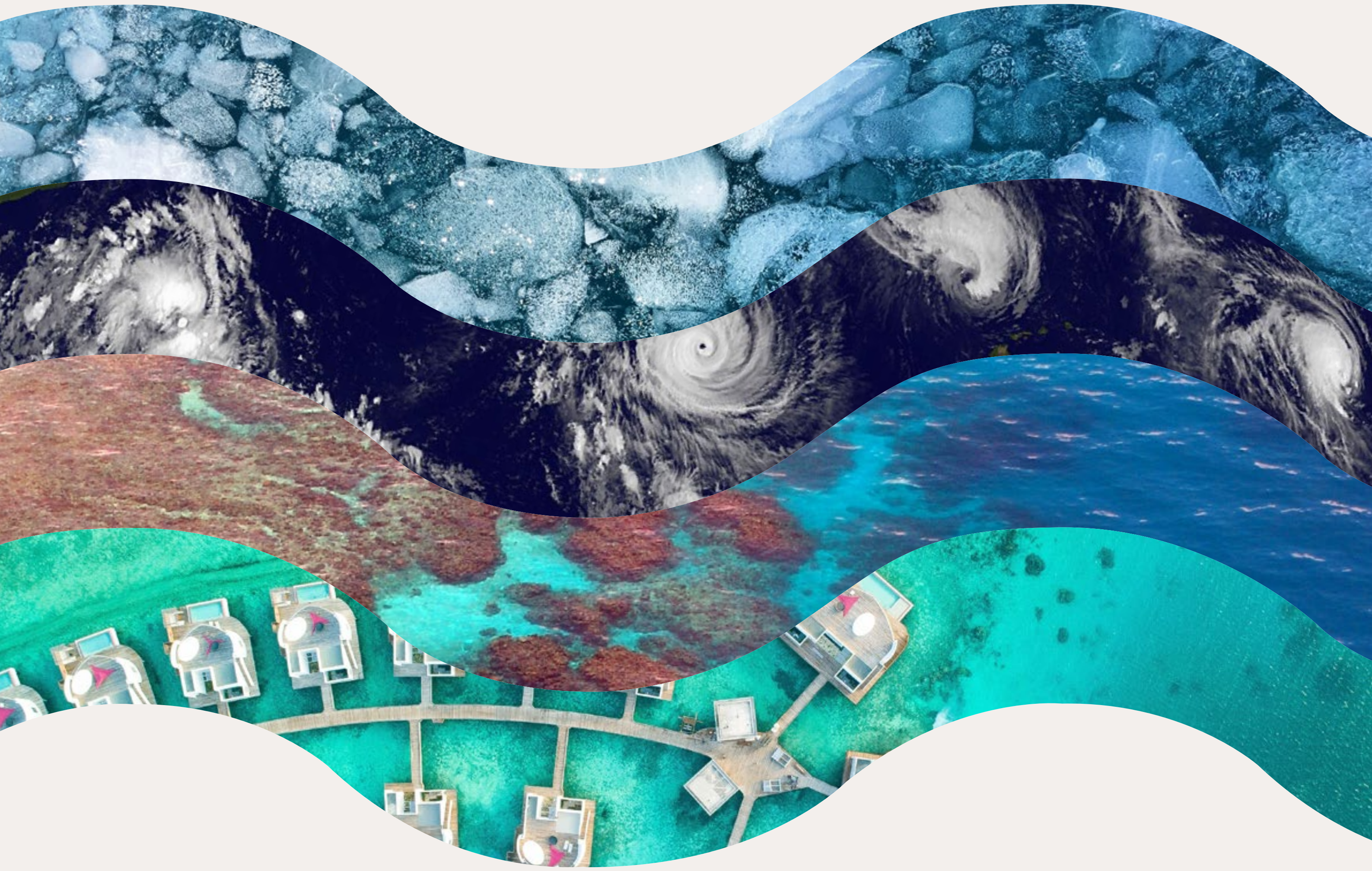
# OCEAN & CLIMATE CHANGE: NEW CHALLENGES

