Chapter 1

Learning about tropical climates in the past

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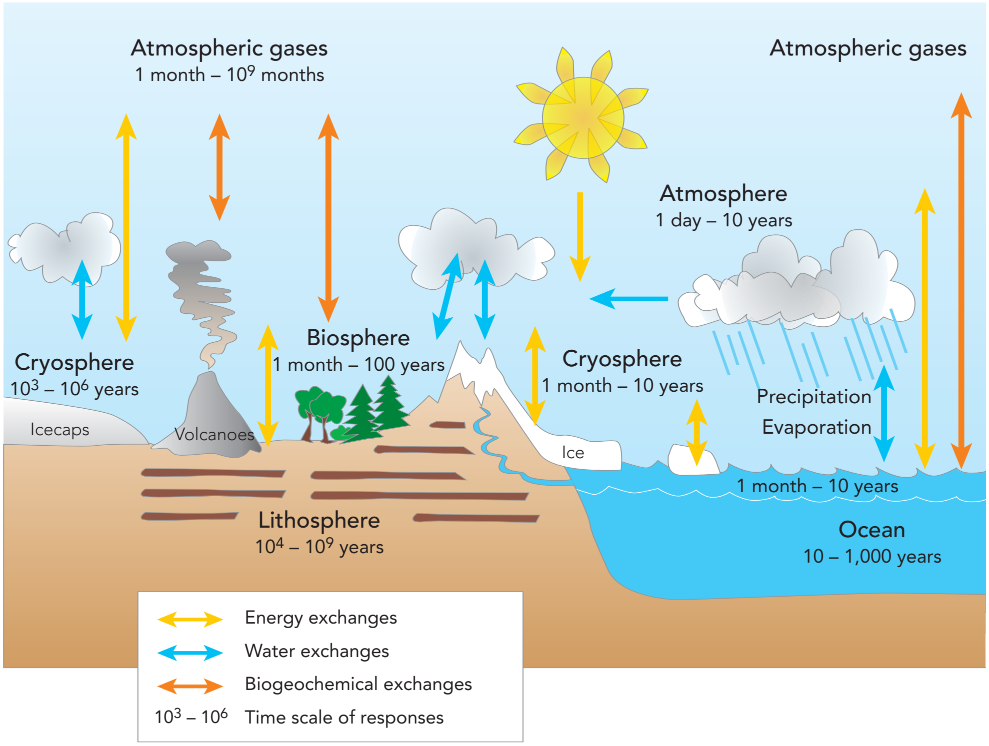
Drilling camp at the summit of Monte Valentin (3,900 m), Chile.
Glacier core drilling in the Andes provides access to more than 20,000 years of climate records.

Knowledge of past trends is essential for understanding the present climate. Thus paleoclimatology gives a picture of the natural variability of the climate and puts into perspective the variations observed today. It also gives better understanding of the mechanics of climate and especially the dynamics of tropical climates. The **water cycle** in these regions is different to that of temperate latitudes as evapotranspiration is much greater and tropical **convection** plays a major role in the water balance and that of terrestrial energy. The study of climate variability over a long period also gives better knowledge of seasonal and interannual climate variation, such as monsoons and the El Niño phenomenon that strongly affect the tropics.

This study of past climates is based on the many traces left at the surface of the earth. Glacier ice core samples, sea and lake sediment, stalactites and stalagmites in caves, coral, etc. all form natural climate records. Subjecting them to physical, chemical and biological analysis makes it possible to reconstruct and quantify past climate changes as long as these records can be dated reliably.

Figure 1.
The main components of the climate system and their response times.
The numerous interactions between the atmosphere, the oceans, the biosphere, etc. play a determinant role in the evolution of the climate and take place at scales ranging from a day to tens of thousands of years. Paleoclimatology makes it possible in particular to study slow interactions.
Source: JOUSSAUME, 1999.



The secrets of tropical ice

Ice in Greenland and the Antarctic has made it possible for about 50 years to reconstruct the climatic and environmental variations during the last glacial-interglacial climate cycles. The rich results drawn from polar ice encouraged several international research teams to extract glacial ice cores in other cold parts of the world. IRD and its partners started to study the tropical and subtropical glaciers in the Andes (Sajama and Illimani in Bolivia, Chimborazo in Ecuador, Coropuna in Peru, San Valentin in Chile) in the 1990s.

Andean ice cores gave information about the pattern of the tropical climate in the southern hemisphere over periods going back as far as 25,000 years for the oldest ice. They also enabled better understanding of regional climatic phenomena such as the South American monsoon system.

