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THE TEXTS OF THE EXHIBITION

CLIMATE

the 360° exhibition

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On the occasion of the World Climate Summit held in Paris from the 30th November to the 11th December 2015, ‘Climate, the 360° exhibition’ explores all the questions raised by climate change due to the increase in greenhouse gas emissions linked to human activity. It also provides a better understanding of the climate system, with researchers’ latest observations, simulations and analyses.

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Editorial

To stop burying our heads in the sand

So is there still any room for doubt? No. The Earth has been getting warmer for more than a century now. We also know for a fact that the proportion of greenhouse gases (GHGs) in the atmosphere has increased over the same period. A third certainty is that this increase coincided with the growth of human activities emitting GHGs (energy, transport, industry, etc.). So, based on these observations, what can we expect to happen? Since we have no crystal ball, our only means of forecasting future climate change are climatologists' projections. And their conclusion is clear: if we do not change our production methods and consumer habits, we can expect a snowball effect resulting in climate disruption and all the disasters that implies. So what can we do? 'Adaptation' and 'mitigation' are the key strategies in climate policies agreed after much negotiation at major international summits, but are we in our developed and developing nations ready to build a 'decarbonised' world? With the approach of the 21st World Climate Conference (COP21) in Paris, which promises to be crucial to our future on this planet, the purpose of this exhibition is to explore every aspect of the climate crisis, providing a panoramic 360° view so we are not left with our heads buried in the sand.

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Diagnosis of warming and its initial consequences

Meteorological stations, tide gauges, floats drifting in the oceans and satellites are all used to monitor changes in the Earth's climate… and show us that the Earth is warming. This warming is already having observable consequences – for instance, the melting of the Arctic ice pack and the retreat of most continental glaciers. Is this something new in our planet's history? To answer that question, climatologists are examining all natural climate records in the environment: ice cores, cores of marine and lake sediments, rings in tree wood, coral reefs, grains of pollen and so on. Their conclusion is that different natural factors have increased the temperature of the Earth's climate in the past. It was heavily warmed by a strong greenhouse effect in the Eocene epoch 60 million years ago and then in the Pliocene epoch about 3 million years ago. However, the kind of warming observed over the last thirty years has never happened before in the past 1,500 years, particularly given its global nature and initial impacts.

Climate is not the same thing as weather!

Climatology, with its long time scale and the many processes it involves, is very different to meteorology.

Meteorology describes the state of the atmosphere at a given moment in a specific part of the world, along with changes that can be forecast a few days ahead. Regional climatology, though, considers meteorological conditions as a whole over a long period (at least thirty years). So climatologists work in the long term – unlike meteorologists, who make short-term predictions –, examining the average values of atmospheric parameters: air temperature, precipitation, atmospheric pressure, the force and direction of winds, etc. More generally, on a global scale, climate is primarily defined in terms of energy. The Earth is warmed by solar energy, and climate – or rather what we call the 'climate system' – redistributes the flow of solar radiation on the surface of the Earth. The state of the Earth's climate depends on the balance between energy received from the Sun and energy radiated back into space. Any disruption of this balance leads to a change in the Earth's climate. Factors that disrupt the equilibrium are known as 'forcing mechanisms'. These can be natural (for instance solar and volcanic activity) or anthropogenic, i.e. resulting from human activity. Current global warming results from an accumulation of energy in the climate system, 93% of which is absorbed by the oceans, 3% the land, 3% ice and 1% the atmosphere.

Global monitoring

Meteorological stations, tide gauges, floats drifting in the ocean and satellites are all used to monitor changes in the Earth's climate.

To observe the Earth's climate, major global meteorological and oceanographic measurement networks have been set up over more than a century. Using standardised measuring instruments, they record physical parameters such as air temperature, pressure and humidity, and the salinity of seawater. For the last forty years, satellite climate monitoring has complemented the information provided by these measurement networks. Satellites supply data on the temperature of the atmosphere and oceans at sea level, patterns of precipitation and cloud, the varying size of the ice caps and their estimated mass, etc. Dozens of these satellites, as well as 11,000 meteorological stations and nearly 6,000 tide gauges and drift floats in the ocean are used to gather information. This coordinated global operation grew over time. It was initially designed to forecast the weather and was then developed to monitor climate. One of the indicators of climate change is the year-on-year monitoring of changes in the average temperature on the Earth's surface, which is around +15°C. Estimation of this temperature is based on the combination of data which have no uniform temporal or spatial coverage, given the lack of measurement stations in certain regions and changes in instrumentation over time. To homogenise all this information, climatologists use complex statistical procedures.

Ever deeper in the oceans

Since the 1990s, the automated measurements made by floats drifting in the ocean (Argo floats) have been added to observations made by oceanographic research vessels. To improve the monitoring of sea currents – which have an impact on climate –, new floats that are currently at the trial stage in France, the USA and Japan will enable study of the ocean depths down to 4,000 or even 6,000 metres.

Will the Arctic Ocean soon be ice free?

Since satellite monitoring of the Arctic ice cap began in 1979, its surface area, measured in September, has shrunk by 10% on average every decade. Comparison with historical data shows that the warming observed over the last century is three times greater in the Arctic than in the rest of the world. According to certain hypotheses, the Arctic Ocean ice pack could disappear totally in summer from 2050 on. The situation is less clear-cut in the Antarctic at the South Pole, where ice has been melting on the Peninsula and in the west of the continent (since the mid-20th century), but the ice cap is tending to spread.

A planetary heatwave!

The Earth is getting warmer with already visible consequences, such as the melting of the Arctic ice pack, the retreat of glaciers and a rise in sea levels.

