Chapter 2

What are the signs of current climate change?

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A flooded coconut plantation on the island of Loh in Vanuatu.
The rise in the water level is caused by both global warming and the sinking of the islands.

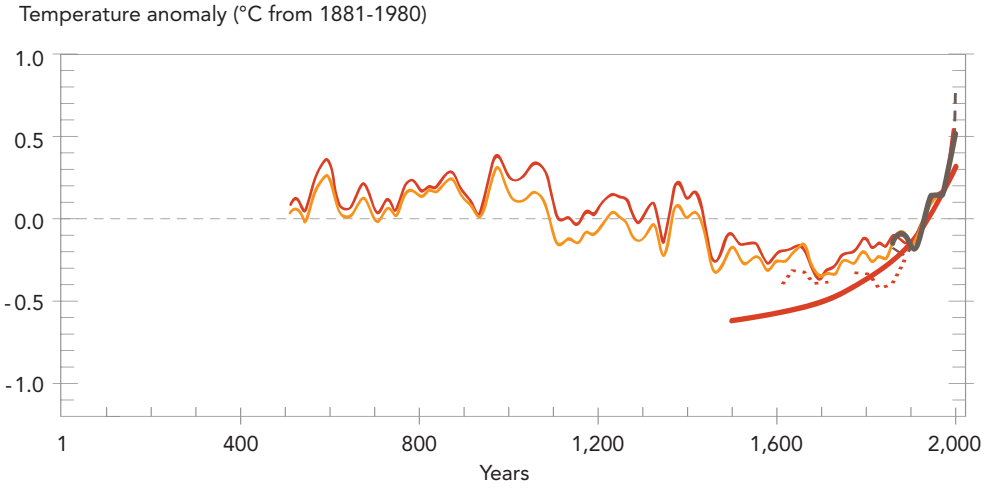
The main indicator of climate change is the unprecedented scale and speed of the increase in temperature at the surface of the globe. But there are others such as the retreat of ice, changes in the global water cycle and in certain climatic extremes, the warming of oceans and an increase in average sea level.

Surface warming

Reconstitutions of the climate over the last 2,000 years show periods of several decades in which temperatures were locally as high as they are today. However these warm periods were not in synchrony in the various parts of the world, which makes them different to the recent 'global' warming. The present rapidity of warming has not been observed previously (Fig. 2).

According to the IPCC's 2013 report, the average temperature at the surface of the globe —measured 2 metres above ground level—has increased by 0.85°C since 1880. This global average hides substantial variations according to the region (Fig. 3) and the time of year. For example, the temperature has increased by 1.5°C since the 1950s in the hot part of the Sahel.

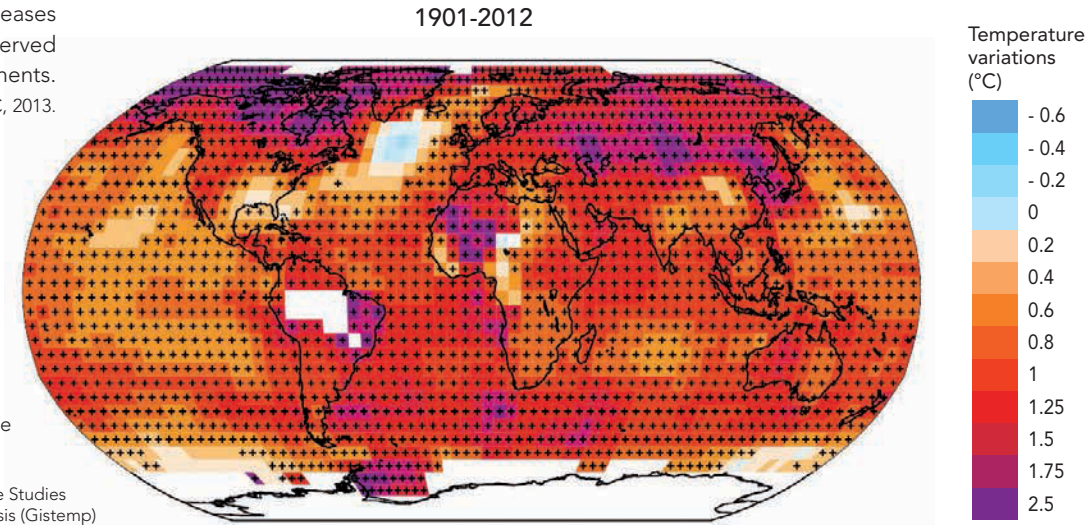
Figure 2.
Reconstitutions of the annual land and ocean temperatures during the last two thousand years. Since 1950, the temperature has increased more than its natural variability.
Source: IPCC, 2013.



