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THE INTERACTIONS BETWEEN OCEAN AND CLIMATE

6 fact sheets for the general public

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THE ROLE OF THE OCEAN IN CLIMATE DYNAMICS

A Living Ocean, a Living Planet

Graphism: Xavier Bougeard and Elsa Godet

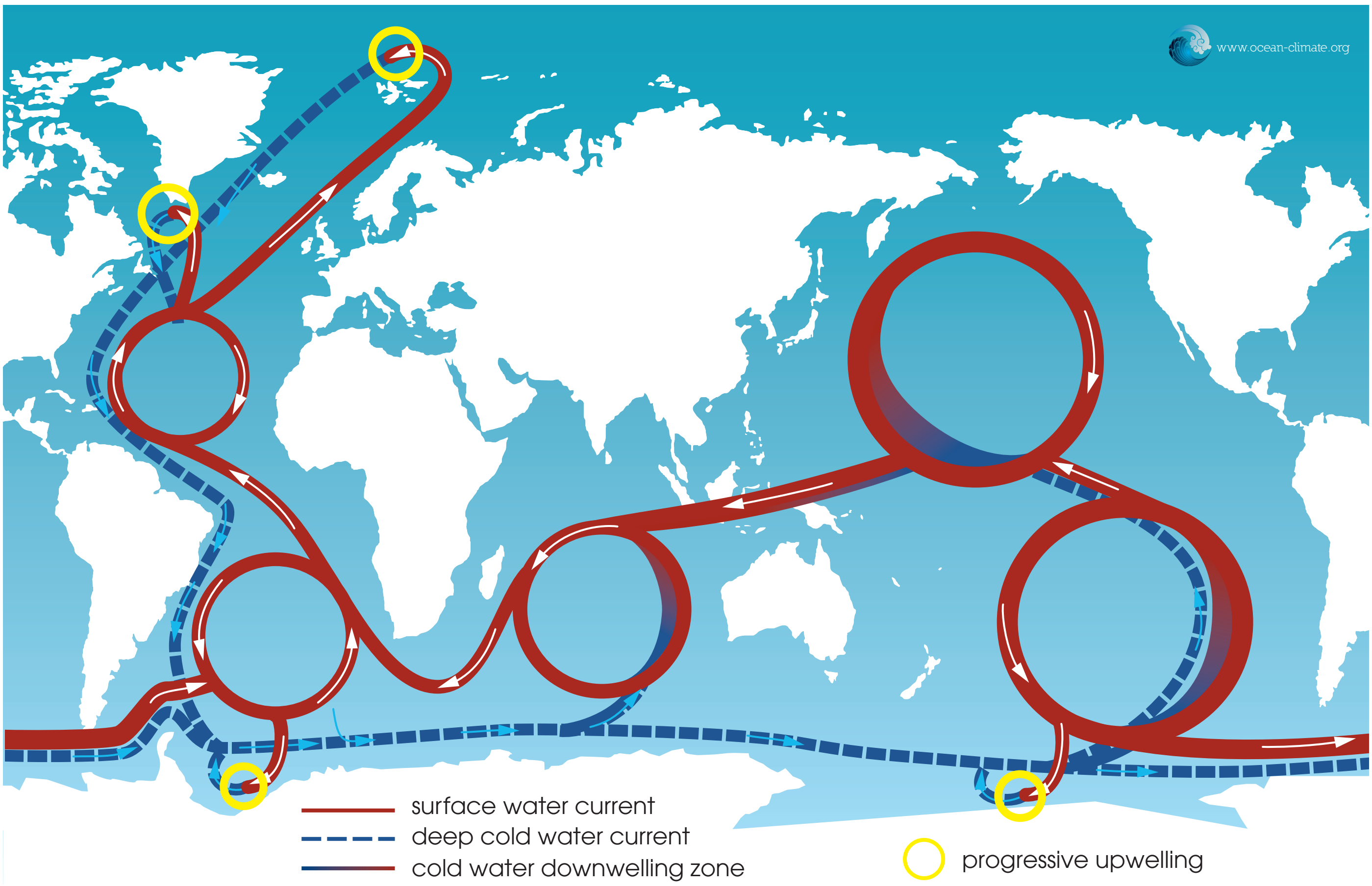
THE OCEAN, THE PLANET'S THERMOSTAT (1/2)

An Ocean is a Massive Pump!

The ocean is constantly exchanging with the atmosphere. It stores and distributes large amounts of heat around the globe via ocean currents. In this way, the ocean plays a key role for the global climate. However this regulatory mechanism is presently disturbed by global warming, consequence of the greenhouse effect.

The five oceans: the Atlantic, Pacific, Indian, Arctic and Southern, all communicate with each other, forming the global ocean. This huge mass of water affects the climate by absorbing solar energy and releasing heat. Indeed, the Ocean has a strong heat capacity. It can heat up and cool down very slowly and is capable of storing around a thousand times more heat than that of the atmosphere. The ocean then restores this heat to the atmosphere over periods that can cover several centuries.

