

CLIMATE CHANGE – Issue 54 of the Bulletin “Rayonnement du CNRS”***Robert Kandel***

Issue 54 of this bulletin included English-language abstracts of the principal articles on some of the issues of climate change research. I did not however provide a translation of my introductory note on the scientifically established facts of climate change. Visitors to this website will find it here.

In France, many scientists, not only in the CNRS but also at Météo-France, INRA, CEA and other French and European agencies as well as in the universities are working on questions of climate and climate change in different disciplines involving observation, experimentation, theory, and numerical modeling. Their findings constitute major contributions –world top-level in some specialties – to climate science.

The articles in this issue deal essentially with climate change in the recent past and the near future. Let me explain. Earth’s history extends over more than four billion years during which the Sun, the Earth, its atmosphere, its climates and life have incessantly evolved, sometimes undergoing dramatic changes. Many research groups, in France and elsewhere on Earth, are engaged in the engrossing task of unraveling this long and multifaceted history. But this issue deals with a more limited time span. In their articles, Valérie Masson-Delmotte and Hervé Le Treut examine the “recent” past, a past that goes well beyond the several millenia of historians (or even pre-historians): essentially the past million years. In the same vein, for future climate change, our authors mainly consider the coming century, forgetting neither the next few decades nor the new millenium, but without going as far as the next Milankovitch cycle. Limiting the time horizon in this way simplifies the task of understanding evolution and variability of the climate system, although the problem remains extremely complex.

By *climate* we understand a summary of the physical conditions – temperatures, notably, but also freshwater availability – that determine the possibilities of life at the surface of the Earth. Climate depends on the Sun, but it depends equally on the Earth’s atmosphere, the thin gaseous envelope surrounding the globe. Over the last century at least, human activities have been altering the atmosphere of the entire planet. Since the 1970s, confirmation and quantification of the discovery of this alteration have made more and more pressing the question of the risk of anthropogenic climate change and its implications for the global economy and geopolitics. This led to the creation in 1988 of the Intergovernmental Panel on Climate Change (IPCC, GIEC in French), whose mode of operation is described in the articles by Hervé Le Treut and Michel Petit. Growing attacks against IPCC and the semi-failure of the Copenhagen Conference in December 2009 were front-page news for several months. In *Le Monde* (22/12/2009) philosopher Michel Serres wrote: “They forgot to invite the Earth”. For me, the problem is rather that many political leaders – and many ordinary citizens too – tend to forget that they have to live on Earth, and that we have only one such livable planet at our disposal. Nature’s reactions to human activities can be inconvenient (to say the least), and once en route they cannot easily be prevented or reversed by political decisions – democratically decided or not. In any event, this Bulletin is not the place to try to follow day-to-day political news.

Let me recall some solidly established facts

1. Over past decades, human activities have involved increasing emissions to the atmosphere of gases composed of certain polyatomic molecules, in the first place carbon dioxide (CO_2) as shown in figure 1. As a result, the amount of carbon dioxide in the global atmosphere has increased significantly, well above the natural annual cycle. This appears clearly (fig. 2) in the measurements made systematically since the International Geophysical Year (1957) at the Mauna Loa (Hawaii) observing station, where composition of the air is close to a good average over Northern Hemisphere. The annual cycle reflects mostly the activity of vegetation on the continents in the North Temperate Zone. Plant photosynthesis removes some atmospheric CO_2 during the growing season, but returns it to the atmosphere the rest of the year when respiration dominates.

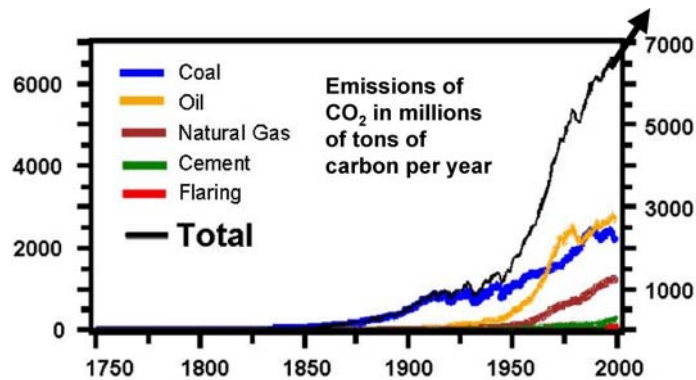


fig. 1 Growth of annual global CO_2 emissions to the atmosphere (expressed in millions of tons of carbon per year) due to combustion of coal, petroleum, and natural gas, to cement production, and to flaring.