*Focus on 5 key themes of the IPCC Special Report on the Ocean and Cryosphere*



ocean-climate.org

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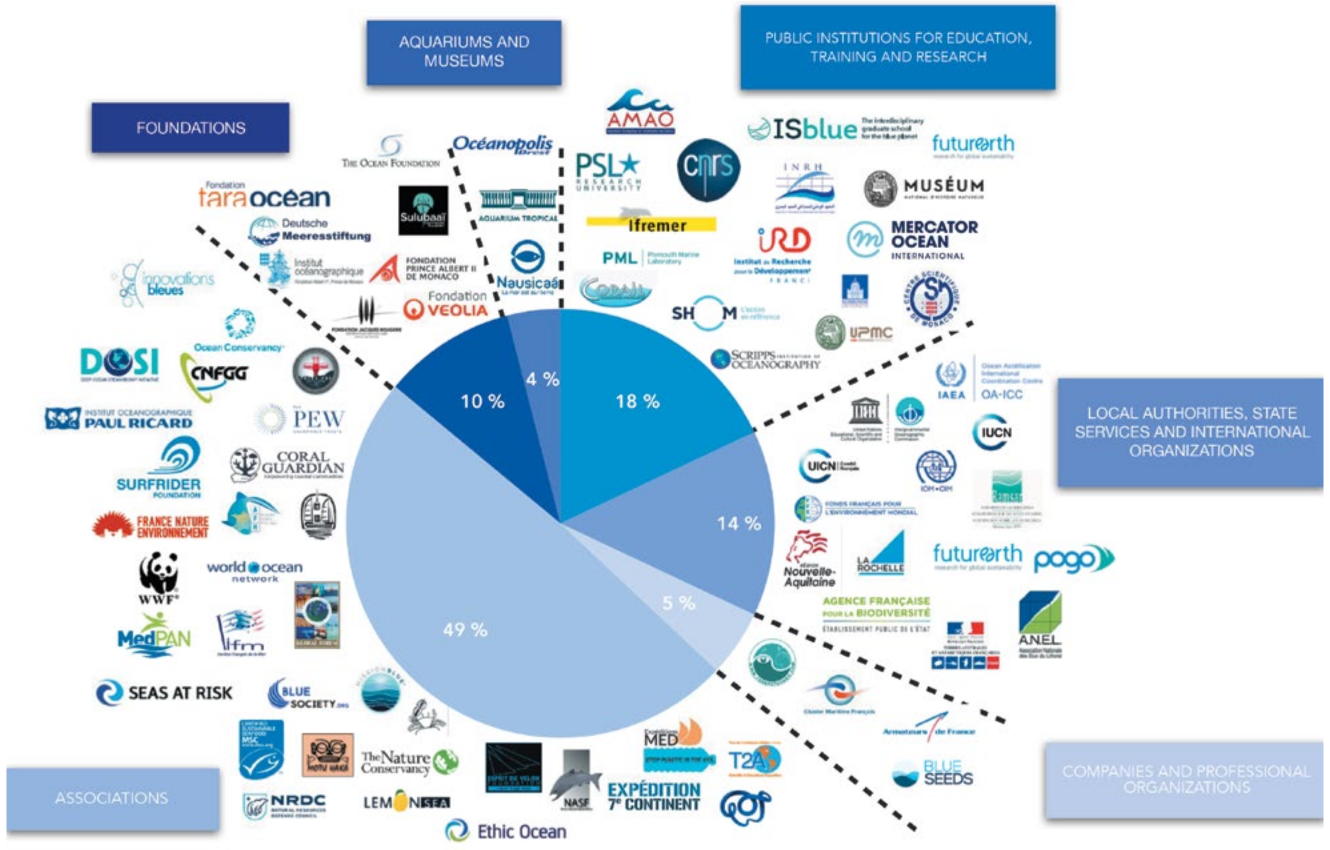
# About the Ocean and Climate Platform

The Ocean and Climate Platform (OCP) was formed out of an alliance between non-governmental organizations and research institutes. It brings together more than 70 organizations, scientific institutes, universities, research organizations, etc., whose objective is to enhance scientific expertise and advocate on ocean-climate issues with policy-makers and the great public.

Relying on its strong expertise, the OCP supports decision-makers by providing them with scientific information and guidance to implement public policies. The OCP also responds to a need expressed by both the scientific community and representatives of the private sector and civil society by creating a space dedicated to meetings, exchanges and reflection where ocean and climate stakeholders can build an effective and holistic approach to address the challenges of protecting marine ecosystems and combating climate change.



