ATMOSPHERE... CLIMATE REVEALED BY THE ICE

Musée des Arts et Métiers
french ministry of foreign and european affairs

ATMOSPHERE... CLIMATE REVEALED BY THE ICE

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* 1.2 *

The poles of our planet Instinctively, the globe-trotter situates the Earth's poles somewhere distant and inaccessible in the northern and southern regions of the planet. The geographer uses the latitude of the polar circles, 66°33', where the sun never rises the day of the winter solstice and never sets the day of the summer solstice. The climatologist prefers thermal criteria, for example, in the north, the average air temperature responsible for the permanently frozen ground, or permafrost.

To the north. In the north, the Arctic Ocean (13 million km^2) bathes the geographic pole, surrounded by huge continents. The Arctic polar circle crosses several islands and 8 political divisions (Alaska, Canada, Greenland, Finland, Iceland, Norway, Russia, Sweden), which are home to many peoples such as the Inuit, the Saami, the Evens... The Arctic is the region of the polar bear.

To the south. In the south is the Antarctic, the planet's sixth continent. A huge ice desert measuring 14 million km^2, it is isolated in the middle of the menacing Antarctic Ocean. Covered with a layer of ice 4 km thick, the Earth's crust contains rocks there that are almost 4 billion years old. There are high mountains and even active volcanoes. The Antarctic is the region of the Emperor Penguin.

The poles at the heart of climate The polar regions are strategically important. Although practically uninhabited and located very far from areas of human activity, they nevertheless reflect the degradation of our environment. At the heart of the major climate changes, they are the site of the new scientific adventure, the outposts of research into the changes that are affecting our planet.

* 1.3 *
WHAT THE POLAR LIGHTS TELL US

The polar regions are primarily known for being the location of the Earth's magnetic poles : as a result, any traveller equipped with a compass at any place on Earth can be oriented toward a precise direction, north. The magnetic field is created by the difference between the speed of the Earth's rotation and that of its liquid core which, through friction, acts as a dynamo.
It protects us from the flows of ionised particles emitted by the sun by diverting them. But inside this natural shield, some areas of weakness exist : the polar regions. That is where the electrons and protons from the solar wind manage to penetrate the Earth's atmosphere during solar eruptions. When they encounter the oxygen and nitrogen molecules in the air, the latter emit light and produce the Southern and Northern Lights.

SuperDARN Dual Auroral Radar Network is a network of high-frequency radars used for studying the dynamics of the upper atmosphere and Earth-Sun relations. Nineteen radars are divided between the southern and northern hemispheres, encircling the auroral and polar zones. The SuperDARN network involves eleven countries, including France.

* 1.4 *

The extraordinary colours of the Polar Lights (auroras) are the result of the different characteristics of the gases present in the atmosphere : yellow-green for oxygen, red-purple for nitrogen. Although they seem to glow at cloud level, the auroras are actually located at a much higher altitude, between 100 and 400 km. Occasionally, astronauts from the International Space Station pass through an aurora.

THE ATMOSPHERE, OUR PROTECTIVE ENVIRONMENT

2

* 2.2 *
A VERY THIN LAYER OF GAS THAT KEEPS US WARM

The development of life on Earth is largely based on the presence of a favourable atmosphere. In contrast, the Moon, which has no atmosphere, is a celestial body that is dead, although it is located at the same distance from the Sun as the Earth. Our atmosphere is a thin layer of gas a few dozen kilometres thick. Thanks to its existence, a natural phenomenon takes place, the greenhouse effect, which helps to maintain the average temperature of our planet at +15°C, whereas otherwise it would be -18°C. It is in these conditions that fauna and flora can develop.

The greenhouse effect Our planet receives energy from the sun, a part of which is absorbed while the rest is sent back into space. By penetrating the ground and the oceans, this energy heats the Earth, which then emits infrared radiation into space. But the clouds and certain atmospheric gases absorb a part of it and thus hold some of the heat from the Sun. These greenhouse gases, such as water vapour (H_2O), carbon dioxide (CO_2) and methane (CH_4), represent less than 1% of the gases present in the air that we breathe, which is mainly nitrogen (78%) and oxygen (21%).