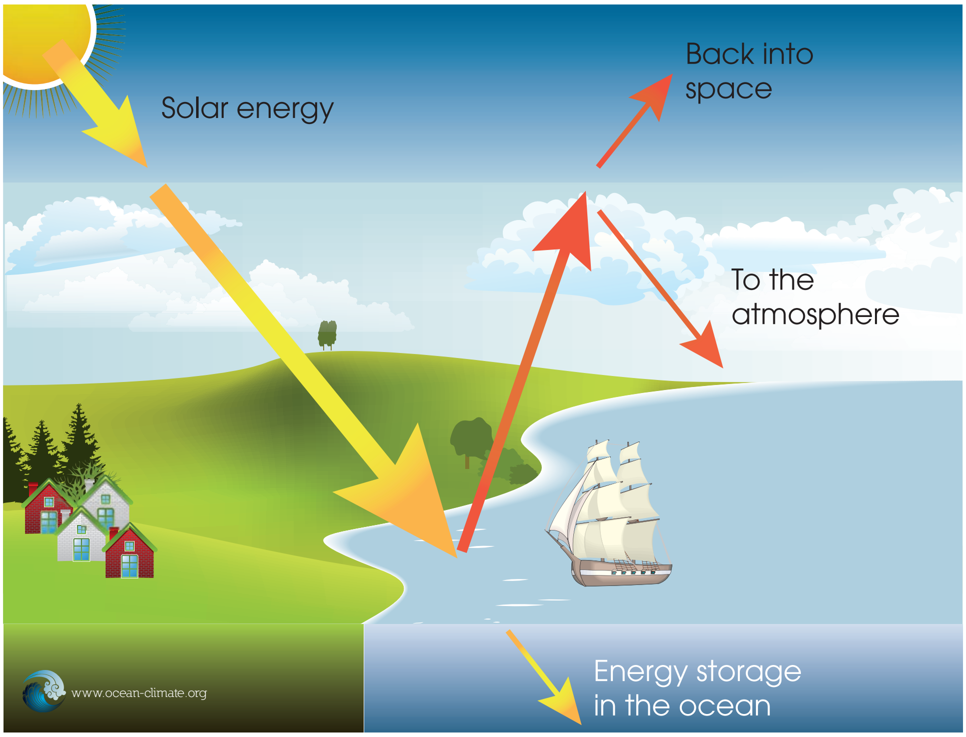
Ocean currents redistribute the absorbed solar energy. Ocean circulation is controlled by surface winds, by the rotation of the earth and by certain physical properties such as temperature and salinity. Warm water masses carry surface heat accumulated in the tropics towards the poles, thus reducing latitudinal temperature differences. The Gulf Stream, for example, has this role. Coldwater currents at great depths follow the opposite direction. This global "conveyor belt" circulation contributes, with constant exchanges to and from the atmosphere, to the redistribution of heat across the planet.



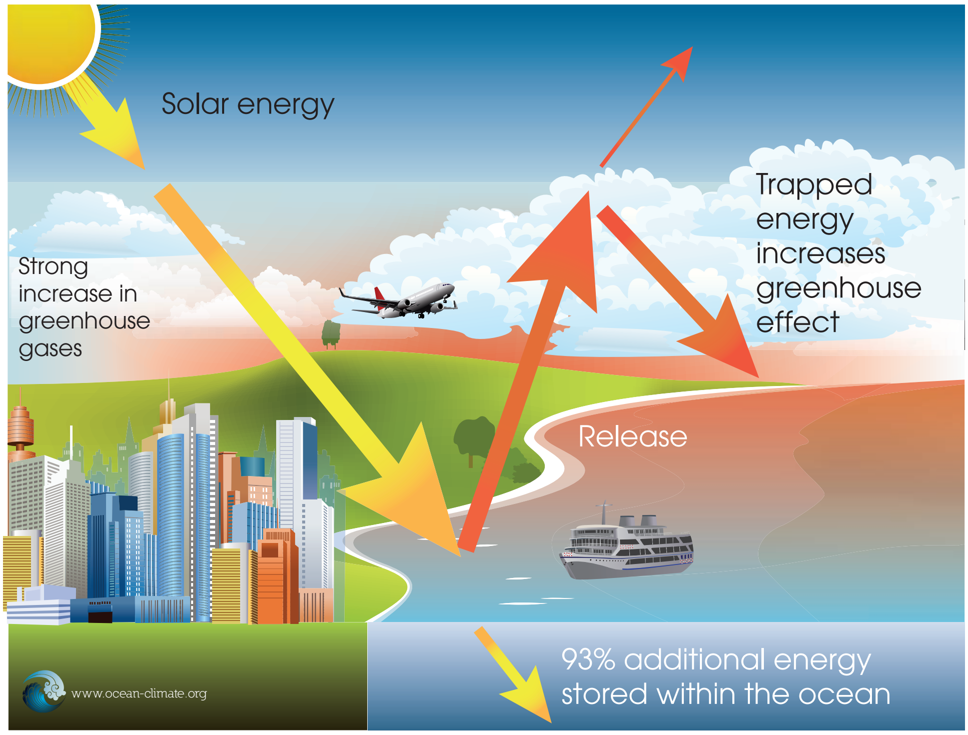
Simplified diagram of the global ocean circulation

THE OCEAN, THE PLANET'S THERMOSTAT (2/2)

BEFORE INDUSTRIAL DEVELOPMENT



CURRENT SITUATION



Increase of the greenhouse effect

Ninety three per cent of the excess heat generated by human activities via the greenhouse effect is absorbed by the ocean, thus mitigating the increase in temperature of the atmosphere. This heat absorption causes a slight warming of the ocean. This can be felt down to at least seven hundred meters depth. It has now reached the great depths of the polar regions and is being spread towards all the ocean basins. Given the volume of the ocean, this represents an enormous amount of heat! However, even if greenhouse gas emissions were to be interrupted today, the effects of the increasing ocean temperature would persist for several decades.

The global ocean therefore has a role in the regulation and control of the large natural planetary balances. It regulates climate fluctuations. Indeed, the latter would be much more rapid and more powerful if they were only governed by the atmosphere.

The increase in temperature related to human activities affects all global thermal mechanics, including the ocean, while the ocean and atmosphere continue to interact permanently.