Over the last few decades, atmospheric concentrations of CO_2 and of methane (CH_4) have risen to levels well above the range of natural variations of the last 740,000 years at least, as shown in figure 4 of the article by Valérie Masson-Delmotte. Figure 3 (here) shows CO_2 variations of the last 420,000 years, as revealed by the Vostok (Antarctica) ice core.

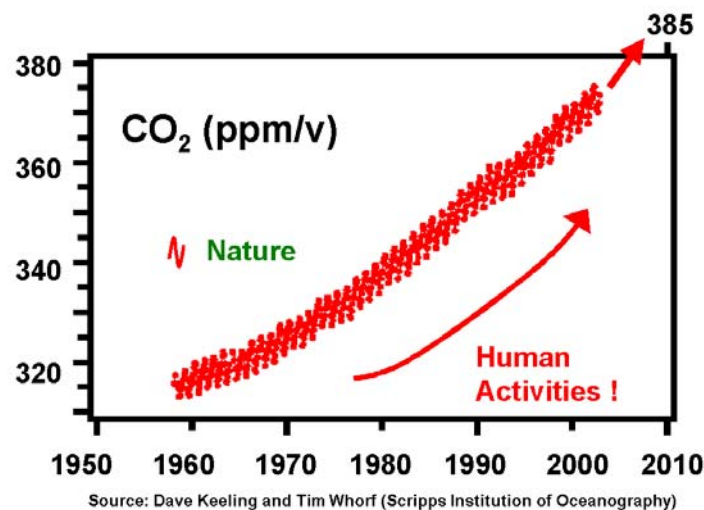


fig. 2 Atmospheric concentration of CO_2 (expressed in parts per million by volume, i.e. $\text{cm}^3 \text{CO}_2$ per m^3 of air) measured at the Mauna Loa station since 1957.