Air sample bottle, Laboratoire des Sciences du Climat et de l'Environnement (LSCE), near Paris. Placed in a special case, this bottle was used at the atmospheric observatory on Amsterdam Island, one of the most isolated islands in the world, situated in the southern Indian Ocean, on the Kerguelen Island archipelago. The air sample is analysed at the laboratory to study its greenhouse gas content, especially that of carbon dioxide. With over 20 stations worldwide, the LSCE's RAMCES network has been taking measurements continuously for 25 years. It belongs to a huge international network created on the occasion of the International Geophysical Year (1957-1958).

* 2.3 *
A VERY THIN LAYER OF GAS THAT FILTERS UV RAYS

In the atmosphere there exists a natural protection that filters the highly dangerous ultraviolet radiation from the sun: the ozone layer. Located in the stratosphere, between 15 and 50 km in altitude, it is extremely thin. If it were spread out on the ground, it would have an average thickness of only 3 mm.
Ozone (O_3) is a molecule made up of three oxygen atoms. It is generated by the action of the sun's rays, which split the oxygen molecules in the air. The association of an oxygen atom thus obtained with an oxygen molecule produces an ozone molecule: (O_2 + sun's rays) + O_2 - > O + O_3

Ozone: both good and bad The ozone present in the stratosphere protects us from ultraviolet rays. When it originates naturally, it is crucial to life on Earth. In contrast, when produced by urban pollution, the ozone present in the air we breathe is irritating and a health risk.

* 2.4 *
ICE SHELF, SALT AND ALBEDO

On Earth, the climate system involves four main players: the atmosphere, the oceans, ice and vegetation. The polar regions play an essential role.
The climate system is like an engine, with regions at low latitudes (tropics) serving as the heat source and the polar regions as the heat sink. The transfer of heat to the poles is carried out by atmospheric and oceanic currents. At high latitudes (poles), some of the water freezes (-1.8°C) and forms sea ice (pack ice). In doing so, it expels its salt, which increases the salinity of the liquid water. Saltier, colder, and therefore denser, this water then "plunges" towards the bottom of the Arctic and Antarctic Oceans and feeds into global oceanic circulation like a conveyor belt. This cycle is referred to as thermohaline circulation.
The polar regions are at the centre of another phenomenon that contributes to global climate regulation. This is the albedo effect. The huge white masses of snow and ice reflect the sun's rays into space like mirrors, which has an influence on the Earth's temperature.

THE POLES: ONE-OF-A-KIND LABORATORIES

3

* 3.2 *
MEASURING THE ATMOSPHERE

The polar bases constitute ideal measuring laboratories. The experiments performed there can be conducted nowhere else on Earth. Researchers have access to sophisticated scientific instruments, which often need to be adapted on site due to the difficult weather conditions. Benefitting from technologies in the fields of chemistry, physics, optics, air dynamics and many other disciplines, measurements relating to the atmosphere and climate vary. Some are carried out on the ground (air, water or ice samples), others take place on board sounding balloons. From the small balloons used by meteorologists to large stratospheric balloons, their size differs accordng to the type of measurements being taken, the duration of the flight and the target altitude. Scientists also use sounding (radar, lidar…) depending on the parameters to be studied. In addition, satellites and remote sensing from space help monitor the evolution of the oceans, the pack ice, the volume of the ice caps or the ozone layer. The information collected supplies databases that are then used to simulate phenomena using computer models.

A system similar to radar, lidar (Light Detection and Ranging) projects a laser beam into the stratosphere up to 50 km in altitude and thus collects the light retrodiffused by the molecules and particles in the environment it passes through.