+0.85°C: this was the increase in average temperature over the surface of the Earth (continents and oceans) between 1880 and 2014. The climate is warming generally, but not uniformly: the northern hemisphere is affected more and warming is greatest in high latitudes (the Arctic) and higher on the continents than in the oceans. This is already having different effects on the environment. The most striking of them is the melting of the Arctic ice pack in summer, reducing both its surface and thickness. Generalised shrinkage of glaciers in tropical, temperate and polar regions can also be observed. Measurements provided by tide gauges and satellites show a rise in sea levels of 3 millimetres a year over the last twenty years. As it warms, the water in the oceans expands. This, together with the melting of continental ice (mountain glaciers and the ice sheets of Greenland and the Antarctic), is causing rises in sea level. Other signs of global warming include the migration of certain species such as pine processionary caterpillars, which are heading up towards the north of France, or greylag geese, which are increasingly wintering in France rather than migrating to Spain or Africa. Some fruit trees are blossoming earlier. Finally, in many regions of the world, the average number of days of frost each year has fallen and the number of hot days (a temperature higher than 25°C) has increased since 1950 (by more than 50% in Paris).

Expert's view

Jean-Louis Etienne

Doctor and explorer specialising in the Arctic and Antarctic

« The Arctic – the Far North – is warming much faster than the rest of the planet. There's a simple reason for that: it's changing colour. It used to be white nearly all year round. The Arctic Ocean was covered in ice and the entire crown of the Earth – Siberia, Greenland, Northern Canada – was blanketed with snow. And, as we all know, white reflects solar radiation. Today, snow is arriving later and disappearing earlier on land in the north. That land, known as permafrost – permanently frozen ground – used to be white most of the year, but now it's turning darker and so absorbing solar radiation. As a result, permafrost is melting down through the ground. It turns into marshland, which emits methane that joins the CO_2 in the atmosphere. So there's a runaway effect. In the North, the Far North – in other words, the pole and its frozen ocean – there are now areas of open water because the pack ice is breaking up. There are more and more of these areas not covered by ice. And these dark surfaces absorb solar radiation, the surrounding ice melts, and so on. As a result, there's a runaway effect caused by the changes in the surface of the Arctic, an effect that was long underestimated in climate models. There are places in the Arctic where the average temperature has risen by almost 5°C in 80 years! This steady disappearance – or rather reduction – of cold in the North will reduce its ability to balance out excess tropical heat. We worry about the melting ice pack, of course. Our first thought is for the polar bears, but it'll impact on us too. You might say we've left the refrigerator door open and we're losing the chill that could make up for surplus tropical heat. As a result, the polar regions, especially the Arctic, aren't just major signs of climate change, but also contributing factors. »

Unprecedented warming?

The Earth's climate has already experienced periods of warming in the past, but if we look at the last 1,500 years, the current episode is unique.

To decide whether current global warming is unprecedented, we need to look at climate records spanning long periods of time. Palaeoclimatologists, i.e. scientists who study the history of climate, can refer to a number of natural climate records. By analysing sea sediments, they can build a picture of variations in sea level and temperature in the oceans over more than 60 million years. Core sampling in the Antarctic ice sheet shows variations in the polar climate and the makeup of the atmosphere (based on air bubbles trapped in the ice) for the last 800,000 years. Sediments in lakes and cave concretions provide information about climate change over thousands to hundreds of thousands of years. For the last millennia, data recorded season after season in the rings of trees or in coral play a valuable role. All these indicators show that the Earth's climate has changed many times in the past because of different natural factors. Continental drift has impacted on climate over periods of millions of years; variations in the Earth's orbit over millennia. Solar activity and volcanic eruptions also play a part in natural climate variation. Even so, climate warming over the past thirty years has been unique in the last 1,500 years, especially in its global nature and initial impact.

Millennial archives

Marine and lake sediments, ice, tree rings and coral reefs all retain a record (in their physicochemical composition and structure) of the prevailing climate conditions (temperature, rainfall, salinity, etc.) when they were formed. By analysing and dating samples from these natural archives, palaeoclimatologists can 'reconstruct' climate change in the past, site by site and then region by region. Their conclusion is that temperatures in the northern hemisphere have varied little (less than 2°C) over the last two millennia.

Glacial retreat

With the exception of certain glaciers (Karakorum) in the Himalayas, most continental glaciers are shrinking in volume. In France, La Mer de Glace retreated by 1.8 km between 1823 and 1995 with a loss of 700 m from 1993.

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The causes of climate warming and human responsibility

It is a fact that our planet's surface is warming, but why? Many factors influence the Earth's climate. Firstly, the Sun – the driving force behind the climate system – but also volcanic activity and the greenhouse effect. Certain greenhouse gases are naturally present in the atmosphere and trap heat on the Earth's surface, keeping the average temperature at +15°C when it would be -18°C without them. Since the Industrial Revolution, human activity (industry, energy, construction, transport, agriculture, deforestation, etc.) linked to very high population growth has also produced greenhouse gases which have joined those already present in the atmosphere. Despite the arguments of those who call themselves 'climate sceptics', climatologists are virtually 100% certain that human contribution to the greenhouse effect is responsible for most of the global warming observed since 1950.

The Sun's role

Every eleven years on average, our star becomes more active, which results in an increase in the number of sunspots and the volume of solar energy reaching the Earth. This causes a fluctuation of 0.1°C (at most) of the average temperature on the Earth's surface. So solar activity alone cannot explain the global warming observed over the last few decades.

Pulling the strings of climate

The Sun, volcanic activity, the natural greenhouse effect and, recently, human activity: many factors influence the Earth's climate.