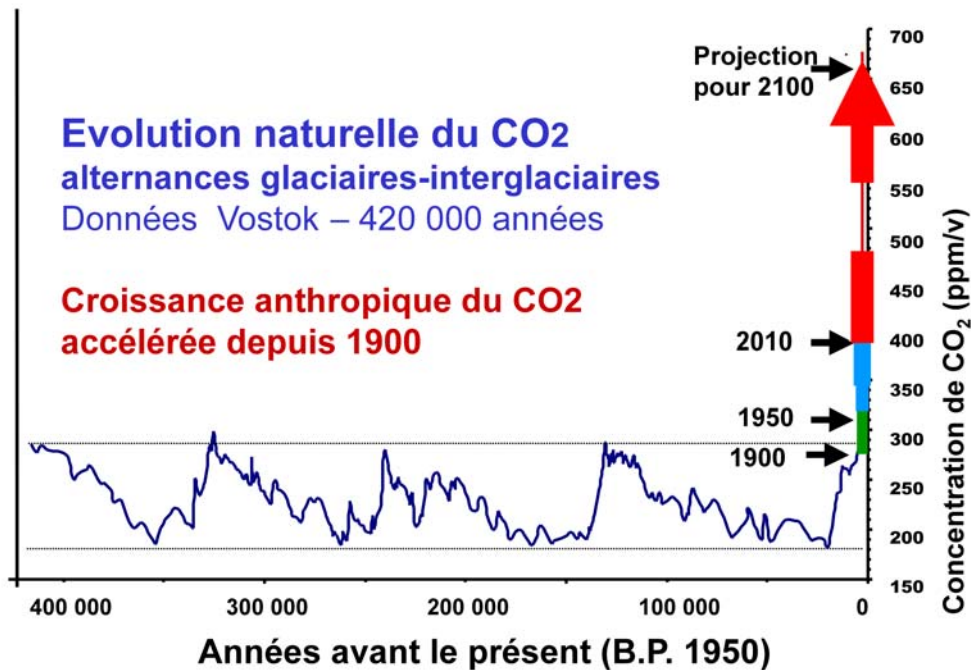


fig. 3 Atmospheric concentration of CO₂ over the past 420,000 years, determined from air bubbles trapped in the Vostok ice core. Since 1900, anthropogenic growth has taken atmospheric CO₂ to levels well above the natural glacial-interglacial cycle.

2. Reflection of the Sun's radiation depends largely on the properties of clouds and land surfaces (figs. 4 and 6). Clouds (collections of liquid water droplets and solid ice crystals suspended in the air) represent a minuscule fraction of the atmosphere's mass and of Earth's water. Absorption of Earth's thermal infrared radiation and its reemission to space (figs. 5 and 6) depend almost entirely on gases (H₂O and CO₂ in the first place) constituting only a tiny fraction of the atmosphere.

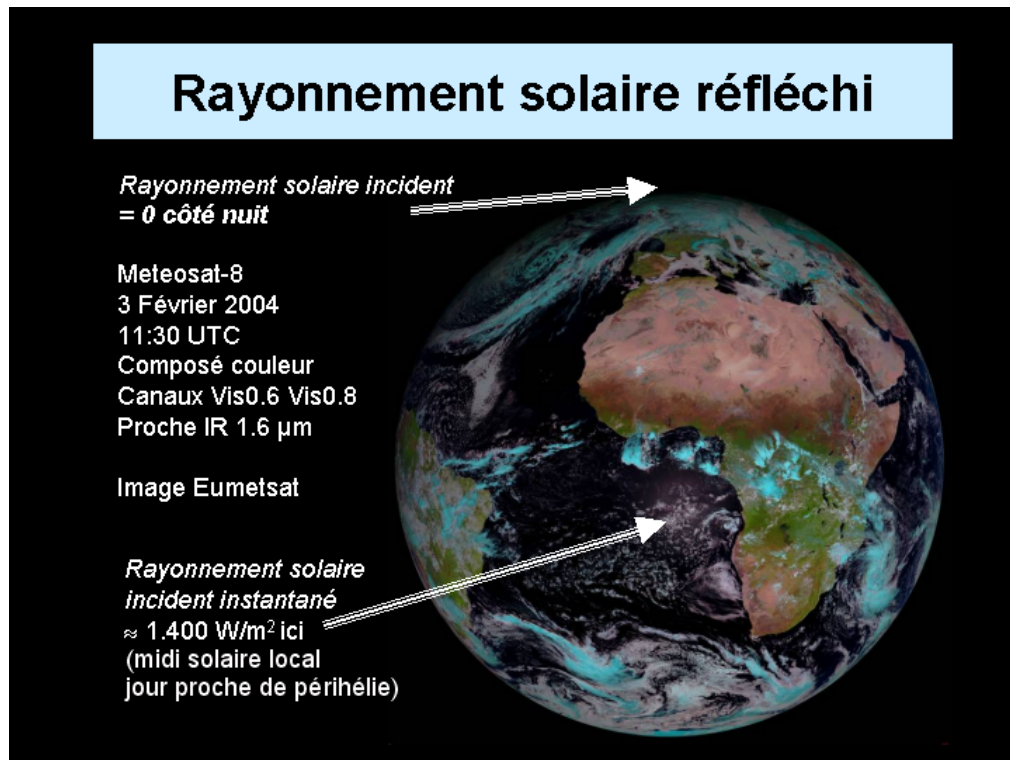


fig. 4 Reflected solar radiation at 11.30 UTC, 03/02/2004, i.e. in northern winter, Earth near perihelion. Incident solar radiation averaged over the surface of the globe (night/day, poles/equator) close to 350 watts per square meter on this date; 342 W/m^2 averaged over the year.