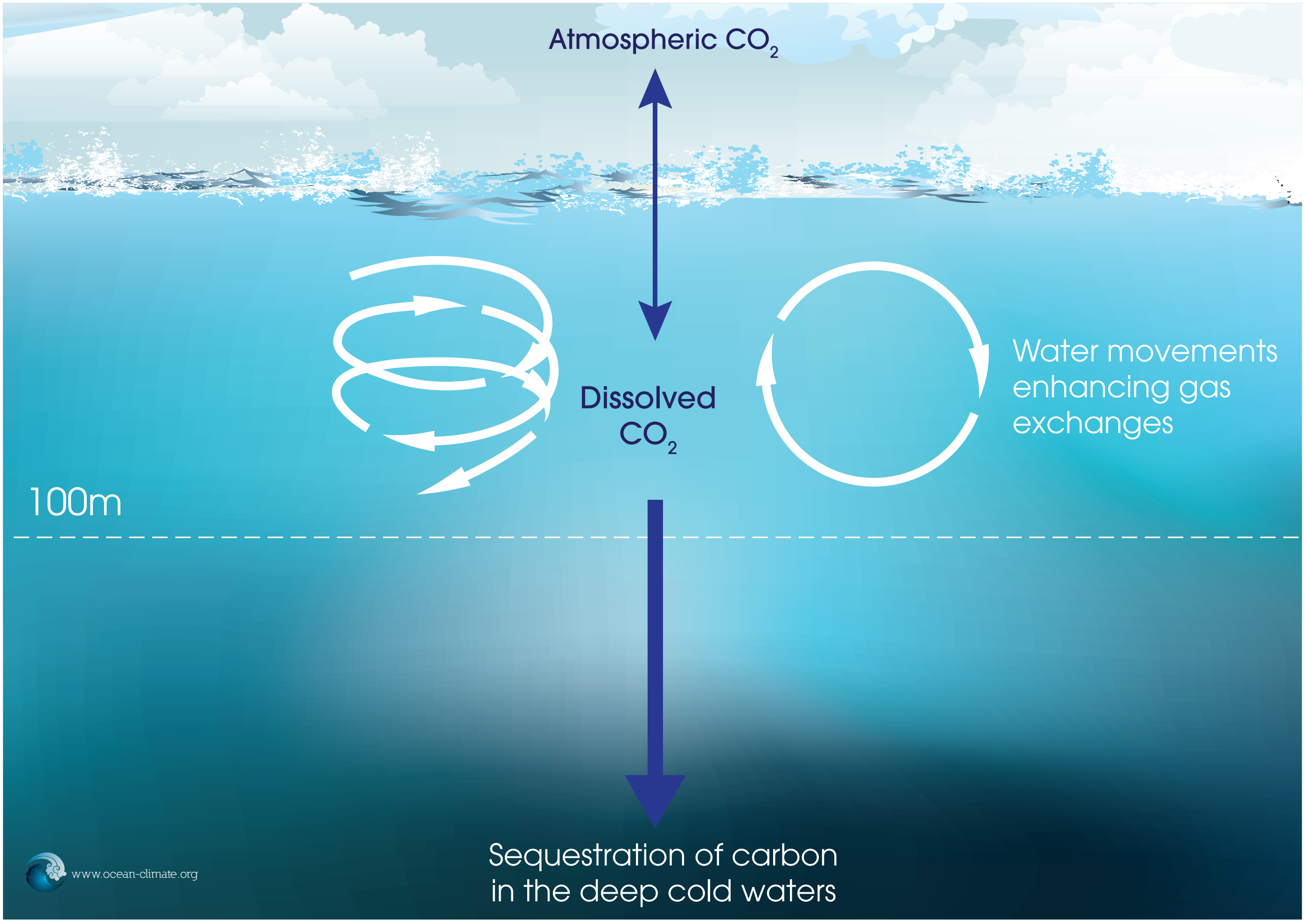
THE OCEAN, ORIGIN OF LIFE ON EARTH (1/2)

As Long as there is Plankton!

The ocean is home to a population called plankton. Invisible to the naked eye, it is formed by microscopic organisms that flow with the ocean currents. It represents more than 95% of marine biomass and is characterised by an extraordinary diversity: viruses, bacteria, microalgae, reproductive cells, fish larvae, micro-crustaceans, etc.

A part of the plankton, phytoplankton, also called microalgae, behaves just like plants: through photosynthesis, it absorbs carbon dioxide and produces more than 50% of the oxygen we breathe.

Two main mechanisms transfer the carbon dioxide (CO_2) from the atmosphere to the ocean. The most important phenomenon is physical: about nine-tenths of atmospheric carbon dioxide is transferred to the ocean by simple dissolution of the gas into surface seawater which is then transported by ocean currents to the deep layers of the ocean.



Physical carbon pump

THE OCEAN, ORIGIN OF LIFE ON EARTH (2/2)

The second mechanism, which represents 10% of the accumulation of carbon in the oceans, is related to biology: phytoplankton, suspended in the sunlit ocean surface layer, takes part in the carbon cycle by producing organic matter via photosynthesis. This plankton is considered as a «lung» for the planet, comparable to forests on land: indeed it absorbs CO_2 and produces oxygen (O_2). Over geological timescales, photosynthesis has led to the oxygenation of our atmosphere.

thanks to plankton. Nonetheless this pump is increasingly affected by global climate change, leading to important questions that arise. What is the resilience of plankton communities? How vulnerable is this sophisticated climate machine?