A number of natural factors affect the Earth's climate – primarily the Sun, which is the driving force behind the climate system. The amount of solar energy reaching the Earth varies. It depends on the tilt of our planet's axis of rotation and the configuration of its orbit around the Sun. These astronomical parameters have resulted in the glacial and interglacial periods that feature in the record of variations in the Earth's climate over the last few million years. Volcanic activity also impacts on the Earth's climate, as does the greenhouse effect. Certain gases present in the atmosphere, such as water vapour, carbon dioxide (CO_2) and methane (CH_4), retain part of the heat received from the Sun. Without these greenhouse gases (GHGs), the average temperature on the Earth's surface would be -18°C instead of +15°C, so they have always been essential to the development of life on Earth. On a geological time scale (millions of years), the natural greenhouse effect has varied, especially according to volcanic activity and the specific capacity of the oceans to capture carbon dioxide during glacial stages. Since the start of the industrial age (200 years ago), human activity has been adding GHGs to those naturally present in the atmosphere. This supplementary greenhouse effect is increasing atmospheric warming and, according to the IPCC (5th report), can explain observed global warming since 1950.

Cooling particles

When explosive volcanic eruptions eject large quantities of ash and sulphate aerosols, they cause short-term cooling (for one to three years) of the atmosphere. Some polluting particles (industrial and exhaust emissions, smoke from forest fires) also have a cooling effect on the climate, which reduces the warming effect of greenhouse gases.

Climate specialists

20,000 scientists are conducting research into the climate and its past and future variations. The IPCC's task is to produce reports that review the state of our knowledge.

Climatology is a multidisciplinary, international science. Physicists, chemists, glaciologists, statisticians, oceanographers, meteorologists, geologists, astronomers, biologists, historians, geographers – in all, 20,000 scientists all over the world, including around a thousand in France – are studying the climate and its variations in ancient times and over the years to come. Assisted by computer scientists and mathematicians, they are developing powerful computer models that are able to simulate the climate system and predict future developments. Meanwhile, technicians and engineers are devising innovative, increasingly efficient measuring instruments (probes, satellites, etc.). Five organisations are monitoring changes in the average temperature on the Earth's surface: the National Oceanic and Atmospheric Administration (NOAA) and National Aeronautics and Space Administration (NASA) in the USA, the Met Office's Hadley Centre in the UK, the University of California, Berkeley, and the Japan Meteorological Agency. Each year, thousands of scientific papers on climatology are published, so regular reviews of the state of knowledge in the field are needed. That is the job of the Intergovernmental Panel on Climate Change (IPCC) set up in 1988 by the United Nations and the World Meteorological Organisation (WMO), whose reports (the 5th was published in 2013 and 2014) are written by hundreds of people on the basis of scientific publications and checked by more than 1,000 researchers. This scientific institution set up collectively and approved by all our governments provides the basis for international climate talks.

The warming footprint of El Niño

Covering 71% of the Earth's surface and absorbing 93% of the energy captured by our planet, the oceans play a key role in the climate system. In the short term, the main source of natural climate variability on a global scale is El Niño, a phenomenon involving the warming of the surface waters of the Equatorial Pacific Ocean that occurs every two to seven years. This leads to a series of extreme meteorological events (floods and droughts) in tropical regions and an increase in the average global temperature*. The phenomenon was strong in 2015 and even stronger in 1998.

* The opposite phenomenon also occurs. Called La Niña, it causes a drop in global temperature.

Human responsibility for global warming

According to the latest scientific data, there is now virtually no doubt that humans are mainly responsible for the warming observed since 1950.

For the Intergovernmental Panel on Climate Change (IPCC), it is "extremely probable" that human activity (use of fossil fuels, intensive farming, deforestation, etc.) is the main cause of the warming observed since 1950, because of the greenhouse gases released into the atmosphere. To identify changes in the composition of the atmosphere over time, scientists combine direct measurements and the results of their analyses of air from the past trapped in Antarctic ice. The conclusion is that an increase in the proportion of CO_2 began at the start of the industrial revolution. This increase has been accompanied by a reduction in oxygen, showing that the additional carbon dioxide is produced by combustion processes, i.e. by human activity. Another argument that tends to confirm the impact of human activity on the climate is that climate models based solely on natural factors (variations in solar activity and volcanic eruptions) cannot explain the warming observed since the 1950s. So anthropogenic greenhouse gases play a dominant role in the rise of world average temperatures, although this is partially offset by the cooling effect of certain polluting particles also produced by human activity.

Expert's view

Valérie Masson-Delmotte

CEA Director of Research at the Climate and Environmental Sciences Laboratory

« Looking at the composition of the atmosphere today, we can see a sharp increase in the volume of the main greenhouse gases, such as carbon dioxide and methane. Comparing it to the measurements we get from around 800,000 years of polar ice, we can actually see there's a clear difference. We're well beyond the range of glacial/interglacial variation for these gases. Today, atmospheric carbon-dioxide is about 400 ppm, 40% higher than the normal level during an interglacial. It's comparable, for instance, with the level during the warmest stages of the Pliocene around 3 million years ago, when the climate was 2 to 4°C hotter than today and sea levels were much higher. The global carbon cycle has been totally disrupted by human activity. The ocean absorbs about a quarter of the carbon dioxide we release into the atmosphere, and vegetation and land another quarter, so half of our emissions remain in the atmosphere. We can see our activity is decisive – especially our fossil-energy consumption, deforestation and cement production, which are the three main human activities emitting carbon dioxide. As for atmospheric methane – the second most important greenhouse gas emitted by human activities – it's now at two and half times its natural level. So there's no doubt that the change in atmospheric composition is driven by our industrial and farming activities, to simplify. And climate change is just beginning. The climate will continue to react to the greater atmospheric greenhouse effect we've caused. Looking at possible future developments, we anticipate from 2 to 4°C or 5°C of warming by 2100. Compared to past climate change, warming of more than 2°C by 2100 would be a truly extraordinary event. »

Air trapped in ice

The analysis of 800,000 years of CO_2 and temperatures in Antarctic ice shows that along with global warming, the concentration of carbon dioxide in the atmosphere has increased by 40% since 1750 because of human activity. Glaciologists can detect the signatures of fossil material combustion in air trapped in the ice. The European Project for Ice Coring in Antarctica (EPICA) aims to extend the period analysed to over a million years. France's Subglacior project is developing a new kind of corer probe using laser technology to achieve this.