This physical effect, well known since Fourier, has by imperfect analogy been given the name of “greenhouse” effect. Gases added to the atmosphere by human agricultural, pastoral, and industrial activities reinforce trapping of infrared radiation in the lower atmosphere, warming the Earth’s surface (fig. 6). This perturbation of Earth system energy fluxes (“forcing” in physicists’ jargon) is already at least ten times stronger than forcing by the weak cyclical variation of total solar irradiance (fig. 7). Moreover this climate change forcing by anthropogenic intensification of the natural greenhouse effect will continue to grow until anthropogenic greenhouse gas emissions are cut by at least 50%.

Furthermore, forcing of climate warming by the additional greenhouse effect has – at least since the 1970s – grown stronger than the opposite forcing by fluctuating and increasing “parasol effect”, i.e. reinforcement of reflection of solar radiation (fig. 4). Such reinforcement (fig. 7), in the direction of cooling, has grown along with pollution by sulfur dioxide and particles, and also increases strongly but temporarily after volcanic eruptions (for example Krakatoa in 1883, Pinatubo in 1991).

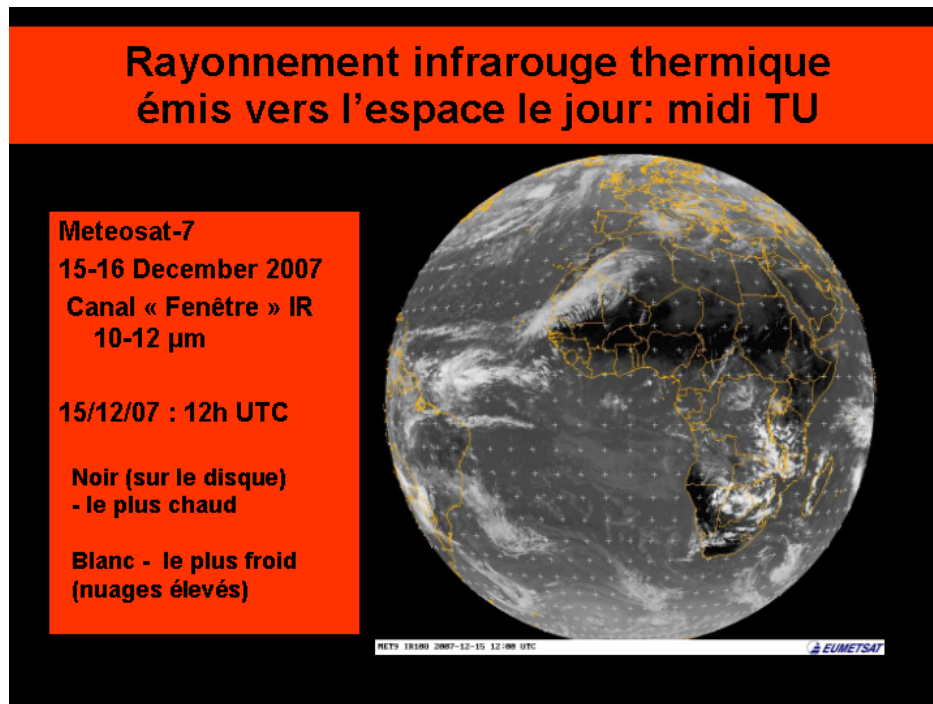


fig. 5a Thermal infrared radiation emitted to space – daytime – Meteosat image 12.00 UTC, 15/12/2007. The weakest signal, shown in white, comes from high clouds (cirrus, cumulonimbus). In cloud-free areas, the strongest signal (shown in black) comes mainly from warm land surfaces (especially the Sahara, Arabian and Namib deserts), which warm up much more during the day than the sea surface.