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# Introduction

Seen from space, our Earth is blue. There is a good reason for this: the Ocean – the largest ecosystem on the planet –represents 71% of the world's surface and more than 90% of the volume of habitat available to the living world.

Both a carbon sink (absorbing 30% of anthropogenic emissions) and a heat reservoir (having absorbed 93% of the heat emitted since the Industrial Revolution), the Ocean plays a key part in regulating the climate by limiting global warming. It also plays a central role in our human societies. Indeed, approximately 30% of the world population lives within 100 km of the coasts; about 3 billion people depend on sources of protein of marine origin; and many economic activities, such as shipping or tourism, are linked to the sea.

However, the Ocean is now strongly affected by human activities that alter its ability to limit the impacts of climate change. There is an urgent need to maintain the functional quality of marine ecosystems and restore those that are deteriorating in order to safeguard the future of our planet.

Strong and scientifically informed political action is now essential to tackle climate change. The Ocean has long been absent from the climate negotiations. This fact led to the creation, in 2014, of the Ocean and Climate Platform, a coalition of scientists from various disciplines, NGOs, aquariums and French and international institutions, who gathered ahead of COP21 to include the Ocean on the political agenda. This collective initiative was a success, as reflected in the introduction of the Ocean into the preamble of the Paris Agreement, and the publication of a Special Report on "the Ocean and Cryosphere in a Changing Climate" (SROCC) by the Intergovernmental Panel on Climate Change (IPCC) in September 2019.

The only French NGO to have taken part in the government review of this major document, the Platform now presents "Ocean & Climate Change: New Challenges", a booklet analyzing five key themes addressed in the Special Report: global warming, ice melt, sea level rise, extreme events, and deoxygenation. These alarming phenomena are real challenges for the future. Their complex interactions are summarized in two diagrams, entitled "Consequences of human activities on ocean-climate interactions" and "Ocean and climate change: Overview of the consequences". A healthy Ocean means a protected climate.

Our ability to preserve a sustainable world, respectful of all living things, depends on a proper understanding of these cause-effect relationships.

## *FACT SHEET 1*

# OCEAN & CLIMATE: WHERE DO WE STAND?

*Christine Causse, Nausicaa.*
*Françoise Gaill, CNRS and Ocean and Climate Platform.*

The Ocean and cryosphere (snow, ice, glaciers, pack ice, frozen soils) are the basis of balances sustaining life on our planet. They are also at the core of climate regulation. Global warming resulting from increased greenhouse gas emissions related to human activities is causing significant and sometimes irreversible changes in the ocean environment and the cryosphere. Their impacts will be felt from the mountain tops to the deep ocean floor, disrupting living conditions and posing unprecedented risks to living organisms, ecosystems and human communities.

## ① CONSEQUENCES OF HUMAN ACTIVITIES

Throughout our planet's history, changes have affected the ocean and cryosphere through natural processes. However, those that are currently occurring are unparalleled in their speed of appearance, magnitude and extent. Scientific results show that most of the changes affecting the ocean and cryosphere originate in human activities. With climate change, environmental conditions that have not been seen for millions of years are being observed in the ocean and cryosphere.

## ② CHANGING ENVIRONMENTAL CONDITIONS

Changes in the ocean and cryosphere play a key role in determining global climate. Moreover, their impacts on ecosystems and human societies are now evident (high level of confidence). These changes include a constant warming of seawater, ocean acidification and deoxygenation, reduced snow cover in the northern hemisphere, general recession of mountain glaciers and pack ice in Greenland and Antarctica, and the melting of permafrost (i.e. permanently frozen ground). Some of these changes are irreversible on human timescales (ranging from several decades to centuries).
The ocean is at the center of climate regulation. It absorbs more than 90% of the excess heat resulting from human-induced climate change, thus limiting the rise in atmospheric temperature. It stores and redistributes massive amounts of heat around the globe through marine currents, between the equator and the poles, and from the surface down to the sea floor. As ocean water warms up, it expands and occupies more space. This is one of the main mechanisms responsible for rising mean sea levels. Increase in ice melt has also contributed to accelerating the rise in mean sea levels over the past few decades (very high level of confidence).