CO_2, the main gas accused

Carbon dioxide makes up more than half the world's emissions of greenhouse gases (GHGs) caused by human activity.

Human activity releases different greenhouse gases into the atmosphere: carbon dioxide (CO_2), methane (CH_4), nitrous oxide (N_2O), ozone (O_3), HCFCs (substitutes for the CFCs banned by the Montreal protocol in 1987), etc. CO_2 is produced by the combustion of fossil fuels and forest fires. CH_4 is emitted by rice fields, ruminant digestion and leaks during the transport or use of natural gas. N_2O is emitted by certain industrial processes and by the soil's transformation of nitrogen fertilisers; O_3 is produced by pollutants emitted by vehicles, heating and certain industries. CFCs, which are still present in the atmosphere, were long used as refrigerating or propellant gases. CO_2 makes up more than half the world's emissions of greenhouse gases (GHGs) caused by human activity, far in front of CH_4 (15%), O_3 (12%), CFCs (11%) and nitrous oxide (5%). That is why we measure the effect of the other GHGs as CO_2 equivalent. Also, the CO_2 accumulating in the atmosphere has a very long lifespan (up to several thousand years) so at least 20% of current emissions will still have an impact on the atmosphere in 1,000 years' time. That is not true of methane: while it has a warming effect 23 times greater than carbon dioxide, its lifespan is much shorter (10 to 20 years). So CO_2 is mainly responsible for the greenhouse effect caused by human activity (a 'radiative forcing' of 1.7 watts/m^2 out of a total 2.3 watts/m^2).

Shrinking forests

Over the world, forest fires and deforestation (particularly the massive destruction of tropical forests) account for 11% of greenhouse gas emissions into the atmosphere. They are the second source of carbon dioxide emission after the combustion of fossil fuels. Not only is CO_2 released by fires, but the vegetation destroyed can no longer play its vital role in absorbing CO_2 by photosynthesis.

Ultra-polluting coal

Coal is the biggest pollutant of all the fossil fuels. Its combustion produces 43% of the world's CO_2 emissions, followed by oil (33%) and natural gas (18%). China alone accounts for almost half the world's coal consumption. In Europe, Germany consumes the most coal, which it uses to generate electricity, ahead of Poland and the UK.

Have we now entered the Anthropocene epoch?

Some scientists, including Nobel Prize for Chemistry winner Paul Crutzen, believe that the geological Holocene epoch (which began about 11,700 years ago) has ended and that we have now entered the Anthropocene epoch, where human lifestyles have become the main modifying influence on the environment. A committee of scientists has been appointed to report on the question and should deliver its verdict in 2016.

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Greenhouse gas emission scenarios and climate change

To understand how the climate system operates and predict future change, climate research centres are working on numerical models produced by computer programmes, which enable the simulation over space and time of 3D atmospheric and oceanic circulation, and all its characteristics (air and water temperature, winds, precipitation, humidity, etc.). Around forty of these models have been developed worldwide, two of them in France. They are still being improved, but they have already revealed the main trends, enabling scientists to reach a conclusion: if emissions of greenhouse gases related to human activities follow the present curve, we can expect warming up to four times faster over this century than in the last, and a rise in sea levels that could reach a metre by 2100, submerging certain regions of the world. Not to mention the destructive effects of more intense extreme weather events and the loss of ecosystems in the sea and on land. Only a drastic reduction of greenhouse gas emissions will enable warming to be limited to 2°C by the end of the century.

Climatologists' projections

There are around forty climate models worldwide, two of them in France. They are the only means of predicting future climate change.

To understand the operation of the climate system and predict future changes in climate, scientists produce digital models based on computer programmes to simulate various parameters over space and time (air and sea temperature, wind, humidity, precipitation, etc.). Climate modelling involves the mathematical formulation of climate phenomena based on the laws of physics. For instance, fluid mechanics provides a mathematical description of wind and ocean currents. Initially devised for weather forecasting, general atmospheric circulation models have been steadily improved. Today, 'Earth system' models also take into account the composition of the atmosphere (greenhouse gases, aerosols, etc.), oceans, land and the dynamics of vegetation, as well as the carbon cycle. There are around forty models worldwide, two of them in France*. Climatologists face many challenges in developing these predictive models – for example, the diversity of scale of the phenomena encountered and the complexity of the interactions between the various components of the environment. Sometimes, this means that different models produce different results. So climatologists prefer to speak of climate projections rather than climate forecasts when they publish the conclusions of their models. For now, these models are the only means of assessing future climate risks.

*The models of the Centre national de recherches météorologiques and the Institut Pierre Simon Laplace.

A virtual planet

Like any digital modelling, models of Earth climates are based on dividing up or 'gridding' the zone involved into subsections of 100 x 100 km. Those units are still too large for the simulation of micro-processes, such as cloud formation or the movement of aerosols, so they cannot be explicitly represented. Even so, to take their large-scale impact on climate into account, the researchers use an empirical method called 'parameterisation', which is the greatest source of model uncertainty.