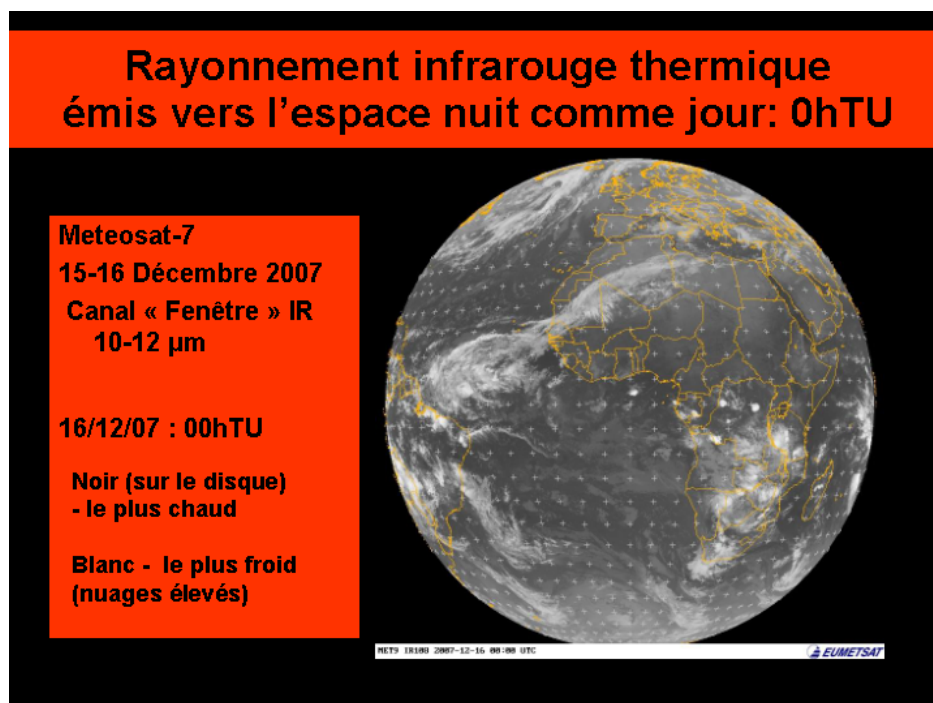


fig. 5b Thermal infrared radiation emitted to space – nighttime – Meteosat image 0.00 UTC. In cloud-free areas, the strongest signal comes mainly from the surface. The land-sea contrast reverses. At night, the sea surface remains warmer (see especially the Red Sea and the eastern Mediterranean) while land surfaces (note the Iberian peninsula, North Africa, Arabia) cool more rapidly.

Physical conditions in the atmosphere react nearly instantaneously to these forcings. On the contrary, for the ocean as for liquid water at and under the land surface, response times range from a few days (locally) to one or two millenia (globally); and even longer for water in the form of large solid water (ice) masses.

3. Since more than a hundred years, climate has warmed globally, but with geographical differences and with fluctuations forced by volcanic eruptions, by changing pollution patterns, perhaps also by solar variations (fig. 8).

Since the 1970s, global warming has accelerated. Some self-styled “skeptics” announce that warming has stopped. This is not so. On average over the globe, the 2000-2009 decade was the warmest (fig. 9) since meteorological measurements began. The measurements and statistics on which this conclusion is based come from many different weather services around the world. For the presently warming climate, as for climate changes over the next few decades, the relevant time scales are neither the 20,000- to 400,000-year (Milankovitch) variations of the orbit and rotation axis of the Earth... nor the calendar of government cabinet reshuffles!