Furthermore, warm water is less dense than cold water. As a result, in the ocean, the first few hundred meters of warm and salty water lie above intermediate colder and saltier waters.
As surface waters warm up, this stratification phenomenon increases and mixing of the different water masses becomes more difficult.

As a result, this limits oxygen transport to ocean 5 depths, where living organisms need it to breathe. Microorganisms also need oxygen to ensure organic matter decomposition, which is essential to the life cycle in the ocean. By absorbing approximately 20%

to 30% of anthropogenic $CO_2$ emissions, the ocean contributes to limiting carbon dioxide concentrations in the atmosphere, thus reducing the magnitude of the greenhouse effect.
However, the $CO_2$ dissolved in seawater causes a chemical reaction, increasing water acidity. It becomes more corrosive for marine organisms producing a calcareous skeleton or shell, such as coral and shellfish (mussels, oysters, etc.).

Rising water temperatures, deoxygenation and acidification are therefore the three main threats related to climate change that are causing disruptions in the ocean. These stress factors have a global influence because they affect the ocean down to depths greater than 1,000 m and impact all marine ecosystems.

In addition, changes affecting the cryosphere are also ubiquitous. Ice melts from mountain glaciers, polar ice caps in Greenland and Antarctica, and in the Arctic Ocean are due to warming of the atmosphere and the ocean (very high level of confidence).

## 3 INFLUENCE ON CLIMATE CHANGE

Changes in the rate of evaporation from the ocean surface affect the water cycle, which is essential to sustaining life on Earth.

Ice cover on mountain slopes and at the poles reflects the sun's rays back into space – when ice melts, darker ice-free land or water absorbs more of these rays than white surfaces, further amplifying global warming.
Moreover, when permafrost melts, potentially significant amounts of methane are released into the atmosphere. This gas strongly contributes to the greenhouse effect due to its warming potential approximately 25 times higher than that of $CO_2$.

## 4 THREATS TO HUMAN SOCIETIES

About 27% of the world population, or 1.9 billion people, live within 100 km of the coasts and less than 100 m above sea level. Approximately 13% of the world population lives in the Arctic Ocean or in high mountain regions. Their lives, as well as the lives of people living inland or far from icy regions, are linked to the health of the ocean and the cryosphere. These two natural systems influence the living conditions on the planet.
All populations depend on the ocean, which lies at the center of many activities: shipping and passenger transport, food (fishing and aquaculture), tourism, health, leisure, etc.
Seafood products represent 20% of the protein intake (other than cereals) in the human diet worldwide and 80% of international transport of goods is by sea.

The safety of coastal populations is also linked to the ocean's health. The rapid increase in sea levels and in the frequency of severe storms is threatening millions of lives, as well as the livelihoods of many people and billions of dollars in coastal infrastructure.
Among other things, sea level rise causes saltwater incursions inland, altering water tables (i.e. sources of drinking water) and irrigation water along the coast.
In parallel, changes in the cryosphere will have consequences for the security of water supply for people who depend on glacial melt water.

Moreover, changes affecting the water cycle -such as the intensity and frequency of rainfall due to seawater evaporation -increase the risk of flooding in some areas and drought in others. Adapting to these phenomena will involve implementing water regime regulation systems (management of ice melt and rainwater, for instance).

Marine ecosystems respond to the environmental impacts caused by climate change.

Coral reefs are increasingly subject to mass mortality. When water temperature increases, coral undergoes bleaching events. It loses the unicellular algae with which it lives in symbiosis and which is responsible for its beautiful color. It then whitens and is deprived of 70% of its food.

As a result, reef species lose their natural habitat. In addition, organisms building a calcareous skeleton or shell (coral, shellfish) become threatened by ocean acidification.
Stress factors related to climate change combine with other anthropogenic disturbances, such as pollution, thus increasing their vulnerability.
Fish are subject to increasing fishing pressure, in addition to the change in their environment due to global warming.

The distribution area of many species changes as their environment alters: some species disappear locally, while new ones appear. Availability and abundance of marine resources are therefore modified.

## 5 DEALING WITH THE IMPACTS OF CLIMATE CHANGE

Reducing greenhouse gas emissions would limit the risks and even eliminate them in some cases. This would enhance the effectiveness of adaptation measures.