* 3.3 *
READING THE CLIMATE IN THE ICE

The ice in the polar caps contains air bubbles that have been imprisoned for hundreds of thousands of years. These valuable indicators help us monitor the evolution of atmospheric composition over time. In order to date the ice, markers are used such as aerosols or dust from distant regions. This is also possible through an analysis of the physical properties of the ice and estimating the quantities of snow cover. In north and south alike, extraction sites are established at the summit of the polar icecaps, where the ice is thickest and most stable.
In the Antarctic particularly, in 1999, drilling to a depth of 3,623 metres in Vostok, the result of a joint project between Russia/USA/France, provided access for the first time to natural records of 420,000 years of climate history. The record of the oldest archive (800,000 years) was obtained in 2004 thanks to drilling conducted at Dome C, as part of the European EPICA programme (European Project for Ice Coring in Antarctica).

Less cold The deeper the ice, the more packed it is, and the older it is. But the age of the archives obtained depends also on the drilling site. In the Arctic, the ice is not as old as in the Antarctic, but the resolution of the record is finer, even enabling the seasons to be distinguished. In 2004, the European NGRIP* campaign revealed 125,000 years of archives, dating back to an era in which the climate of Greenland was less cold and more stable.
* North Greenland Ice Core Project

800,000 years of climate history revealed in the Antarctic by the European EPICA project

6,000 samples taken between 1995 and 2004 from an ice core 3,200 metres long.

* 3.4 *
PRECIOUS CARROTS

Valuable cores The ice core samples are cut up and carefully filed away in cold chambers far from the polar regions to be analysed. Chromatographs separate the gases they contain, which are then identified by mass spectrometers. Scientists determine the temperature at which the layer being studied was formed by measuring the concentration of deuterium, a hydrogen isotope*. The data collected then serve to enrich the climatologists' digital models, which have benefitted from the existence of very powerful supercomputers for around 40 years.

Troubling revelations Ice drilling at the poles provides paleoclimatic information that retraces the natural variations in climate linked to the glacial–interglacial cycles. An analysis shows that over the past 800,000 years, the Earth has undergone 8 climate cycles, a regular alternating of glacial periods and warmer periods, with a sudden change in rhythm 420,000 years ago. An interglacial period is of particular interest to researchers, since it is similar –

in terms of atmospheric and astronomical parameters – to the period in which we are now. But with one difference: the concentration of greenhouse gases in the Earth's atmosphere has never been as high as it is today
It is through the results of drilling that the role of greenhouse gases in the intensification of climate changes was confirmed: when their concentration increases, we witness a warming of the planet.

Each chemical element exists in different forms or isotopes, which differ solely in their number of neutrons. They have the same chemical properties, but different physical properties, notably their mass. An isotope of "normal" oxygen (oxygen 16) is oxygen 18. A hydrogen isotope is deuterium. Thanks to these isotopes, the temperature of the past can be reconstructed: the more of them there are in the water (and therefore in the ice), the hotter the climate was.

Légende : Air bubble seen under polarised light through a slice of ice core.

THE POLES IN TURMOIL

4

* 4.2 *
THE DESTRUCTION OF THE OZONE LAYER

For over 20 years, every spring, a major reduction in the ozone layer takes place between 14 and 22 km above the Antarctic. The quantity of ozone can drop by 60 to 70%. This hole in the ozone layer is caused by chemical reactions produced by chlorine and bromine compounds (CFC, etc) resulting from human activities.

CFCs, manufactured until the 1990s, mainly for use in refrigerators, act like time bombs. They reach the stratosphere in the space of a few years and release the chlorine and bromine they contain. In winter, when the temperature above the poles drops to -90°C, the chlorine gets trapped under ice clouds, formed by a very violent and turbulent cold wind, the polar vortex. However, in the spring, when the sun returns, the chlorine is released and destroys the ozone molecules.

The Montreal Protocol (1987) aims at eliminating all global emissions of ozone-destroying compounds. The measurements currently being taken by researchers are destined to help understand how the stratospheric clouds maintain the formation of the hole in the ozone layer.