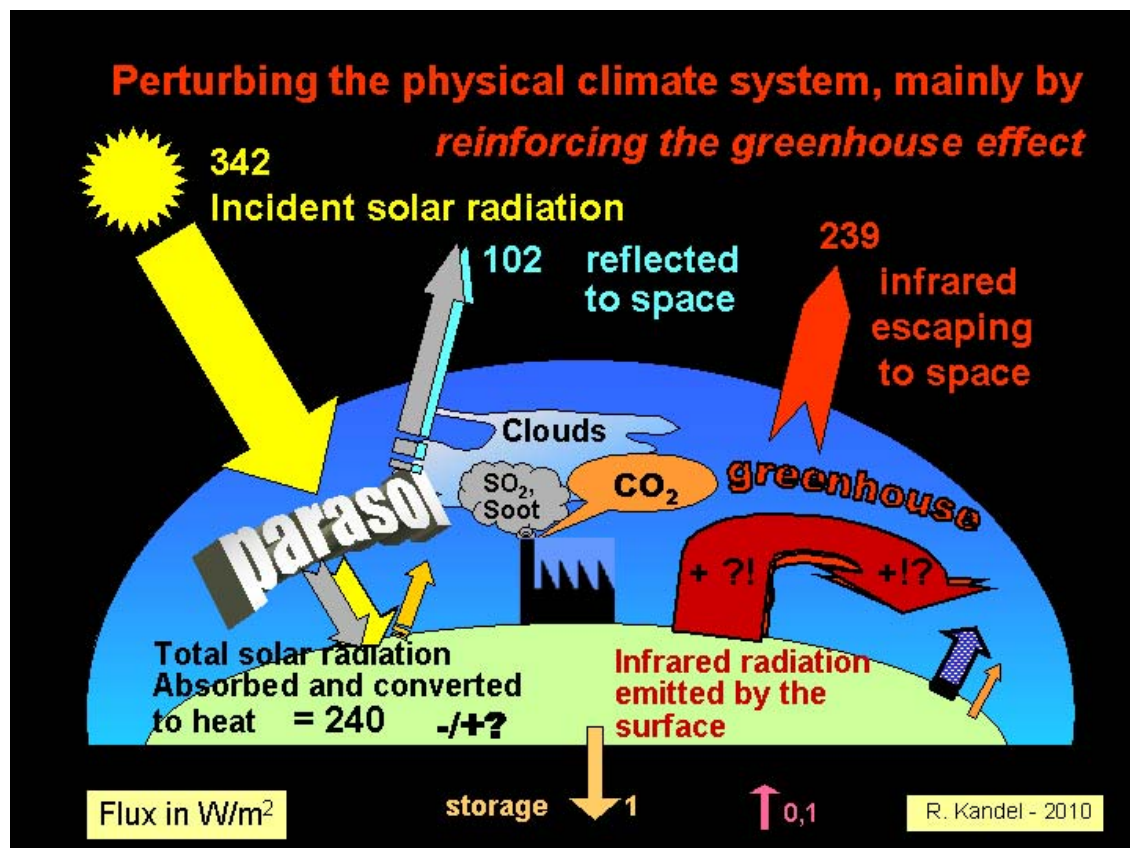


fig. 6 We perturb climate, especially by reinforcing the greenhouse effect. The arrows to the right correspond to heat fluxes from surface to atmosphere by evaporation and dry convection. And they too will change.

4. Of course many uncertainties remain, in particular with respect to the ways in which different types of cloud respond to changes in the physical state (temperature, humidity...) of the atmosphere. Such cloud *feedback* could be negative, limiting climate change, but it could

be positive, amplifying the warming. We do not yet know. Even more critical are the large uncertainties regarding geographical distribution and amplitude of changes in precipitation. Some “climate skeptics”, citing the very real problems of supplying clean drinking water to growing populations of poor countries, would have us assign low priority to the climate change problem. I note however that freshwater needs of agriculture – what might well be called “eating water”, are at least ten times greater than the need for drinking water. Climate change inevitably modifies the conditions governing the practice of agriculture. Although in France the impacts, as examined by Bernard Seguin, may not be dramatic, the problems of adaptation to the changing climate will be of a different order of magnitude in many poor parts of the world.

