that carbon with a given isotopic composition is replaced in the atmosphere by carbon with a different isotopic composition initially stored in the oceans or plants. Thus, the isotopic composition of carbon in the atmosphere is definitely not the correct parameter to determine the lifetime of the carbon that resides in it: it provides an estimation of the time of residence of a CO_2 molecule in the atmosphere but not the characteristic time of a global disturbance of the composition linked to the human-made CO_2 emissions that accumulate over the years.

Origin of Atmospheric Carbon

Some authors contend that the carbon that accumulates in the atmosphere is emitted by the ocean as a result of the global warming that marks the end of the Little Ice Age in the middle of the 19th century. This statement is contradicted by fact: the amount of CO_2 dissolved in sea water is constantly increasing and this results in increasing acidification (decreasing pH) of the oceans. Rising levels of dissolved CO_2 imply absorption, not emission, by the ocean.

Furthermore, the balance of carbon in the atmosphere shows that its annual increase is about half of the man-made emissions. These can be determined with a precision of about 10% since we know the amounts of fossil fuels extracted and subsequently burned. The half of our emissions that does not remain in the atmosphere is absorbed in the environment (oceans and continents); a proof that the environment is not at the origin of the CO_2 that accumulates in the atmosphere.

Naive Assertions

Current CO_2 Concentrations

Some claim that the small amount of CO_2 present in the atmosphere cannot have an impact on the climate. This reasoning, which does not rest on theory, ignores a number of truths. First, the amount of CO_2 (0.04%) is not negligible: if, instead of being mixed together, the different gases were to separate and stratify according to their density, the CO_2 would form a 3.20 meter thick layer all around the globe. Plus, a very small concentration is not a proof of insignificant effect. Indeed, hormones in our bodies have concentrations 1000 times smaller than that of CO_2 in the atmosphere, yet they play an essential role in keeping us in good health.

CO_2 Concentrations in the Past

In the past, the Earth has had much larger CO_2 concentrations than today, without their inducing warming. Yet, what we mean by past has to be clarified as well as exactly what happened then. The past, can be the years before precise CO_2 measurements were done at a distance from pollution sources; these were initiated by Keeling in 1958. It can also be the Earth's past geological eras.

Regarding the various measurements done prior to 1958, the results present considerable variations over very short times; these cannot characterize the Earth's atmosphere as a whole. Indeed, no process can, at the global scale, absorb enough CO_2 in a very short time to cause a shift from a large measured value to a small value measured a bit later. In fact, in these cases, the measurements were done near the laboratories so that they reflected the amount of CO_2 that had just been emitted locally by the factories, by heat generated for buildings, by traffic. It is precisely in order to be free from the fluctuating disturbances due to human activity that Keeling came up with the idea of installing the measuring stations far from these disturbances, on an island in the middle of the Pacific.

Regarding the geological eras, the general conditions were quite different from what they are now. One needs only recall that the sun's activity increases with its age (7% increase per billion years) so that, a few hundred million years ago, the CO_2 concentration would have had to be much larger than today to reach the same temperature on the globe's surface.

CO_2 Emissions and Climate Variations

The Earth's climate has met with considerable variations. Think, for example, of the glaciations the Earth has experienced during the last 3 million years. We have pretty precise knowledge about the last hundreds of thousands of years thanks to an analysis of ice cores taken from the Antarctic and Greenland. In some instances, the temperature variation seems to have occurred before the atmospheric CO_2 concentration changed. If such is indeed the case in the event of cooling, whose cause lies in the astronomical parameters of the Earth's orbit, it is untrue at least for some of the warming episodes. Nevertheless, some authors deduce from the instances when the initial warming is thought to have preceded the rise of CO_2 concentration in the atmosphere that it is not CO_2 that impacts the climate but the opposite. Is it so extraordinary for two phenomena to be the potential cause of each other, depending on the circumstances? Think of an induction motor which, if it receives an electric current starts rotating and, if it is rotated by an external force, produces electric energy. Note, in addition, that if the greenhouse effect is not the process that triggers a glaciation, its reduction because of decreasing atmospheric CO_2 and water vapor concentrations did have a fundamental role in giving the amplitude that we observe to the cooling.

Some mention past climate variations where the CO_2 does not have a leading effect, such as the optimum (a warm period) 8000 years ago. It so happens that we know that this optimum is due to the particular orbital configuration of the Earth relative to the sun, a situation that sets in over thousands of years, not tens of years like the variations that human activity is currently producing.

Others mention geographically limited observations where regional warming in one place was counter-balanced by cooling in other areas.