Increasingly powerful supercomputers

Climate projections require much more complex calculations than weather forecasting, which only examines changes in the atmosphere. The capacity of current computers enables accuracy down to a scale of 8 km for weather models and 100 km for climate models. It takes almost a year of processing to model climate over 2,000 years. The development of more powerful computers in the future should enable scientists to narrow the grid and produce simulations faster.

Are models reliable?

Models are put through a series of tests, some even checking their ability to replicate the climates of other planets.

There are several ways of checking the reliability of a climate model. It is possible to compare its results to existing observations (meteorological stations, Argo floats, satellite measurements, etc.) and assess its capacity to reproduce seasonal climate traits in each region (tropical monsoons, winter glaciation in the Arctic, etc.), along with recently observed climatic trends (global warming). It can also be tested in very different contexts to current Earth climate, either by checking its ability to replicate past climates (for instance, during ice ages) or by testing it on other planets in the Solar System, such as Mars or Venus. The results produced by the models are then stored in a database that all researchers can access, so they can be verified by scientists outside the modelling community. Some results are common to all simulations and so have a high confidence figure for scientists (for instance, warming in the Arctic); others vary greatly from one model to another and so are more uncertain. For example, the way of integrating clouds within a single scenario examining greenhouse gas emissions due to human activity can produce global warming estimations that differ by a factor of two. This means that models must be further improved. Even so, they can already predict the main trends in climate change, although they are so far unable to forecast the location, timing and extent of their impacts.

The contrasting effects of clouds

Clouds are an important source of uncertainty in projecting climate change. Apart from the fact that they are hard to model, depending on their altitude, size and shape, they can have either a warming greenhouse effect or a parasol effect that cools the atmosphere. So it is important to gain a better understanding of how they form. That is the aim of measurements made by certain satellites. In the A-train satellite constellation, Calipso's laser and Cloudsat's radar can now map clouds in three dimensions.

Permafrost thawing

The permanently frozen ground that covers a fifth of the world's land (90% of Greenland, 80% of Alaska, 50% of Canada and the former Soviet Union) is beginning to warm. If this permafrost melts it could release methane and carbon dioxide into the atmosphere and so exacerbate global warming. Researchers from eight French and Canadian laboratories* are closely monitoring the state of permafrost. Some cities, such as Yakutsk in Central Siberia, and certain Inuit villages, such as Kuujjuarapik in Northern Canada, are built on this frozen ground.

*ATP project (Acceleration of Permafrost Thaw by Snow-Vegetation Interactions)

Emerging climate disruption

If fossil energy continues to be used at the current rate, climatologists' projections show a further 4°C of warming by 2100.

Since 2010, climatologists have been working on four hypotheses related to greenhouse gas concentrations (known as RCPs: Representative Concentration Pathways) over the decades to come. The resulting climate models show that the extent of future global warming will be proportional to the volume of greenhouse gas emissions caused by human activity. Although all the scenarios point to a relatively comparable global warming over the next thirty years (the inevitable result of existing human impact on climate), major differences subsequently appear. In scenario RCP 2.6, which includes a very sharp reduction in greenhouse-gas emissions, average temperatures will continue to increase by 1°C between now and 2050 and then stabilise. Sea level will rise by 40 centimetres by 2100 and the Arctic ice pack will not disappear in summer. However, for the most extreme scenario, RCP 8.5, which includes increasing use of fossil fuels as is the case today, the climatologists' models show warming up to four times faster in this century than in the last (4°C more by 2100 and even 6°C by 2200 and 8°C by 2300), a rise in sea level of up to 1 metre by 2100 and an ice-free Arctic Ocean in summer.

Increasingly violent cyclones

In the space of sixteen months, two Pacific archipelagos were hit by exceptionally destructive cyclones: the Philippines in November 2013 (7,000 dead and parts of the Philippines suffering heavy damage) and Vanuatu in March 2015, with gusts reaching more than 300 km/h. According to climatologists' projections, the incidence of this type of very violent cyclone should increase in line with global warming. Today, the UN estimates the financial loss caused by natural disasters at between 240 and 290 billion euros per annum.

Expert's view

Christian de Perthuis

Professor of Economics (Paris Dauphine University)

Scientific Director of the Chair of Climate Economics

« If we continue on today's emission curve, by the end of the century, we may see a rise in average sea level of between 60 cm and 1 metre. So what would a one-metre rise in sea level mean for the economy? About half the world's population lives in coastal areas today. In Asia, 350 million people live on deltas. So we're trying to measure what the cost of this rise in sea level would be for society. There are various types. First, production losses. The prime effect of the rise in sea level would be soil salinization, causing a huge drop in agricultural productivity. We have to measure this cost. Second, if we want to protect ourselves against higher sea levels and adapt to their impact, we'll have to build sea defences and organise our societies differently. That will cost money, a huge amount of money. Just think, most of Manhattan is less than a metre above sea level. Can you imagine how much it would cost to protect Manhattan from a one-metre rise in sea level? And, realistically, we know that this rise in sea level would cause population displacements, which would have a cost because they'd be forced, not at all voluntary. So the first task of economists is to measure the future costs of damage caused by climate change. There are obviously many uncertainties. So we produce hypotheses that suppose action will be taken to adapt, and hypotheses that suppose there won't be future conflicts caused by climate change. Yet events could take a far more dramatic turn than those we include in our models. So I'd like to stress that the models are and will continue to be full of uncertainties. As science has progressed – both climate science and our ability to analyse climate economically – we've realised that these effects are extremely complex and uncertain, but the uncertainty is no excuse for inaction. »

Moderate effects, major consequences

The Earth's warming is leading to chain reactions that will continue to grow with a destructive effect for the environment and humans.