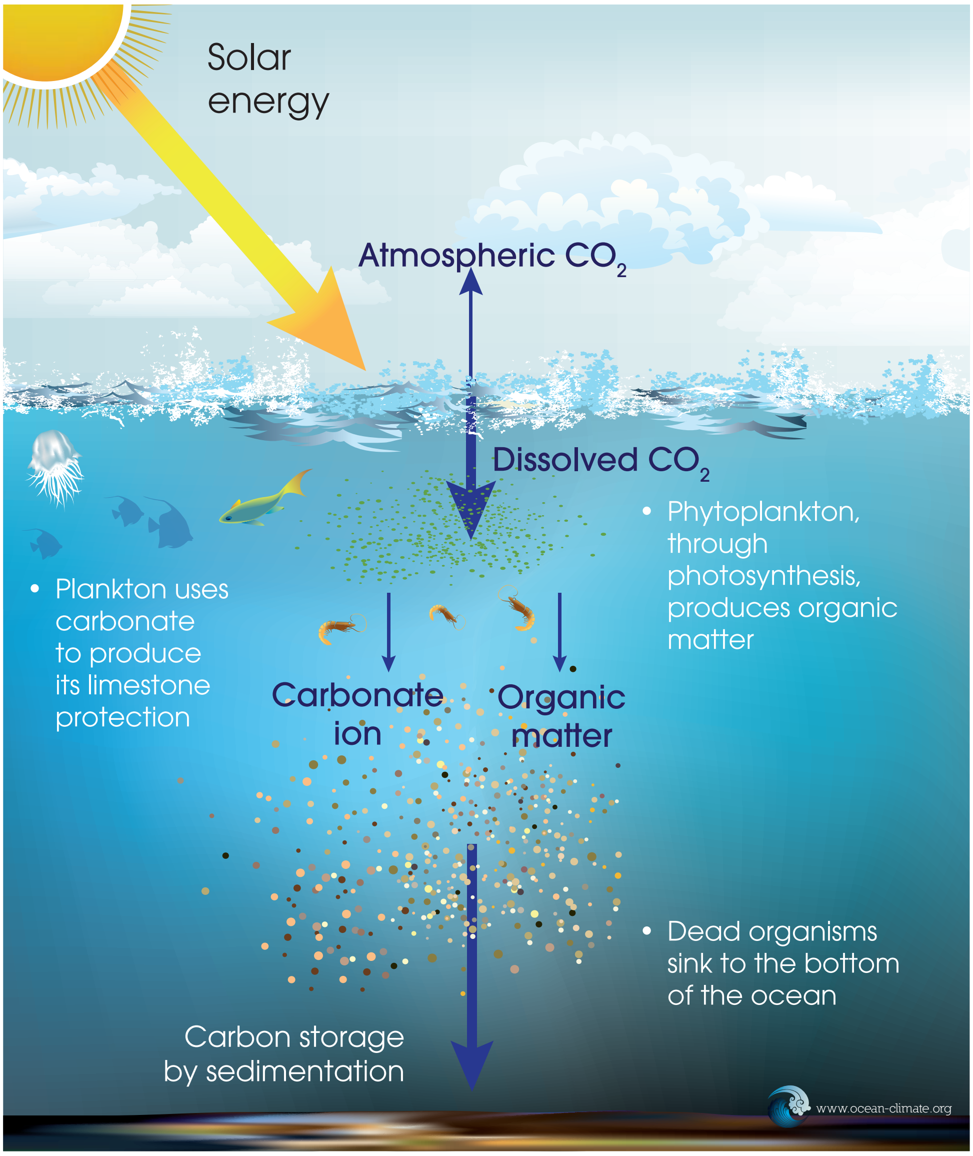
The role of plankton biodiversity in climate regulation therefore represents one of the major issues for the global climate.

When plankton is not consumed and dies, it sinks to the bottom of the sea where it accumulates, forming thick layers. The carbon-rich organic matter contained in this sediment can eventually evolve into oil or gas.

Phytoplankton species with calcareous shells are also involved in carbon sequestration as they store calcium carbonate ($CaCO_3$) in their shells. These sediments then develop into limestone. The cliffs of Dover are a typical example.

This biodiversity is represented by thousands of species of algae and planktonic animals. It is the first link in the marine food chain and is vital to all fisheries and to the global economy which depends on it. However, knowledge about the global ecosystem is very patchy. The way it works, its biological importance and economic value are yet poorly known by policy makers, as well as the general public.

The ocean therefore plays a major role in climate regulation as it acts as a carbon pump and source of oxygen