Misinterpreted Satellite Data

Satellites are widely used to acquire meteorological and climate data and to monitor their evolution. The instruments aboard satellites provide valuable information, particularly because a single instrument can provide practically daily global coverage. With several instruments aboard a given satellite various parameters can be observed simultaneously. However, there are limits that some users of these data are not aware of or choose to ignore. In recent years, climate change deniers have put forward the atmospheric temperature as reconstructed from the infrared and microwave radiation intensity emitted by the medium. A major limitation is that the temperature thus obtained corresponds to that of a thick and poorly defined layer of the atmosphere. Its connection with the surface temperature is not direct and can vary with time. In addition, the calibration of the onboard instruments is tricky and a source of uncertainties. Climate change deniers put forward these temperature indexes without mentioning their limitations and, more important, without stating that they are not direct representations of the surface temperature which is the parameter of interest: we live on the surface, not 5 km above sea level.

Experts Without Expertise

The controversy on the impact of man on the climate in contradiction with the conclusions of the IPCC is seldom due to climatologists. To be sure, there are a few (John Cristy, Judith Curry, Richard Lindzen) who participate in it. But what theory does not have its critics within the community of specialists? The theory of evolution, general relativity, quantum mechanics all have had their opponents and a few remain, although general relativity and quantum mechanics are at work everywhere in our daily life (without them, our computers or the GPS would not work).

Among scientists, the large majority of those who dispute contemporary man's influence on the climate belong to other disciplines. These scientists, then, have only a limited knowledge of the processes at play. They are among the proponents of the false theories mentioned above. Some, in order to make their point of view more credible, claim to be climate experts: IPCC experts contributing to the preparation of the reports that this organization publishes regularly.

But who are the IPCC experts? The IPCC reports are prepared in several stages. First, scientists chosen for their expertise in the discipline as attested by their publications in reference journals, are selected as authors of the report. They draw up a first draft which is then submitted to an as large as possible panel of "experts" who review the report, making observations, comments, proposing changes as they see fit. At this stage, any scientist can be approved as an expert and can thus submit a point of view. Thence the ambiguity of this notion of expert on which some play in order to confuse the public. To become an expert, one needs only volunteer explicitly and prove one's scientific competence. Although the large majority of experts are indeed experts in the field, scientists whose skills lie in fields other than climate science are also accepted as reviewing experts. Indeed, it appeared wise to open the review panel to an as wide as possible range of expertise, including outlooks external to the domain itself, so as to guarantee that the reports would be relevant. The authors are under the obligation to examine all the remarks received whatever their origin. If they do not consider a remark relevant, they must explicit their reasons for rejecting it. The draft is subsequently modified to include the expert opinions that have been validated. The second version is submitted to a new panel of experts who can have, or not, participated in the first panel.

What should we think, then of those who, having simply read a report and made comments on it, publicly claim to be "experts with the IPCC"? Only that they are making use of a certification label that is easily acquired within the community so as to play on terms and fool others into believing that they have climate science competence.

The Consequences of Global Warming

Apart from the climate issues proper, we see controversies regarding the impacts of climate change on the environment and on man. In this case, it is not necessarily global warming itself nor that it is man made that is denied. By contrast, the consequences are represented as insignificant, even beneficial for the globe and for mankind. Some examples are given below.

Temperature

"After all, a three degree Celsius temperature increase is nothing more than having in Lille the current climate of Marseilles. It would be rather pleasant."

Unfortunately this sort of jesting assertion is tendentious in three ways:

- On one hand, global warming is not uniform on the surface of the globe; warming is more intense on the continents than in the oceans; and the warming is larger as the distance from the equator increases. This is what we are already seeing today. A mean 3°C warming of the Earth means at least a 5 degrees Celsius warming in Lille.
- The geographical environment of Lille is quite different from that of Marseilles. The city is not near a sea that mitigates the effects of heatwaves.
- Climate change is not limited to a mean temperature increase. The rainfall pattern is changed also. And, more important, extreme events (e.g. heavy rainfall, the intensity and the duration of heatwaves...) are more intense. It's not so much the mean conditions that have a strong impact on us but the extremes.

Some argue that humanity has already been exposed to significant warming episodes. From the maximum of the most recent Ice Age, 21 000 years ago, and the temperature optimum 8 000 years ago, the mean global temperature increased by 6 degrees Celsius. According to them, this occurred without dire consequences to humanity. This statement is hardly verifiable but let us assume it to be true. We should note that the temperature increase was ten times slower than the one we are now creating. Moreover, Earth was inhabited by a few million individuals, not billions as today. Individual and collective adjustments to environmental changes of the time could be managed calmly, without the major contentious issues that massive population displacements risk generating.

Finally, do not forget that earlier climate change episodes are not excluded as the cause of the extinction of some past civilizations.

The Far North will particularly suffer from global warming: all the infrastructures rest on frozen soil, soil that does not give. As it melts, this soil will totally loose its cohesion. Already now, infrastructures and homes are beginning to collapse.