In the 5th IPCC report, there is a long list of risks associated with the continuation of global warming: the disappearance of Arctic pack ice during the summer, oceanic acidification*, the migration and extinction of species, falling agricultural yields, food shortages, an increase in epidemics and the spread of diseases such as malaria to new regions, a reduction in water supplies, even more extreme weather events, rising sea levels, more natural disasters, new population displacements, etc. The variety of consequences is impressive for an increase in temperature that may seem modest (4°C by 2100 if it continues to rise at the current rate). Atmospheric warming causes chain reactions that further amplify its effects. By aggravating evaporation phenomena, it will increase the proportion of water vapour (a greenhouse gas) in the atmosphere, so adding to initial warming. Also, the melting of polar ice and glaciers will speed up. The regions stripped of their ice sheets and packs will not reflect so much sunlight (snow reflects 80% of solar radiation compared to 10% for forests, for example), so they will warm up and contribute a little more to world climate disruption.

*A term adopted by scientists that refers to a fall in the average pH in the surface waters of oceans of 0.1 units since the start of the industrial age. That pH stands at 8.1 today.

The issue of food security

Today, 805 million people worldwide do not have enough to eat. Climate disruption could mean there are 600 million more by 2080 according to the United Nations Development Programme (UNDP). There is expected to be a drop in yields of staple crops (wheat, rice, maize, etc.) and increased crop losses resulting from extreme weather events (see the 5th IPCC report). This means a risk of rising prices making it even more difficult for the poorest populations to secure food.

Europe is also at risk
Nations in the northern hemisphere are affected by extreme weather events too. Since 2000, Europe has experienced ten or so record heatwaves (the one in 2003 caused the death of 35,000 people in Europe, 15,000 of them in France), droughts and floods. The devastating floods that hit the south of the UK in the winter of 2013-2014 were the worst since meteorological records began. Even if it is not fully established that these extreme weather events can be directly attributed to climate change, there is now little doubt that global warming will make them even more violent.

Australian coral in danger
Year on year, Australia typifies the state of severe drought that could prevail in certain regions of the world if global warming continues at the present rate. It also epitomises another characteristic effect of global warming: coral bleaching due to the rise in sea temperature. The Great Barrier Reef has lost half its coral in just thirty years. Global warming is not thought to be the only reason. Intensive farming along the coast and the expansion of industrial ports for coal export also impact on water quality and so the coral of the Great Barrier Reef.

Oceanic acidification: tests at sea
To study the impact of oceanic acidification (due to increased CO_2 absorption) on marine flora and fauna, an innovative experiment was conducted in the Mediterranean from May to November 2014 (eFOCE project). Researchers 'trapped' different sea organisms in boxes reproducing different pH conditions at the bottom of the sea and monitored their development. Initial results show that Neptune grass (an aquatic plant) tolerates the pH level anticipated at the end of the century (-0.3 pH units). Analysis of the effect on other organisms (epiphytes, benthos, bacteria, etc.) is still in progress.

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Climate change: the world in search of solutions

So what can be done to combat climate change and mitigate or adapt to its impact? Internationally, in Europe and in France, are we really acquiring the means to reduce greenhouse gas emissions? What technological and industrial solutions are being studied? Should financial regulation processes be introduced, such as the very controversial 'carbon tax'? There is talk of energy and agricultural transition all over the world, but what form should it take? How can we avoid penalising developing nations? So many issues must be considered if the governments that participated in the Copenhagen Climate Change Conference sponsored by the UN in 2009 are to achieve their objective: to limit global warming related to human activity to 2°C by 2100 (compared to the pre-industrial level). To do this, at the end of 2015, they must reach a universal agreement on reducing greenhouse gas emissions to follow on when the Kyoto Protocol expires in 2020.

World objective: 2°C

Nations need to commit to far-reaching climate policies if they are to achieve their goal of keeping warming down to 2°C by 2100.

Limiting global warming to 2°C at the end of the century (compared to the pre-industrial level): that is the objective fixed by the governments that participated in the Copenhagen Climate Change Conference in 2009. To achieve this goal, climate projections show that no more than 1,000 gigatons* of carbon dioxide can be added to the 2,000 Gt already emitted into the atmosphere by human activity since 1750 (half of that since 1970). However, at the current rate, this critical CO_2 threshold will be reached in thirty years' time. So the objective announced by participating nations may soon prove impossible to achieve if nothing is done to drastically reduce (-40 to -70% by 2050) greenhouse gas emissions. Solutions exist in every sector and must be backed by major climate policies. The sole international agreement to date is the Kyoto Protocol, which only set binding obligations for developing nations and which will expire in 2020. So the aim of COP21 (the 21st Conference of the Parties to the United Nations Framework Convention on Climate Change), to take place in Paris from 30th November to 11th December 2015, is to forge an ambitious, universal agreement on the reduction of greenhouse gas emissions to replace the Kyoto Protocol. All the parties attending COP21 will be required to submit their commitments after the Conference. The European Union (28 countries emitting 9% of the world's GHGs) has announced a reduction of 40% of its emissions by 2030 compared to 1990 and an energy mix including 27% of renewables and 27% energy savings.

*1 gigaton of CO_2 = 1 billion tons of CO_2 = 10^9 tons

Popular demonstrations

On the 21st September 2014, nearly 600,000 persons joined the People's Climate March in 158 countries, half of them on the streets of the New York borough of Manhattan where the Leaders' Climate Summit organised by UN Secretary-General Ban Ki-moon was held a few days later. At the same time, an online petition (on the site of the NGO Avaaz) demanding 100% clean energy worldwide by 2050 was signed by 2 million citizens around the globe. In the run-up to COP21, different initiatives are being launched with the aim of influencing the decisions made in Paris.