Vorcore In 2005, around twenty pressurised weather balloons were dispatched into the stratosphere during the Stratéole-Vorcore campaign conducted by the CNES, the CNRS and the Ipev, and supported by the NSF. The balloons, 10 metres in diameter, were equipped to study the polar vortex, along with the links between the formation of stratospheric clouds and the destruction of the ozone. Flying over the Antarctic continent over a period of several months, they collected over 150,000 measurements.
Sometimes over a century is required for the elimination of certain CFCs. In 2006, the surface area of the ozone hole was still 27 million km^2..

* 4.3 *
IN THE ARCTIC, WARMING IS ACCELERATING

In the Arctic, the temperature has increased by over 3°C in the past 50 years, in other words over 3 times faster than the rest of the planet. The melting of the permafrost is particularly significant. Already, two million km^2 (i.e. 20%) are seriously affected, with the appearance of lakes and marshes instead of the traditional frozen ground. The Arctic ice pack has receded 10 to 15% in thirty years and could disappear in the summertime by 2040.
As part of the European Damocles* programme, the schooner Tara, locked in the pack ice, took less than sixteen months to get back to open water, as opposed to almost

three years in the previous experiment, in 1896 by Fridtjof Nansen. However, through a feedback mechanism, the widespread receding of the white surfaces is both a cause and effect of the warming. In the Arctic, when the snow cover is reduced and the ice pack recedes, the albedo drops: more solar energy is therefore absorbed by the surface. This process thus intensifies the warming and destabilises the role played by the Arctic Ocean in ocean currents.

* Developing Arctic Modelling and Observing Capabilities for Long-Term Environmental Studies

The Intergovernmental Panel on Climate Change (IPCC), co-prizewinner of the 2007 Nobel Peace Prize, established that, by 2100, on Earth, the average temperature could increase by 1.1 to 6.4°C, and the sea level could rise by 20 to 60 cm above its current level, or even more. In the centuries to come, this rise could be a few metres because of the expansion of the ocean and the possibility of a partial melting of Greenland.

* 4.4 *
THE THREAT TO BIODIVERSITY

In north and south alike, the polar regions are home to specific species that have succeeded in adapting to the cold. For over 50 years, French researchers have been monitoring some twenty species of birds (albatross, penguins, petrels…) and marine mammals (sea elephants, seals…) in the French Austral and Antarctic Territories. This uninterrupted database provides information on the physiology of animals, their behaviour and the evolution of their environment. Tagged by Argos markers or electronic chips, the animals are monitored by satellite.

Adapted centuries ago to withstand extreme conditions, these animal and plant species are the first victims of the climate change that is disrupting their environment and their life cycles. Everything is being disrupted: habitat, diet, fertility, breeding seasons…, not to mention the fact that new predators are invading. Certain emblematic species are particularly affected: polar bears and snow foxes, in the Arctic; and in the Antarctic Ocean, krill (a type of shrimp), upon which a whole food chain depends: sea lions, penguins…

The scallop thermometer Some organisms even enable climate variations to be reconstructed. This is the case of the Antarctic scallop, a type of mollusc whose valves "record" the characteristics in their environment during their growth. By measuring and deciphering the chemical message contained in their shell, scientists have made these scallops their valuable assistants in understanding the evolution of the planet.

THE NEED FOR INTERNATIONAL COOPERATION

5

* 5.2 *
THE STATUS OF THE POLAR REGIONS

Scientific research is based on the networking of observations and results between the countries involved. The extreme conditions make this collaboration even more necessary. Thanks to the impetus resulting from the four International Polar Years (1882-1883, 1932-1933, 1957-1958, 2007-2008), scientific work has succeeded in overcoming any economic rivalry or political conflict.

A reserve dedicated to peace and science
In the Antarctic, 37 scientific bases representing 20 nations are permanently established. A unique case in history, the Antarctic continent is an international territory protected until 2041 by the Antarctic Treaty, signed in 1959, and by the Madrid Protocol, signed in 1991. Any form of territorial claim is frozen, and any exploitation of energy resources, military activity, nuclear testing and dumping of dangerous materials is banned. But what will happen after 2041?