Biological carbon pump

FROM THE OCEAN TO THE CLOUDS

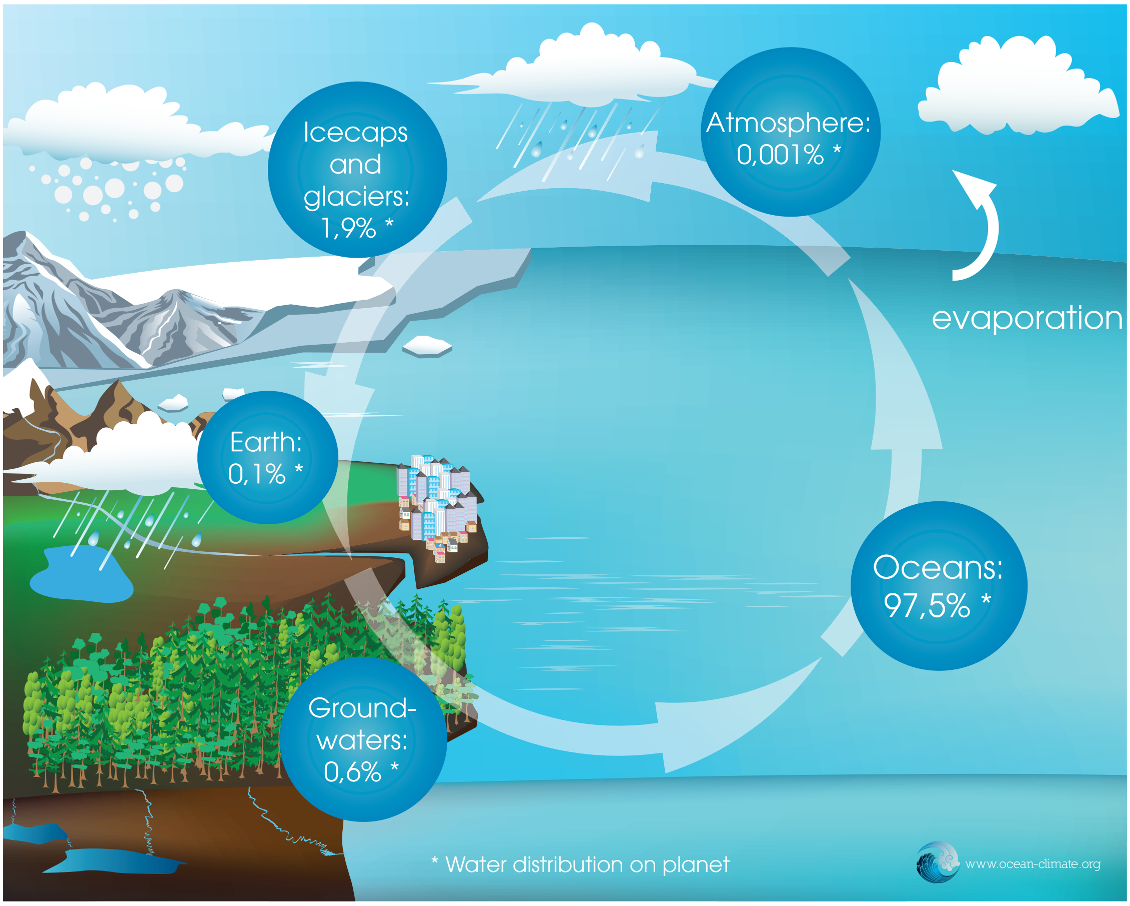
Water: the Great Mystery

Water is essential to life. The ocean covers more than 70% of the surface of the planet and contains 97% of the water across the globe, making it the largest water reserve in the world. For billions of years, the amount of water ceaselessly circulating and recycling on the planet Earth has remained unchanged.

The Earth is the only known planet where, depending on its temperature, water exists in three states: liquid, solid (glaciers, icebergs ...) and gaseous (vapour). Due to solar radiation, surface ocean water warms up and evaporates into the atmosphere. Hence, the role of the ocean in the climate system is fundamental, requiring that close attention should be paid to it.

The water vapour is transported by the ascending air currents to altitudes where low temperatures condense the steam into water droplets or ice crystals that form clouds. Air masses travel with the wind. Under certain conditions, the droplets or crystals grow and then drop down to earth in the form of rain or snow fall. The snow can accumulate and form polar caps and glaciers. Rain and sleet bring fresh water to lakes and rivers. Much of this water seeps into the soil and feeds rivers and groundwater. This water is in constant motion and always ends up by returning to the ocean: this is the water cycle. Typically, a drop of rainwater, just like a drop of tap water, has therefore already been in the ocean many times. It may take a thousand years to be transported across the world ocean by global ocean circulation. However, the course of this drop of water can be profoundly altered by climate change.

As it represents the main reservoir for the water cycle, and with its continuous exchanges with the atmosphere, the ocean is closely related to the climate. Consequently, owing to global warming, this cycle presently tends to accelerate and causes more frequent extreme weather events such as rainfall, droughts, or cyclones.



Water cycle

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THE IMPACT OF CLIMATE CHANGE ON THE OCEAN

With a Degraded Ocean, our Planet is in Danger

Graphism: Xavier Bougeard and Elsa Godet

OCEAN ACIDIFICATION (1/2)

Acid Attack

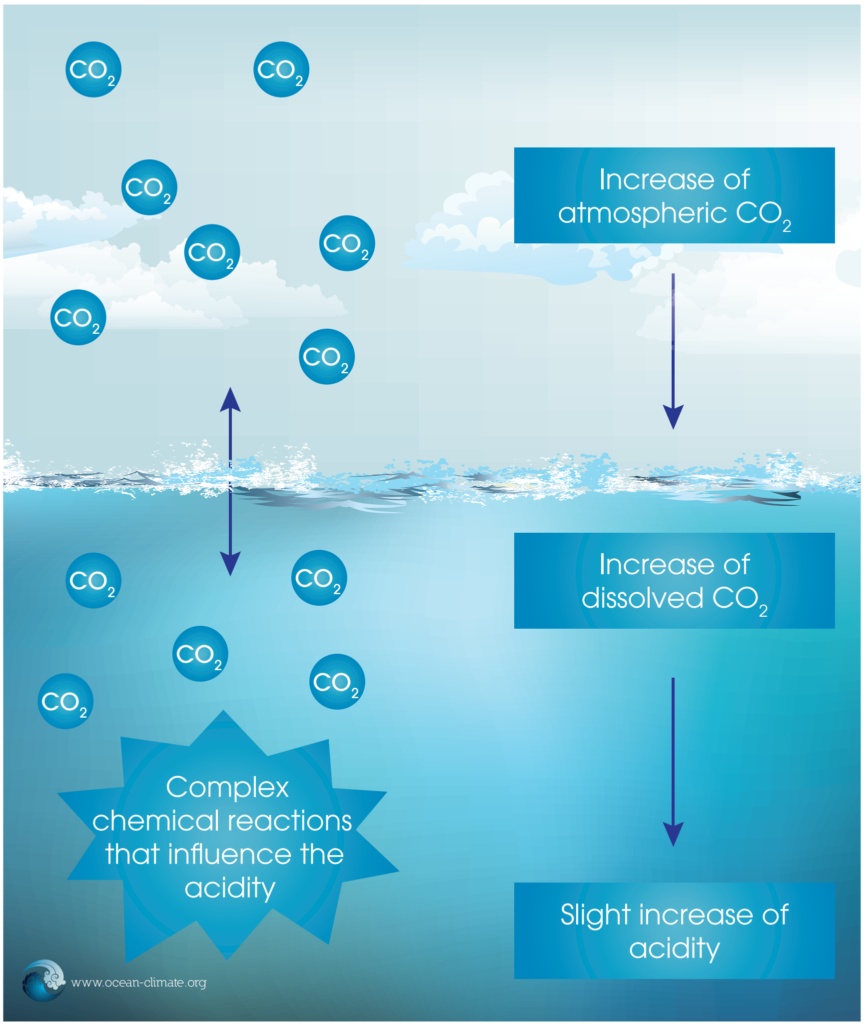
About a third of the carbon dioxide (CO_2) generated by human activities has already been absorbed by the ocean since the beginning of the industrial revolution. This contributes to attenuate the effects of global warming. Without this process, the amount of CO_2 in the atmosphere would have been much greater than that observed today. The effects on the climate would be multiplied.