China-USA: the first steps

In November 2014, China and the United States – responsible for more than 40% of the world's greenhouse gas (GHG) emissions – issued a joint statement on the climate. China, where the level of atmospheric pollution is becoming a major public-health problem, committed to a peak in the volume of its greenhouse gas emissions in around 2030 and then a reduction. The United States plan to reduce their emissions by 26-28% by 2025 (compared to 2005). Was this a first step towards participation in the Paris agreement and its 2°C objective?

The right to development for all

The world population has more than doubled since 1960, from 3 to 7,3 billion inhabitants today. It is expected to grow to 9 billion by 2050. This explosive population growth is accompanied by booming urban development and increasing energy and food demand. According to the UN Food and Agriculture Organisation (FAO), food production will need to increase by 70% over the next 35 years. New agricultural models must be developed if these needs are to be met while limiting agricultural greenhouse gas emissions.

Expert's view

Laurence Tubiana

Ambassador responsible for climate change negotiations, French delegate to COP21

« If I look at what's happening in developed nations, I can see we've actually begun to decarbonise our economies. Slowly, but it's happening! I know that in 2007, China recognised that climate change was a genuine problem and, since then, has been steadily implementing increasingly strict policies to reduce coal consumption, and other policies of that kind. So yes, there is genuine action. Perhaps not in the way we expected: we may not get the impression that high-level negotiations are achieving very much. Well, I've been at those negotiations and know what happens there. Nations learn. They learn two things. First, that it's possible, because other countries are doing it. They realise their narrow national interests are actually threatened by this collective, global phenomenon and they have to deal with it. At the same time, they can't do it alone. It's an incredible learning curve! If we hadn't gone through this process of holding these climate conferences again and again for many years, there'd be no results, because everyone would be pretty much powerless and even uninterested in the issue. The idea is always to focus attention. Another example: the experts who say that international talks are pointless should look at how international trade has changed since 1948. Liberalising trade from 1948 on wasn't a quick or easy task, but it was always positive. Let's say the end of that great stage of liberalising trade came at the end of the 90s. Today, many economies have opened their borders. Trade has increased exponentially. It took us more than 40 years to gradually reach agreements that recognised countries' rights, but also their duties to each other. Climate is the same thing. I don't see why we would say that it has worked for the world economy but it will not for climate. In a way, we have less than 20 years' experience of dealing with climate and well over 40 years of tackling financial-market deregulation and free trade. We're looking at difficult, complex problems and I can't say these international summits are pointless. »

Putting a price on carbon

So as to make renewable energies more competitive, one economic solution would be to make carbon prohibitively expensive.

Many economists believe that the most efficient way of drastically reducing greenhouse gas (GHG) emissions is to put a price on carbon. The aim is to make each CO_2 emitter pay for the damage their emissions cause. Currently, apart from the state of the market, coal, oil and gas prices reflect the rarity of subterranean deposits and the cost of their storage, transport and distribution, but do not take into account their impact on the atmosphere, which has a crucial effect on climate balance because of the greenhouse effect. The atmosphere can currently be used free of charge, as if it were a limitless reservoir able to hold all CO_2 emissions, which is not at all the case. To limit global warming to 2°C in 2100, 80% of coal, half of gas and a third of oil reserves will have to be left underground*! If we put a price on carbon worldwide, renewable energies will become more competitive**. Experiments conducted so far (GHG emissions trading, carbon tax) have not been completely successful, especially because they depend on government enforcement and only cover the GHG emissions of heavy industry (just 40% of GHGs), so economists recommend that the price of carbon should be universal and dissuasive in order to genuinely encourage energy transition.

*Research published by University College London in the journal *Nature* on the 8th January 2015

**In his plan of action for world energy transition (September 2014), the former Vice-President of the World Bank Nicholas Stern notably suggests ending annual subsidies for fossil energies, subsidised five times more than renewables.

A new fossil resource

With the growth of shale fracking, the USA is gradually phasing out the use of coal. The coal output of American mines is now partly exported to Asia and Europe. Fracking for shale oil and gas (a technology that requires huge investments and raises other environmental concerns) is a new source of fossil fuels. Since 2014, it has made the USA the world's top oil producer, just ahead of Saudi Arabia.

Less energy-hungry habitats for the future

To reduce building energy consumption, which accounts for 42% of demand in France, there are two approaches: the thermal renovation of existing buildings (France has set itself the objective of thermally renovating 500,000 homes a year from 2017) and the construction of new, 'energy-positive' ones. 'Energy-positive' buildings produce more energy than they use. They are especially equipped with solar panels on their roofs, high-efficiency thermal insulation and low-energy household appliances.

Energy transition made in France

French law has confirmed the aim of a 75% reduction in greenhouse gas emissions by 2050, notably through the development of renewable energies.

The French bill on energy transition for green growth was adopted after its final reading on the 22nd July 2015. It lays down ambitious goals for reductions in greenhouse gas (GHG) emissions, lower energy consumption and the development of renewable energies. The law aims to achieve a 40% cut in GHG emissions by 2030 and 75% by 2050 compared to the 1990 level; a halving of final energy consumption by 2050 (with an intermediate objective of 20% by 2030); and 30% less primary fossil energy consumption* by 2030. An increase in the carbon tax was also approved with an objective of 100 euros per ton in 2030, compared to 14.50 euros today. The proportion of electricity generated by nuclear energy should be reduced from 75% to 50% by 2025 and the share of renewables in energy consumption increased to 32% by 2030, especially through the development of wind, photovoltaic and biomass production. Other objectives are to renovate 100% of housing stock to 'low-energy building' standards or their equivalent by 2050 and ensure energy self-sufficiency in France's overseas territories by 2030. The investments involved are supposed to create jobs and fuel economic growth.