Sea Level

As it warms, sea water expands. Mechanically, this causes the sea-level to rise. Moreover, the temperature increase is inducing massive land ice melt, whether ice sheets or mountain glaciers. This adds water to the oceans, contributing to the sea-level rise.

Many believe that a sea-level rise of a few ten centimeters in a century is not much: it would be "easy" to build dikes to protect ourselves as the Dutch did to protect their large coastal cities (Rotterdam and Amsterdam) which lie several meters below sea-level. However, the people who say that seem to be unaware of the fact that the sea is not like a flat bowl of quiet water. The world ocean system is exposed to winds and storms. It hosts sea currents. It's temperature is not the same everywhere. For these reasons, the sea-level varies from place to place. These level differences will be amplified by global warming which will also modify the sea currents. Thus, as shown in Figure 4, large geographical disparities are already being observed in the sea-level rise. While some regions are not strongly impacted, with an average sea-level rise amounting to 40 cm to 50 cm (the value currently anticipated by the end of the 21st century) other regions will be severely impacted.

Furthermore, while building and maintaining a dike is within reach for a small developed country such as the Netherlands, it is another matter for poorer countries with an increasing share of the population living along the coast.

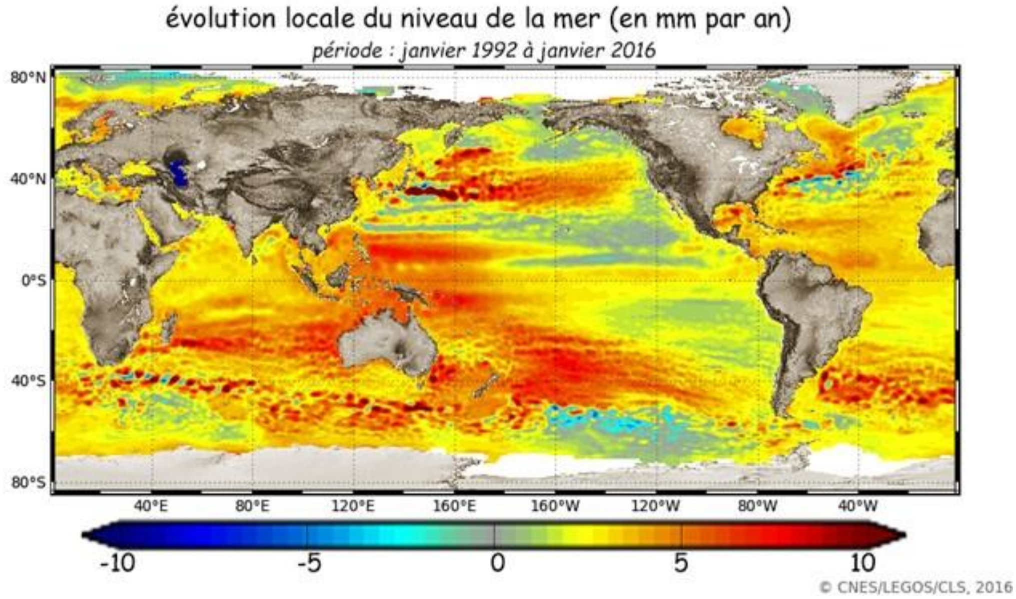

Figure 4: the sea-level is not rising uniformly. The rise is 10 times faster in some regions such as the Pacific Island countries than elsewhere.

Biodiversity

Plant and animal species each develop in environmental conditions (temperature, precipitation) that are favorable to them. When the local conditions change, the species that can migrate do so, in search of new suitable conditions while the other species die off. In theory, most animals are able to migrate as long as they do not encounter a natural (ocean, mountain range) or artificial obstacle (highway, urbanized area) that stops their progression. Remains for them the task of finding an appropriate ecosystem. It is not so with plants, in particular trees whose life-cycle is long. They cannot adjust to the increasingly rapid climate change.

Conclusion

As stated in the foreword, we do not, with this paper, present or discuss the claims put forward by climate change deniers, except in such cases where it is clearly a misconception of the subject that motivates the argumentation. A refutation of most of the arguments often requires a degree of knowledge of the climate system that the layperson does not possess as well as developments whose volume would have made this paper arduous reading. The Institut Pierre Simon Laplace has created an internet site that presents issues pertaining to global warming: "*Le climat en questions*" https://www.ipsl.fr/Pour-tous/Le-climat-en-questions. There, a reader can find answers accessible to a non-expert.

The climate system mechanisms are detailed in a book that is accessible to readers with poor mathematical knowledge (it contains no mathematical formulas) and includes many illustrations: "*Le Climat: la Terre et les hommes*" by Jean Poitou, Pascale Braconnot and Valérie Masson-Delmotte (EDP Sciences). It is available as a printed book or in electronic format (e-book).