Part of atmospheric CO_2 dissolves at the surface of the ocean. Once in the water, it can subsequently be found in different forms, including carbonic acid. This chemical reaction is the cause of the changes in chemical equilibrium of sea water. The result is, firstly, an increase in hydrogen ions, causing acidification and, secondly, a decrease in bicarbonate ions and carbonate ions. The latter are essential elements for the construction of skeletons and other calcareous structures in marine plants and animals.

"Ocean acidification" is defined by a decrease in pH, which is the unit of measurement of the acidity of a liquid. Acidification has increased by 26% since the beginning of the Industrial Revolution (1800). However, certain prediction models expect a 150% increase in acidity by 2100. The current rate of ocean acidification is ten times faster than it ever was at any other period during the preceding 55 million years.

The consequences of this phenomenon began to be studied in the late 1990s and still remain ill known. Experiments have shown that certain types of phytoplankton, such as coccolithophores that are covered with calcareous plates, and some animals with calcareous skeletons, develop defects when living in an acidic environment. Marine ecosystems and their biodiversity and food webs, that human communities depend upon, are therefore likely to be affected by the accelerating ocean acidification.

Acidification is a dramatic change taking place in the ocean. The warming of surface waters is another. Moreover, the latter contributes to reduce the ocean's capacity of absorbing CO_2. This leads to an increase in the concentration of atmospheric CO_2, in turn aggravating its impact on the climate.

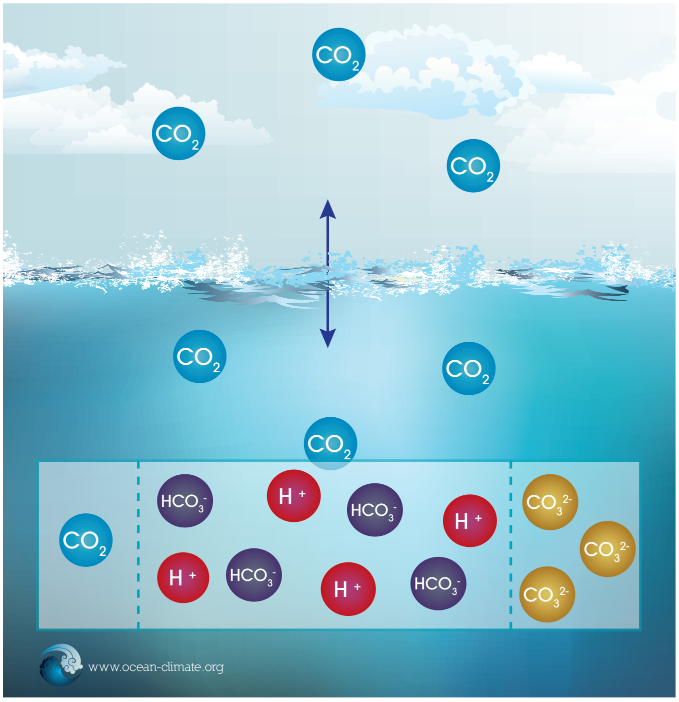


Simplified mechanism of ocean acidification

OCEAN ACIDIFICATION (1/2)

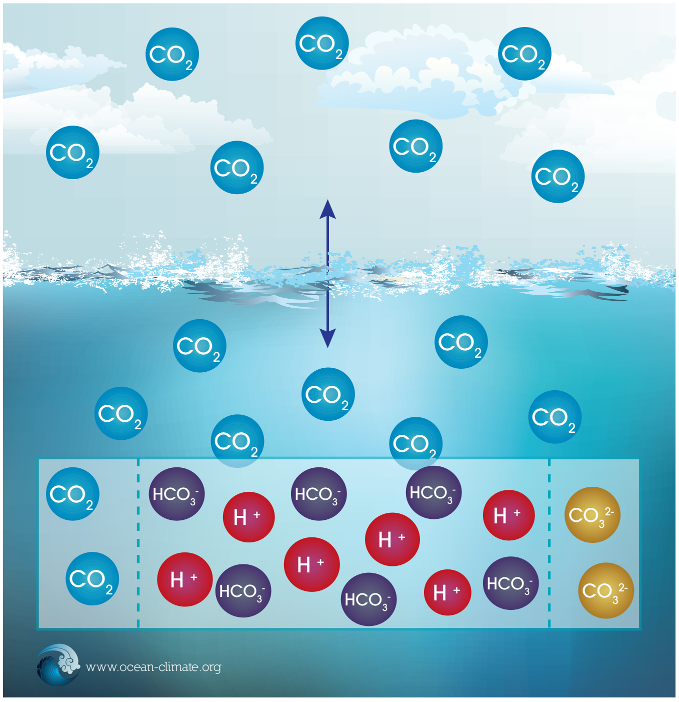
Learn more about the chemical mechanism of ocean acidification