In orange: land and ocean temperatures;
in red: land temperatures only;
in black: temperatures observed by instrument readings since 1860.

The anomalies are given in relation to the average (line 0.0) and smoothed to reduce fluctuations lasting for less than 50 years.

Figure 3.
The evolution of surface temperature observed from 1901 to 2012.
Temperature variations are unevenly distributed at the scale of the world as a whole.
The strongest increases are observed on the continents.
Source: IPCC, 2013.



The white zones indicate incomplete data.

Data source:
Goddard Institute for Space Studies Surface Temperature Analysis (Gistemp)

The retreat of the tropical glaciers

Melting of ice is another important marker of global climate change. Glaciers have retreated in practically all the regions of the world in recent decades. Those in tropical regions—with 99% of these being in the Andes—are among the most affected. Indeed, global warming is particularly marked at the elevation of these glaciers. Several IRD teams have shown the spectacular retreat of the Andean glaciers over the past 30 years, with a decrease in surface area of 30 to 50%. This research confirms the acceleration of climate change at the end of the twentieth century in this part of the world. A continued increase in temperatures combined with negative changes of the rainfall regime could result in the disappearance of most of these glaciers by the end of the century.

The Zongo glacier (6,090 m) on Huayna Potosi Mountain in Bolivia.
The length of the Zongo has decreased by over 800 m since 1940.

Box 3

The spectacular retreat of Andean glaciers over the past 30 years

The glaciers in the tropical Andes have retreated gradually since their maximum between the mid-seventeenth and mid-eighteenth centuries. But the decline has been on a spectacular scale during the last 30 years.

Using studies of the glacial moraines, IRD scientists and their international partners mapped and dated the past positions of glaciers throughout their retreat that started in the 1730s.
Aerial photographs and satellite images were also used to trace the changes in the areas of glaciers after 1950.
In parallel, the scientists modelled the response of the glaciers to present variations in temperature and precipitation to establish a relation between climatic conditions and the retreat of ice.
They thus reconstituted the fluctuations in climate that may have caused the variations in the glaciers observed.
The results show clearly the singularity of recent decades with the fastest ice melt for 300 years.
The areas of the glaciers in Colombia, Ecuador, Peru and Bolivia have decreased by 30 to 50% since the end of the 1970s and as much as 80 to 100% in the most extreme cases.

A single cause?

All the Andean glaciers respond to the same mechanisms of climatic variability.
Precipitation has changed little but the air temperature in the Andes has increased by 0.7°C as a result of the warming of the tropical Pacific since the 1970s.
The temperature is not directly responsible for melting at the altitude concerned but is caused above all by the balance between absorbed radiation and reflected radiation at the surface of the glacier.
However, temperature affects the nature of precipitation—solid or liquid—and hence the conditions for the maintaining or not of the snow layer that contributes to reflecting the greater part of the solar energy received.
Absence of snow considerably increases the melting of the glacier.
This situation of glaciers with no cover—in summer in the tropics or at the equinoxes on the equator—has tended to be more frequent in recent decades.

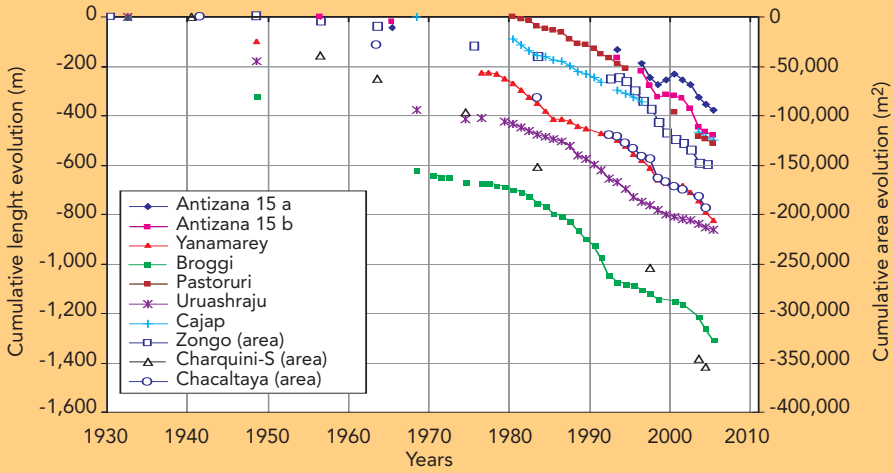


Figure 4.
The spectacular decrease in the areas of ten glaciers in the tropical Andes during the last 80 years.
Source: FRANCOU and VINCENT, 2007.