A coveted ocean While the North Pole, in the centre of an ocean, cannot be claimed by any state, this is not the case of the waters closest to its banks. The Arctic is a much-coveted region for its abundant energy resources, despite the Montego Bay Convention, in 1982, between Canada and Russia, which considers the Arctic Ocean a special zone.
For research, the permanent bases are grouped together on the Svalbard archipelago to the north of Norway. Since the Paris Treaty, in 1920, this region has enjoyed a special status, authorising free access to other countries. Alongside these bases there are many temporary facilities, since the Arctic is easier to reach than the Antarctic.

* 5.3 *
CUTTING-EDGE TECHNIQUES FOR RESEARCH

Ice-breakers, crawler tractors, aircraft… Research in the polar environment requires very specific logistical resources and state-of-the-art techniques. There is also a need to transport staff, infrastructural elements, measuring equipment, along with fuels and the supplies necessary for field campaigns. Not to mention the construction and maintenance of the bases and equipment. But their complexity, heaviness and cost call for close international consultation and, on site, good coordination among technicians, engineers and researchers. For France, the Institut Polaire Français Paul-Émile Victor (Ipev) coordinates the scientific programmes and provides the logistical and technical support for the research. The Ipev also implements oceanographic campaigns using the Astrolabe and Marion Dufresne research vessels.

* 5.4 *

Under the impetus of ethnologist and explorer Paul-Émile Victor (1907-1995), France became involved in the modern exploration of the polar regions, through the creation in 1947 of the French Polar Expeditions. Here, Paul-Emile Victor on the Fjelberg, summer campaign of 1949 to Greenland.

A crawler in "white hell" An overland trek involving tractors and sleds organised every Austral summer to take supplies to the Franco-Italian Concordia base in the interior of the Antarctic continent. At a speed of around 10 km/h, the return journey from the French Dumont d'Urville base 1,100 km away on the coast takes 20 to 25 days.

ADVENTURERS OF SCIENCE

6

* 6.2 *
THE FRENCH PRESENCE AT THE POLES: THE HISTORICAL BASES

In the north and south alike, France has been operating permanent bases for over 50 years. In the Arctic, the Charles Rabot and Jacques Corbel bases are located in Ny-Alesund in the Svalbard archipelago, Norway. Recently, they merged with their German counterparts under the name AWIPEV. The French scientific teams work alongside teams from other countries (China, Korea, Italy, Japan, Norway, Holland, Poland, United Kingdom, Sweden). France also has sites in Alaska, Canada, Greenland and Sweden.

The historical bases In the Antarctic Ocean, France

has bases established on several islands or archipelagos (Kerguelen, Crozet, Saint-Paul and Amsterdam) and in the Antarctic, both on the side facing Australia and on the high plateau. Researchers carry out internationally renowned studies there in the field of life sciences and sciences of the universe. Located on the East coast, in the Pointe Géologie archipelago, the Dumont d'Urville base can host almost 70 people during the Austral summer, from November to March.

Charcot base Created for 2 years during the International Geophysical Year (1957-1958), the Charcot base was at the time, along with the Russian and US bases, one of the 3 permanent bases established in the interior of the Arctic continent. At an altitude of 2,400 metres and over 320 km from the Dumont d'Urville station, with no GPS (!) three young researchers spent the winter there in a 24-m^2 shelter "buried" in the firn.

Specialising in detailed chemical studies of the atmosphere, the Corbel base is a "clean" base whose energy is supplied entirely by renewable, non-polluting sources.