The GREATICE Laboratory team at work on the glaciers of Antisana volcano (5,700 m) in Ecuador.
Core drilling operations in tropical glaciers are carried out under difficult circumstances because of the high altitudes and strong winds.

The discovery of a Small Ice Age in South America

Past variations in precipitation recorded in Andean ice provide precious information today. Study of these combined with observation of the advances and retreats of glaciers in the past has proved recently that there was a Small Ice Age in the Andes. Although less strongly marked than in Europe, the phenomenon resulted in colder, wetter conditions than those of today from the mid-15th century to the end of the 18th century.

Interpreting analyses of Andean glacial ice cores was not easy. One of the tracers used classically to recover information is the **isotopic composition** of water that reflects its various forms ($H_2{}^{16}O$, $H_2{}^{18}O$, HDO). Isotopes of polar ice provide information about temperatures. But the question is different in the tropics where the atmospheric water cycle is much more complex. Substantial research showed that the composition of Andean ice is controlled at a regional scale mainly by precipitation (Box 1).

Box 1

Tropical ice provides more information about precipitation than about temperature

Andean ice forms excellent tropical climate records. However, interpretation of the information drawn from the cores is still a subject of discussion among the scientific community. Scientists at the HydroSciences Montpellier research unit have shown that this ice provides information about variations in precipitation and not about those of temperatures as is the case in a temperate climate.

The isotopic composition of tropical ice provides valuable information for the quantification of past climate variability.
But the interpretation of this geochemical marker is more difficult than at the poles because of the complexity of the atmospheric convection processes that cause the major part of rainfall.

The distribution of isotopes in water between the various reservoirs (water vapour, condensate, rain) in the polar regions depends on temperature, as this controls the quantities of precipitation that form. However, this correlation is not valid for a tropical climate.

In order to understand this difference in processes, scientists at the HydroSciences Montpellier laboratory calibrated the isotopic signal from present precipitation data.
They set up a precipitation collection network in Bolivia, Peru and Ecuador, as close as possible to the core extraction site.

Analysis of rainfall samples combined with the results of climate modelling of tropical South America shows that the isotopic composition is controlled mainly by the quantity of rain that an air mass has lost during its trajectory since it formed above the sea.
At the inter-annual scale, the Andean glaciers would therefore record the history of regional variations of moisture rather than temperature variations.

These results have shown that some parts of Amazonia were wetter during the last glacial peak 20,000 years ago and that a global change in temperature thus plays a determinant role in the rainfall regime in this region.

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Rain sampling for the measurement of water isotopes, Chacaltaya (5,240 m), Bolivia.

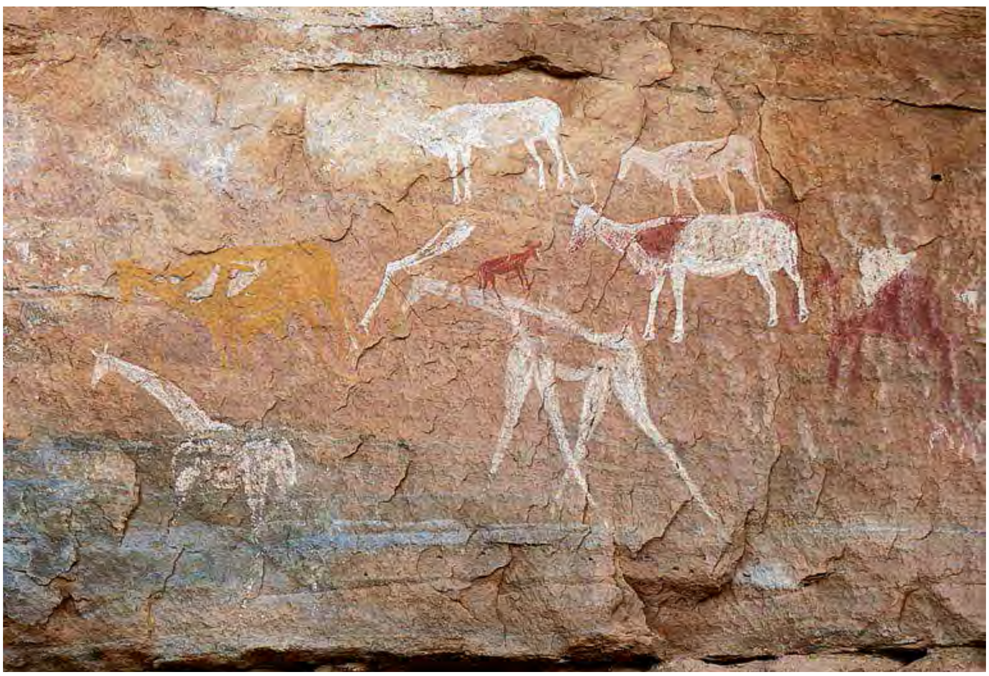
Sediment, coral and other climate records

Glacial ice cores are not the only climate records used in the study of past climates. Outside the polar regions and high-altitude glaciers, lake and marine sediment, coral and speleothems (stalactites and stalagmites) are also environmental markers that are valuable for the reconstitution of past climates.