Before the industrial era (1800)



CO_2, HCO_3^- and CO_3^{2-} are in stable proportions

Today



The balance has shifted:

CO_2 and HCO_3^- increase CO_3^{2-} decreases

Increase of H^+ = Increase in acidity

LEGEND

CO_2 = Carbon dioxide
$H_2CO_3^-$ = Carbonic acid
HCO_3^- = Bicarbonate ion
CO_3^{2-} = Carbonate ion
H^+ = Hydrogen ion

GOOD TO KNOW

In water, the three compounds CO_2, HCO_3^- and CO_3^{2-} are found in stable proportions depending on the conditions.

Dissolved CO_2 reacts with water: $CO_2 + H_2O \rightleftharpoons H_2CO_3$

Carbonic acid dissociates: $H_2CO_3 \rightleftharpoons HCO_3^- + H^+$

Same for Bicarbonate ion: $HCO_3^- \rightleftharpoons CO_3^{2-} + H^+$

GOOD TO KNOW

The concentration of H^+ defines acidity: the higher the concentration, the greater the acidity and lower the pH.

GOOD TO KNOW

The term «acidification» indicates an ongoing process, which is the modification of the pH; however the ocean will still not become an acidic medium.

THE DECLINE OF MARINE BIODIVERSITY

Life in the Ocean: The Day after Tomorrow

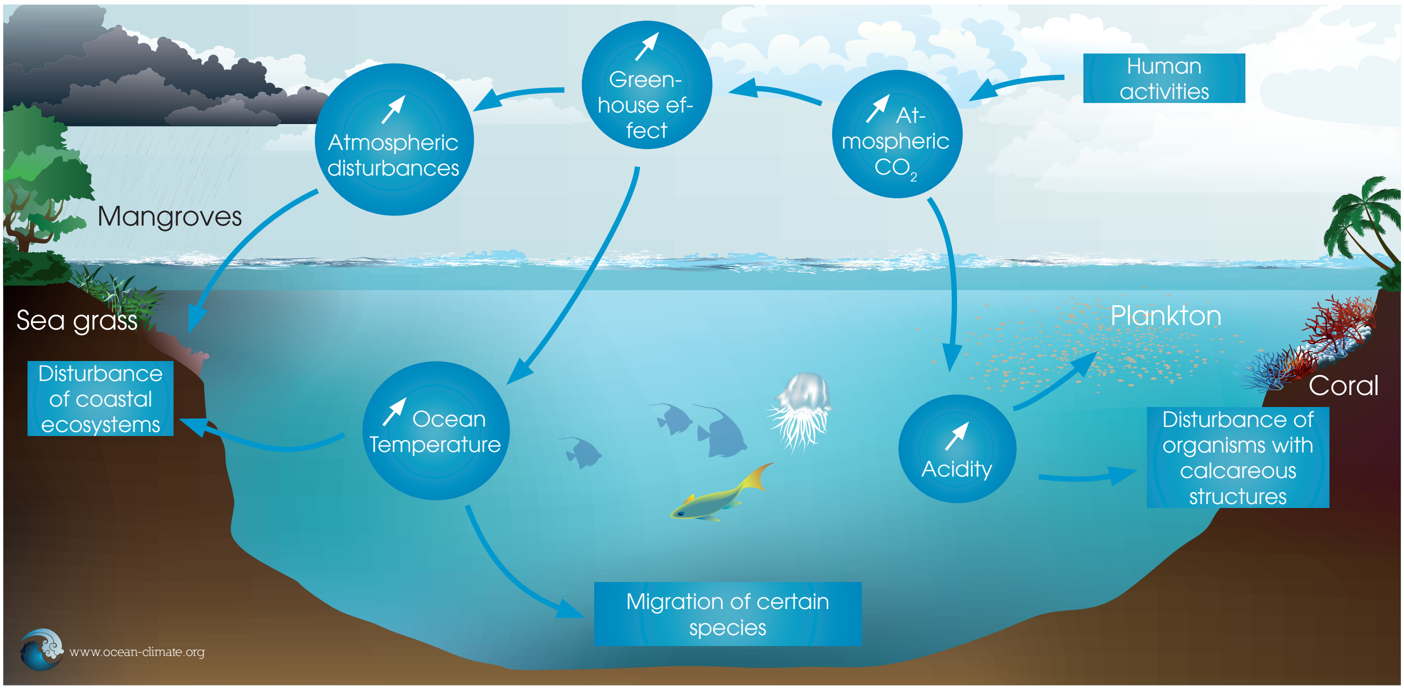
The loss of marine biodiversity is weakening the ocean ecosystem and its ability to withstand disturbances, to adapt to climate change and to play its role as a global ecological and climate regulator.

The ocean is home to millions of species. The health of the oceans is strongly dependent upon this marine biodiversity. Life in the ocean is an essential component of climate regulation. Climate change due to human activity has a direct impact on marine species. It alters their abundance, diversity and distribution. Their feeding, development and breeding, as well as the relationships between species are affected.