Precipitation and extreme climatic events

The rainfall regime has also changed in tropical zones in recent decades. However, it is very difficult to identify overall trends. Research in the Sahel is a good illustration of this complexity. The rainy period in the 1950s and 1960s was followed by a very dry period in the next three decades. Rainfall has practically recovered in the last 15 years. But this return of rains is not a return to the 1960s reference period, first of all because it concerns only part of the continental Sahel whereas precipitation is still decreasing in the west of the continent. And then the increase in rainfall in recent decades results above all from increasingly intense rainstorms. In fact, although storms have become more frequent they are still fewer than before the drought (p. 116).

Direct observations in South America show that the frequency of floods and severe droughts varies from one decade to the next, without any clear trend emerging at the regional scale. For example, the Paraná Plata region in the plains of Argentina has experienced an increase in the rainfall regime since the mid-1970s. The change has caused the formation of a lake with an area of several hundred square kilometres, flooding villages and cropped land.

The 'record floods' of the Amazon

Large rivers are also good indicators of climate change. For example, scientists have reconstituted the levels of the Amazon over a period of a century (HYBAM scientific observatory), showing the increase in extreme phenomena over the last 30 years or so, with an increase in the frequency of floods and historic low water levels and a gradual decrease in flow during the dry season. In recent years, exceptional Amazon floods in 2009 and 2012 successively increased the level of the 'record flood'.

Nevertheless, the series of reliable instrumental observations are only available from 1950 onwards, a period that is too short for the accurate identification of possible trends and the deduction of their causes. This uncertainty is even stronger for extreme

The Amazon River in flood in 2008. Brazil.

events that are exceptional by definition. There is thus no scientific consensus with regard to a higher frequency of cyclones for example. Indirect observations such as the study of lake sediments to describe floods, the analysis of speleothems, etc., are used as valuable sources of information that can broaden the temporal window of observations necessary for understanding recent climatic changes.

Warming of the oceans

The warming of sea water is another climate change marker. According to the fifth IPCC report, the temperature at the surface of the oceans has increased by +0.11°C per decade since 1970, that is to say +0.44°C in less than 40 years. The increase is unequally distributed. For example, recent research shows that the temperature of the eastern part of the tropical Atlantic has increased by more than 1°C since 1975. The surface water temperature of the tropical Pacific has increased by 0.3°C in the last 50 years.

The warm water of the tropical West Pacific generates intense interactions between sea and atmosphere. This immense quantity of warm water is the cradle of the El Nino and La Nina phenomena. Ecuador.

Box 4

The western tropical Pacific is warming

Researchers at the LEGOS unit and their partners have shown that the increase in temperature of the surface water of the tropical Pacific warmed by 0.3°C during the last 50 years. This is one of the first estimates drawn from *in situ* data in this part of the Pacific.

The area of the Pacific Warm Pool, an immense mass of warm water in the west of the tropical Pacific, is 15 million sq. km, 27 times the size of France.
LEGOS unit researchers and their partners have studied the evolution of the Warm Pool.
The water temperature increased by 0.3°C.
The area of water warmer than 29°C has doubled in half a century and zones where the water temperature is higher more than 30°C —rare 50 years ago— are now very widespread.

Furthermore, the average depth of the Warm Pool has increased by about 10 m and is about 100 metres today. The research work conducted thus shows that a much larger volume of heat is thus stored in the water.
In 50 years, the Warm Pool has also shifted east by about 2,000 km.

This work is one of the first estimates, using *in situ* data, of the increase in the temperature of the tropical Western Pacific.
To obtain these results, the research team assembled data and observations gathered over the last five decades by merchant ships, oceanographic campaigns, deep sea data and satellite measurements.

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Aerial view of Rédika islet in the southern lagoon of New Caledonia.
The phenomenon of thermal dilation of the sea caused by the warming of the water contributes to the rise in sea level, threatening certain low-lying Pacific islands.