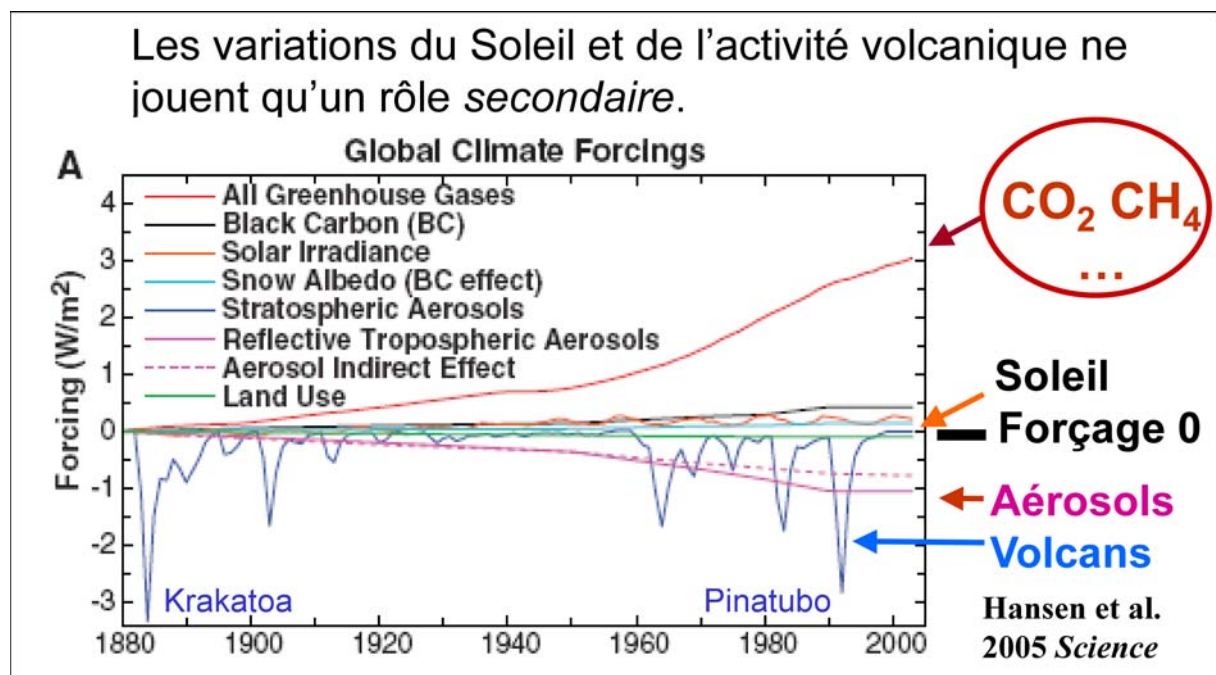


fig. 7 Evolution of global climate change forcing since 1880, after J. Hansen et al. (*Science*, 2005). Solar variations and volcanic activity play only a secondary role.

5. What about the Sun? Solar activity (sunspots, prominences, flares...), at times spectacular, certainly makes itself felt in Earth’s upper atmosphere, especially in the mesosphere and thermosphere, above 50 km altitude. How much can it affect climate?

Total solar irradiance (the number of watts sent to the planet) varies only by 0.1% with the sunspot cycle. Can there be a significant response in the troposphere (the theater of climate: atmospheric layers from the surface to altitudes of 10-15 km) to the very weak forcing linked to this solar activity? With no quantitative understanding of mechanisms which would give warming comparable to the response to the far greater greenhouse forcing, skepticism is warranted.