- Rising temperatures lead to different behaviour patterns according to species. Some adapt to temperature changes, while others migrate toward the poles or to new areas. Other species disappear, as has been observed for certain corals that can rapidly bleach and die when their symbiosis with the unicellular algae, that they shelter and feed on, is interrupted.
- The ocean acidification, caused by an increasing absorption of atmospheric carbon dioxide (CO_2), has a direct impact on the marine organisms with calcareous skeletons or shells: these include phytoplankton, crustaceans, molluscs...
- Extreme climatic events deplete natural environments, for example by erosion and flooding. They disturb marine life in coastal areas, particularly in certain coastal habitats such as mangroves and seagrass beds, which are vital breeding grounds as well as potential CO_2 capture zones.

Fish is a primary source of animal protein for at least one billion people in the world. Apart from overfishing or pollution, climate change alone heavily affects the food resources for human populations, in developing countries essentially. Losses in biodiversity also imply a loss of genes and molecules that are potentially valuable for medical research and industry.

Due to these multiple changes that cumulate on marine ecosystems, the ocean is becoming, in turn, very sensitive to climate change. Indeed, the more ocean ecosystems become depleted, the less they are able to adapt to climate change. The severity of this situation has been considered too lightly.



Consequences of CO_2 increase on the ecosystems

AN OCEAN UNDER PRESSURE

2100: A Climate Odyssey

Climate change is difficult to perceive on a daily basis. This also concerns the rise in air and sea temperature or in the level of the ocean. However its effects on natural phenomena are frighteningly real. The coastal zone is first in line face to the effects of climate change.

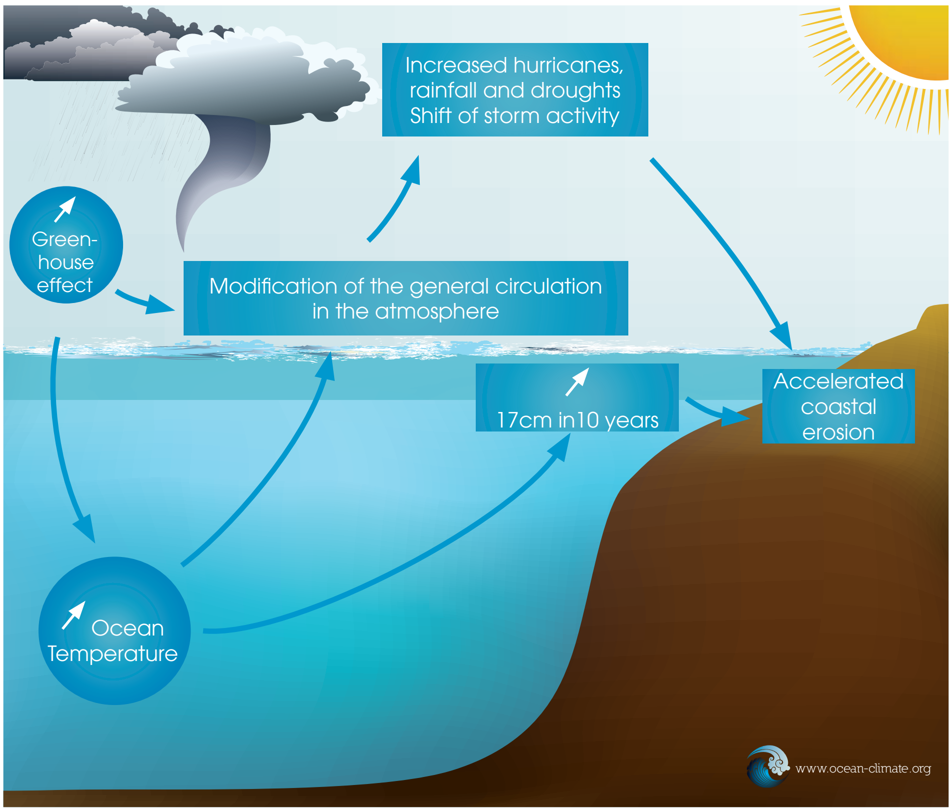
The ocean absorbs and stores both solar energy as well as the excess heat generated directly or indirectly by human activities. The ocean is therefore a massive heat reservoir, possessing a higher thermal capacity than the continents, and worth a thousand times more than that of the atmosphere. It is acknowledged that the volume of water in the ocean expands with the rise in temperature. Indeed, for an equal mass of water, hot water represents a greater volume than that of cold water. Thus, global sea level has been rising due to the effects of excess heat stored by the oceans and to increase in the volume of water from melting glaciers. Since 1992, it has already risen by an average of three millimetres per year. This trend is now accelerating.

Nevertheless, this sea level increase can vary geographically according to the influence of winds and ocean currents. Another attenuating factor can be the progressive rising of certain land masses, in response to the decrease in the weight of the glaciers that have disappeared since the last glaciation. This effect, however, remains very localized.

The more the temperature rises at the surface ocean, the more it heats the air and increases the amount of water evaporating into the atmosphere. Some of this water vapour, transported by the wind, eventually reaches the continents. The water cycle in the atmosphere has therefore changed, becoming more disturbed. The changes observed include a tendency towards an intensification of rainfall and more severe droughts occurring in certain parts of the world.

The increase of heat in the ocean, coupled to interactions with the atmosphere, also seems to have impacted the general circulation of the atmosphere. Large wind structures appear to shift in latitude, with the tropical belt that tends to expand, while westerly wind systems seem to be strengthening in the North Atlantic. Larger and larger networks of observations in this ocean basin are beginning to perceive an increasing intensity of hurricanes. Additionally, increased flooding event have also been reported.

Rising sea levels, strengthening of winds, storms and cyclones particularly affect coastal areas. The deterioration of natural environments also weakens their capacity to resist against the severe consequences of climate change: these include coastal erosion, a drop in biodiversity and migration of populations. They inevitably lead to environmental, economic and social disparities.



Physical consequences of the increase of atmospheric CO_2