The Sao Bernardo cave in Brazil.
Stalagmites (speleothems) are good tracers of the past variations of precipitations in South America.

Environmental markers that tell us about the past

Carbonated concretions (stalactites and coral) are particularly useful for the reconstruction of variations in precipitation and temperature and of sea level. Their rate of growth, isotopic oxygen and carbon ratios and the presence of trace elements (magnesium, calcium, strontium, etc.), with help from dating methods, have been widely used to study changes in the global monsoon system at different time scales.



Tadrat Akakus, a prehistoric site in the Libyan Sahara.
These rock paintings show that the climate was formerly less arid than it is today.

Box 2

An exceptional rise in sea level revealed by coral in the Pacific

Scientists at the CEREGE unit and their partners used cores taken from coral reefs off Tahiti to reconstitute one of the major events of the last deglaciation—an exceptional rise in sea level combined with the break-up of ice.

Global sea level has risen by 120 m since the end of the last ice age 21,000 years ago.
The rise has not been steady but on the contrary punctuated by rapid acceleration combined with massive break-ups of icecaps.
The most marked of these accelerations, referred to by paleoclimatologists as '*Melt-Water Pulse* 1A', was poorly known until the CEREGE team, in collaboration with the universities of Oxford and Tokyo, analysed reef cores collected around the island of Tahiti during the international expedition IODP 310 '*Tahiti Sea Level*' in 2005.

This work made it possible to describe the chronology, amplitude and duration of the event.
The acceleration of the rise in sea level started precisely 14,650 years ago and coincided with the so-called 'Bølling warming' at the beginning of the warm period that marked the end of the glacial period.
Sea level rose by some 14 m in less than 350 years. Furthermore, in contrast with the hypothesis accepted to date, the Antarctic icecap probably contributed to half of this rise.
The massive inflow of soft water strongly disturbed world oceanic movements and affected the global climate.

These results are also very important with regard to the present and future rise in sea level.
Indeed, they highlight the dynamic behaviour of the polar icecaps in response to a rise in temperature, a phenomenon still poorly taken into account in IPCC forecasts for 2100.

Study of corals (*Diploastrea* formation) in the Fiji Islands.
The core extracted will be examined to provide information about the history of the climate in the South Pacific.

Sediments record several types of information related to the origin, quantity and state of conservation of minerals and organic substances in the ground. Organisms with very short life cycles, such as diatoms and some algae are good markers of changes in the physical and chemical conditions of the environment. The degree of conservation of organic substances and their mineralisation also provide information about the temperature, the acidity and the oxygenation of the environment of the deposit. For example, researchers used analysis of pollen grains collected in sediment from Lake Chad to reconstitute the vegetation and precipitation in the region 6,000 years ago in the mid-Holocene. The results are particularly interesting as during the period the Sahara was gradually becoming the desert that we know today. They make it possible to construct models that are useful for understanding present changes in a similar climate context featuring warming.

Reconstruction of Andean paleoclimates

In South America, the gathering of indices from the various paleoclimatic archives has made it possible to reconstruct the changes in continental precipitation on this continent. Analysis of fossil pollen grains and lake sediment gives information about the past and an image of the climate 6,000 years ago. It was much drier than it is today, causing a large decrease in the area of Amazonian forest. In parallel, the discovery of layers of microcharcoal, a sign of ancient fires, in lake sediment and soil proves the exceptional decrease in atmospheric moisture during the period. These interpretations are also confirmed by the trend in oxygen isotope values that indicate a decrease in precipitation. Paleoclimatic simulation shows that the dry phase was caused by an increase in air temperature and a warming of tropical seas in response to an increase of the solar radiation reaching the surface. This gradual increase in insolation in the southern latitudes of the tropics for 10,000 years caused the weakening of the South American monsoon and also accounts for the slow, gradual retreat of the high glaciers in the Andes during this period. In particular, this information has shown the exceptional nature of the melting of the high-altitude glaciers in South America since the beginning of the industrial era. The present speed of melting since 1820 is therefore not accounted for by variations in insolation but by other mechanisms related to the increase in greenhouse gases in the atmosphere.

Hibiscus tiliaceus
Malvaceae pollen grain under optical microscopy.
Pollen grains can be valuable indicators for study of the climate.

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