The oceans store the greater part of the warming of the planet: the increase in the temperature of sea water forms 90% of the additional energy stored by the climate system for 40 years. However, in return the changes in this gigantic reservoir of energy will affect the climate. The circulation in the oceans and its contribution to the energy balance of the planet make it one of the main features of the climate machine. Ocean dynamics also interacts with atmospheric dynamics and this is responsible for the natural variability of the climate.

The oceans also have regulating power with regard to carbon through the storage of carbon dioxide (CO_2) present in the atmosphere. Approximately 30% of anthropic CO_2 emissions are thus absorbed by the seas. But the dissolution of CO_2 in sea water causes acidification of the latter (p. 93).

The rise in ocean levels

The rise in sea level is a well-established phenomenon. The average rise has been some 1.7 mm per year for a century. Paired data from satellites and *in situ* measurements show that this average increase is accelerating as the rise was 3.2 mm per year from 1993 to 2010. The rise is a phenomenon to be expected in view of the thermal dilatation of the sea and the melting of continental ice. But other factors are involved regionally, such as winds, air pressure, ocean currents, etc. The rise in sea level is also very uneven in different parts of the world (Fig. 5). For example, the tropical West Pacific displays a

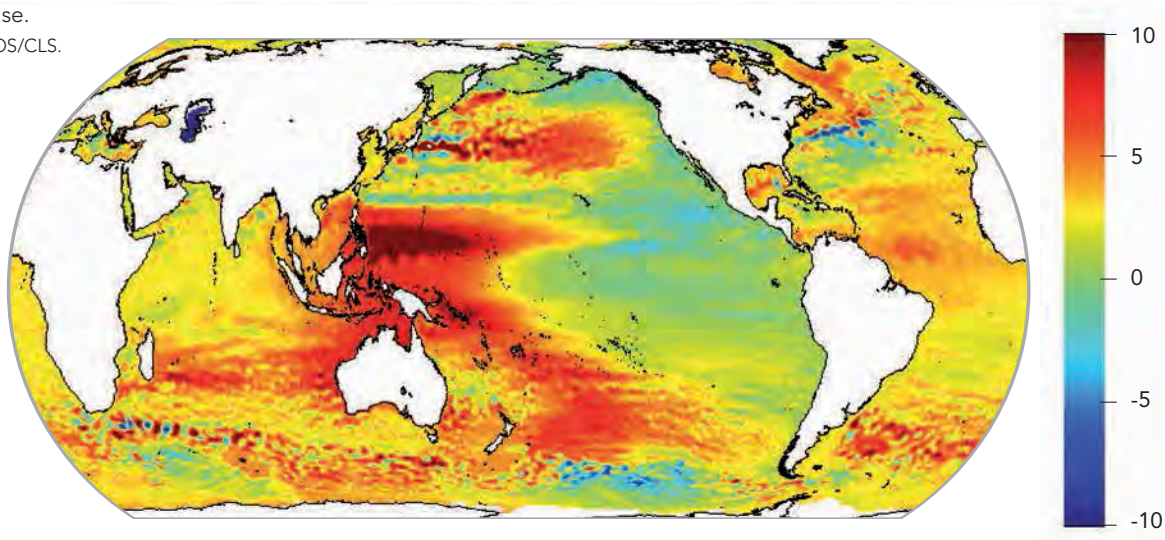

Figure 5.
Evolution of average sea level from 1993 to 2014.
The rise in the level of the West Pacific is distinctly greater than the overall rise.
Sources: CNES/LEGOS/CLS.

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Rising water level in the Tuamotu Archipelago in French Polynesia. With rising sea levels, atolls that often rise to 1 or 2 metres above sea level may disappear one day.

rise of about 10 mm per year—a much higher figure than the global average. In contrast, the rise is less than 3 mm per year in the tropical Eastern Pacific.

The rise in sea level is also variable in time. IRD scientists and their partners have reconstituted the variations in sea level in the tropical West Pacific since 1950. Their work shows that El Niño has a strong effect on the inter-annual variability in sea level in the tropical West Pacific and leads to variations of some 20 to 30 cm in comparison with the average.

As in the rest of the world, present climate trends in the tropics thus confirm the reality of climate change. The amplitude and acceleration of the heating of the air and seas, the rise in sea level and the retreat of glaciers are all proof of a break. However, other climate indicators are not as easy to fit into the main trends. The pattern of the rainfall regime and of extreme events such as cyclones is particularly difficult to describe because of the complexity of the water cycle and of convection phenomena in the tropics.

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