* 6.3 *
CONCORDIA BASE, FACING NEW CHALLENGES

At the heart of the Antarctic, in the middle of the desert, on the Dome C plateau, located over 1,100 km from the coast and at an altitude of 3,200 metres, is the Franco-Italian Concordia base. Built under the aegis of the Paul Émile Victor Polar Institute (Ipev) and its Italian counterpart, the PNRA, it is situated at 75°S, 123°E. The base mainly comprises two cylindrical, three-storey buildings, placed on the ice, with a total surface area of 1,500 m^2. It can house a 16-person mission, for a 9-month winter period, and up to forty people during the Austral summer. A system for recycling used water was designed in partnership with the European Space Agency (ESA). The weather conditions there are extreme: -51°C on average (record of -84°C), and a permanent drought. Dehydration and frostbite of the face, hands and feet are the risks residents must face during the winter, when any help from outside the base has become impossible. For the teams who work at Concordia, this is a human as well as a scientific challenge. Placed outside the world, the residents live in conditions similar to those of a long space voyage.

Concordia's scientific activities are structured around six main themes : aeronomy, astrophysics, biology, geophysics, glaciology and medicine.

* 6.4 *
CONCORDIA FOR SOUNDING THE UNIVERSE

While the ice at Dome C, where Concordia is established, enables climatologists to go back one million years into the past, its nocturnal sky promises astrophysicists a voyage to the origins of the universe, the Big Bang, 13.7 billion years ago. The site of Dome C is one of the driest and coldest on the planet. The absence of human activity there preserves the environment from any form of pollution, and the sky is therefore one of the purest and most transparent in the world. During the winter months, the night lasts 24 hours, which makes Concordia an exceptional site for observing the universe.

The finest details visible through Concordia's telescopes enable the detection of new planets in our galaxy. Astrophysicists attempt to understand the processes of planetary formation and to find out where, in the future, to point the powerful satellites entrusted with the task of detecting signs of life in the universe…

99 days : that is the duration of the polar night at Concordia, during which the Sun never rises.

GÉNÉRIQUE

7

"The defence of Man and of his environment is a problem of survival. Some people deny it. Through self-interest or through stupidity. (...) They are unaware or irresponsible. Never mind them. The others, whatever the final outcome, will at least have the satisfaction of having accomplished a duty. And that may be their only reward."

Paul-Émile Victor, Jusqu'au cou... et comment s'en sortir, 1979, Ed. Fernand Nathan, p. 25

* 7.3 *
THE MUSÉE DES ARTS ET MÉTIERS: TECHNOLOGY AT THE HEART OF CULTURE

This exhibition is a "light" version of an exhibition produced within the framework of the International Polar Year by the Museum of the Conservatoire National des Arts et Métiers (Cnam) in Paris. Created at the time of the French Revolution, in 1794, by Abbot Grégoire (1750-1831), the CNAM is a major public establishment that fulfils three missions: the vocational training of adults, technological research and the dissemination of scientific and technical culture. It comprises more than 180 centres in France and worldwide. Its museum, dedicated to technical innovation, presents to all curious minds, young and old, objects that have had an impact on society: the Lumière brothers' film camera, Pascal's calculating machine, Vaucanson's loom, Cugnot's steam-powered Fardier, Foucault's pendulum, Blériot's airplane, along with the many episodes in the history of locomotion, materials, techniques used in construction or in measuring time and space… Its unique collections comprise more than 80,000 objects and 20,000 drawings, from Ancient times to the present day. The museum visit features an abundance of interactive exhibits and educational models that complement the daily demonstrations and tours. Many different events and exhibitions are organised at the museum every year.

www.cnam.fr www.arts-et-metiers.net

" …**to bring together** newly invented or improved tools and machines" and "to enlighten ignorance which knows not and poverty which has not the means to know" (Speech by Abbot Grégoire in front of the National Convention on October 10 1794 [19 Vendémiaire Year III of the Revolutionary calendar])

Device invented by Auguste de La Rive (1801-1873) for reproducing the Northern Lights, 1862, Paris-Musée des Arts et Métiers, Inv.07273

* 7.4 *
GÉNÉRIQUE

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The exhibition can be found online at the website of the French Foreign and European Affairs Ministry: www.diplomatie.gouv.fr