*Primary energy consumption = final consumption + energy losses incurred during production and delivery

'100% renewable' electricity?

According to a study by the French Agency for the Environment and Energy Management (ADEME) whose initial conclusions were published in April 2015, France's renewable-energy potential is three times greater than its demand for electricity. To realise this potential, wind-turbine production must be greatly increased, especially by installing turbines suited to softer winds, and the electricity network adapted.

What role does nuclear energy play?

Increasing nuclear production could be an option to reduce greenhouse gas emissions, but would involve many difficulties and risks.

The energy sector – from the extraction of resources to storage, transport and final distribution – emits the most greenhouse gas (GHG) worldwide. Its emissions increased by 3.1% a year from 2000 to 2010, compared to 1.7% a year from 1990 to 2000, and are overwhelmingly due to electricity production. One solution to reduce them could be to increase the use of nuclear energy, which emits very little GHG. 11% of the world's electricity production was nuclear in 2012 compared to 17% in 1993, so the proportion has fallen over the last few years. A number of obstacles and risks stand in the way of developing this technology: the danger of accidents in nuclear power stations and related safety issues (see Fukushima, 11th March 2011), waste management, cost (especially of safety), the risk of nuclear weapons proliferation, reliability of supply from uranium mines, public opposition, etc. There are other ways of reducing the GHG emissions of the energy sector: improved energy efficiency of fossil-fuel power stations, replacement of coal by gas, the development of renewable energies, CO_2 sequestration, a reduction in final consumption through restraint and energy efficiency, etc. While scientists determine the possibilities, energy choices are eminently strategic and so political in nature because of their impact on state finances and consequences for development.

The French exception… for how long?
The French nuclear industry (second only to the United States' worldwide) has reached a watershed: nearly half of the 58 nuclear reactors in its 19 plants will reach the end of their lives (40 years) between 2019 and 2025. They will have to be decommissioned or, if the Nuclear Safety Authority allows them to continue, be replaced by new-generation reactors (of the EPR class, like the European Pressurised Reactor at Flamanville). Whatever the decision, the cost will be high – whether to upgrade to the safety standards required by new reactors, manage radioactive waste or decommission the plants.

Living with climate risk
Combatting climate change requires adaptation strategies, particularly in the poorest countries.
Warming is already having an impact in certain parts of the world. Whatever the climate policies applied, the planet will inevitably continue to get hotter over coming decades. So, according to the IPCC*, we urgently need to adapt to climate change. For instance, we will have to build protective infrastructure (flood barriers, hurricane shelters, etc.) or evacuate populations in high-risk areas, improve our water-supply management to counter the risk of drought, diversify our crops and provide agricultural insurance against weather events. The poorest countries, which are most vulnerable to climate change, will not be able to cover the cost of these adaptation strategies. In 2009, following international negotiations, it was decided to set up a Green Climate Fund financed by richer nations to help developing countries tackle climate change through adaptation and mitigation (reducing greenhouse gas emissions). The Fund should receive $10 billion between 2015 and 2018 (France will contribute around $1 billion). That sum is much less than the initial objective of $100 billion a year by 2020. The experts of the IPCC consider adaptation to be essential, but it must be linked to mitigation, which is the only way to limit global warming. So in the 21st century, the amount of risk related to climate disruption will depend on how much our societies are willing to adapt and mitigate.

*5th IPCC report, 2nd volume, published on the 31st March 2014

Adapting to rising seas
Firms of architects are currently designing floating towns and islands where tens of thousands of people should be able to settle. The aim is to adapt to rising sea levels. Floating structures are already being tested in the Netherlands (a floating house in Rotterdam harbour). Docked village and floating leisure islet projects are being studied for use in highly vulnerable locations such as the Maldives.

Burying carbon dioxide
Another solution to reduce carbon dioxide (CO_2) emissions into the atmosphere is to capture it at source, in the smoke released by polluting factories, and store it underground. The main obstacles to this technology are the cost and feasibility of subterranean CO_2 sequestration. Despite this, it is starting to be used. Nine of the thirteen operational installations worldwide are located in Canada and the United States. Also, some specialists are recommending new farming techniques to use the natural capacity of the soil to sequestrate CO_2.

Towards a more restrained world?
Energy efficiency and restraint could considerably reduce world energy consumption and greenhouse gas emissions.
The world's ever-increasing human population will be forced to meet two major challenges: learning to control its consumption (particularly of energy) in order to reduce greenhouse gas (GHG) emissions while enabling poorer and emergent nations to develop in line with their peoples' needs. Energy restraint and efficiency policies combined with the development of renewable energies provide a great deal of leeway in reconciling all these parameters. Energy-saving solutions exist in every sector: better building insulation (thermal renovation), bioclimatic architecture, the development of public transport, the bioconversion of organic waste (biogas) for heating or electricity generation, cogeneration (combined production of heat and electricity), more efficient electric motors, shorter transport circuits (favouring local products), etc. All these solutions will enable considerably lower energy consumption in industrialised countries and the progressive replacement of fossil by renewable energy. In this new context, governments will still have a major role, but users, architects, urban planers, constructors, companies, farmers and local and regional authorities will also play a decisive part. So we must change many of our habits to enable a new energy civilisation to flourish.

Megasolar in India
India is building more and more solar power plants. The largest solar plant in the world should come on line in August 2016 at Rewa in the state of Madhya Pradesh. It will have an output of 750 megawatts and cover 1,500 hectares.

This record should be beaten within seven years by a solar plant with an output of 4,000 megawatts, again built in India, in Rajasthan state*. Will India, a quarter of whose population still has no mains electricity, soon be the world leader in solar energy?

**Scientific American*, 6th February 2014

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