Réchauffement planétaire

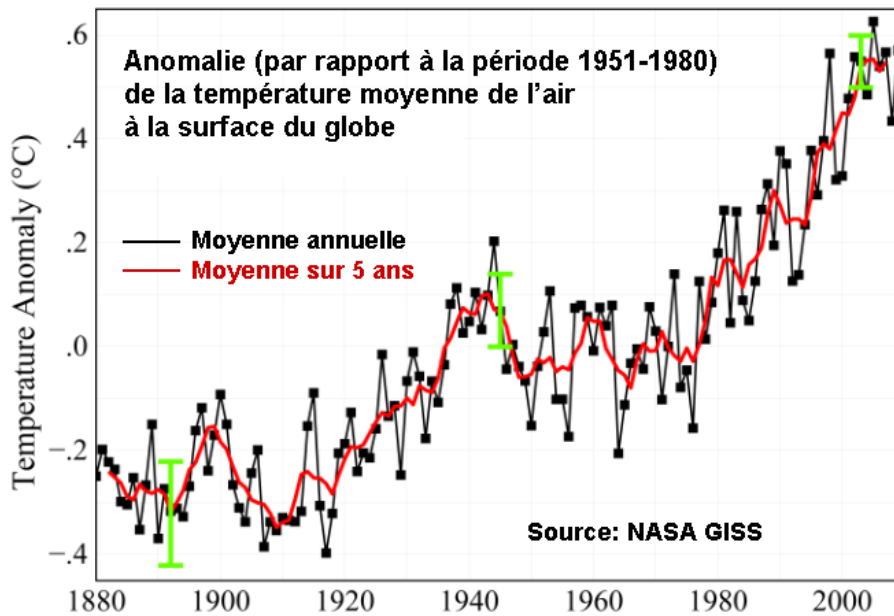


fig. 8 Global warming, decade-by-decade, since the 1880s. Source: UK MetOffice.

Similarly, skepticism is warranted regarding proposed “amplification factors” of such weak forcing, involving for example variations in ocean circulation. A significant problem remains. To what extent do interdecadal climate variations correspond to purely internal variations of the complex climate system, *not* forced by “external” factors? Can such *unforced* variations mask or exaggerate the response of the system to the growing anthropogenic forcing or to natural (volcanic, solar) forcing?

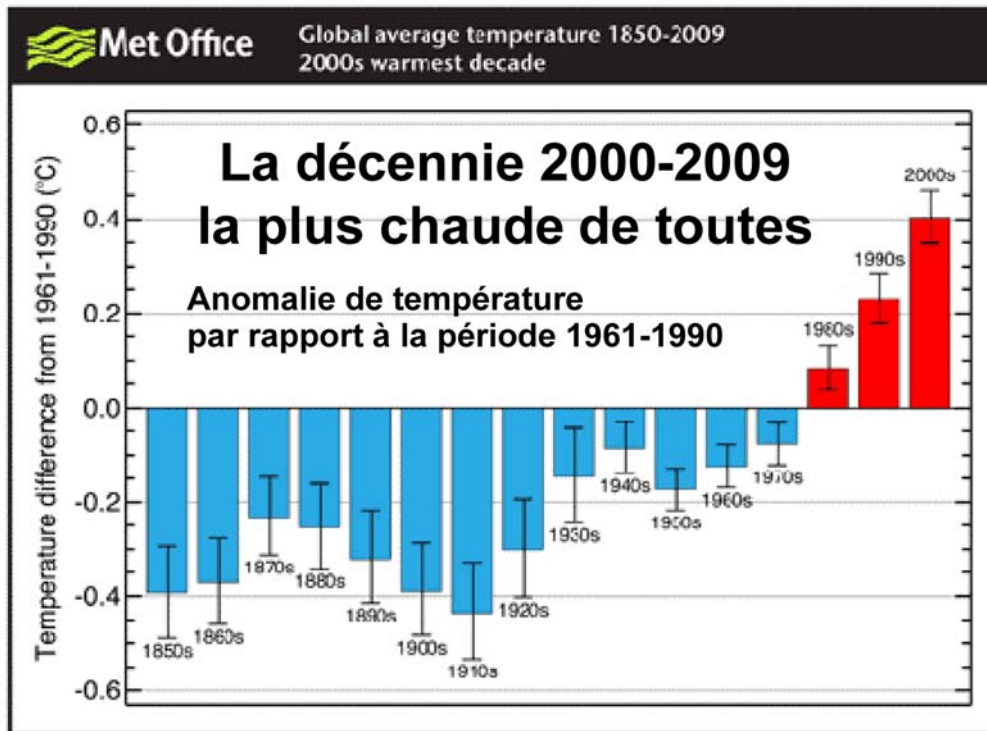


fig. 9 Global average temperature.

The research community has lots of work to do, to reduce uncertainties and to put more detail into projections of our future climate so as to provide a better basis for defining geopolitical and economic strategy. Strategy for what? Strategy for avoiding unacceptable climate futures, strategy for better preparing to adapt to inevitable climate changes.

Have a good read!

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Suggested Reading.

The general references suggested in issue 54 – *Dossier scientifique: le Changement climatique* - were mostly in French. Here are a few additional references, among the many available in English.

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