However, changes such as rising sea levels or loss of ice cover will go on for several centuries regardless of the greenhouse gas emission scenarios. In addition, some ongoing disruptions currently affecting the ocean and cryosphere are not reversible on human timescales (ranging from decades to centuries).
Urgent action is therefore needed to reduce emissions, mitigate the impacts of climate change and adapt to their effects.

Impacts of climate change on the ocean include rising sea levels, an increase in the ocean heat content and number of marine heat waves, deoxygenation and acidification. Impacts affecting the cryosphere include reduced Arctic ice cover, recession of pack ice in Antarctica and Greenland, loss of glacier mass, permafrost melt and reduced snow cover.

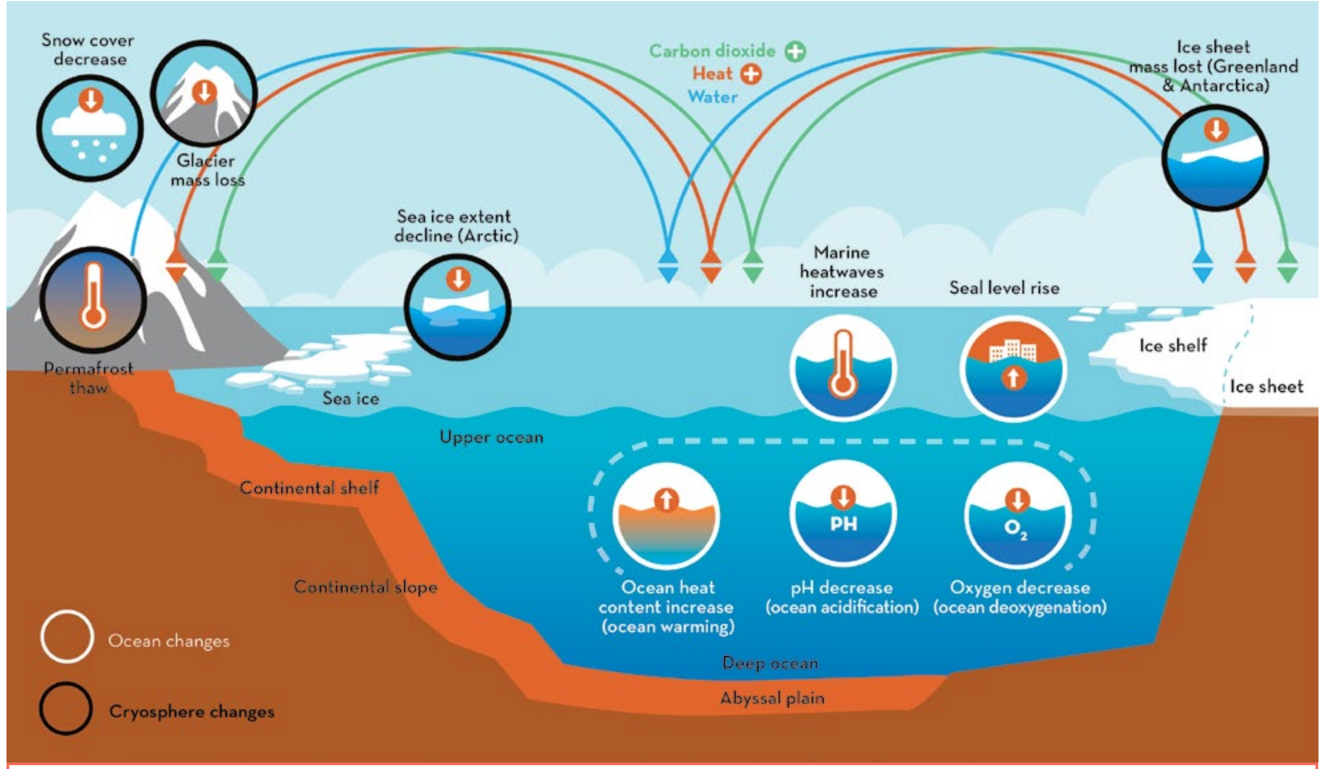


***Figure 1: Key components of ocean systems and the cryosphere, and their evolution in the context of climate change.***
*Source: IPCC, SROCC, 2019. Chapter 1*

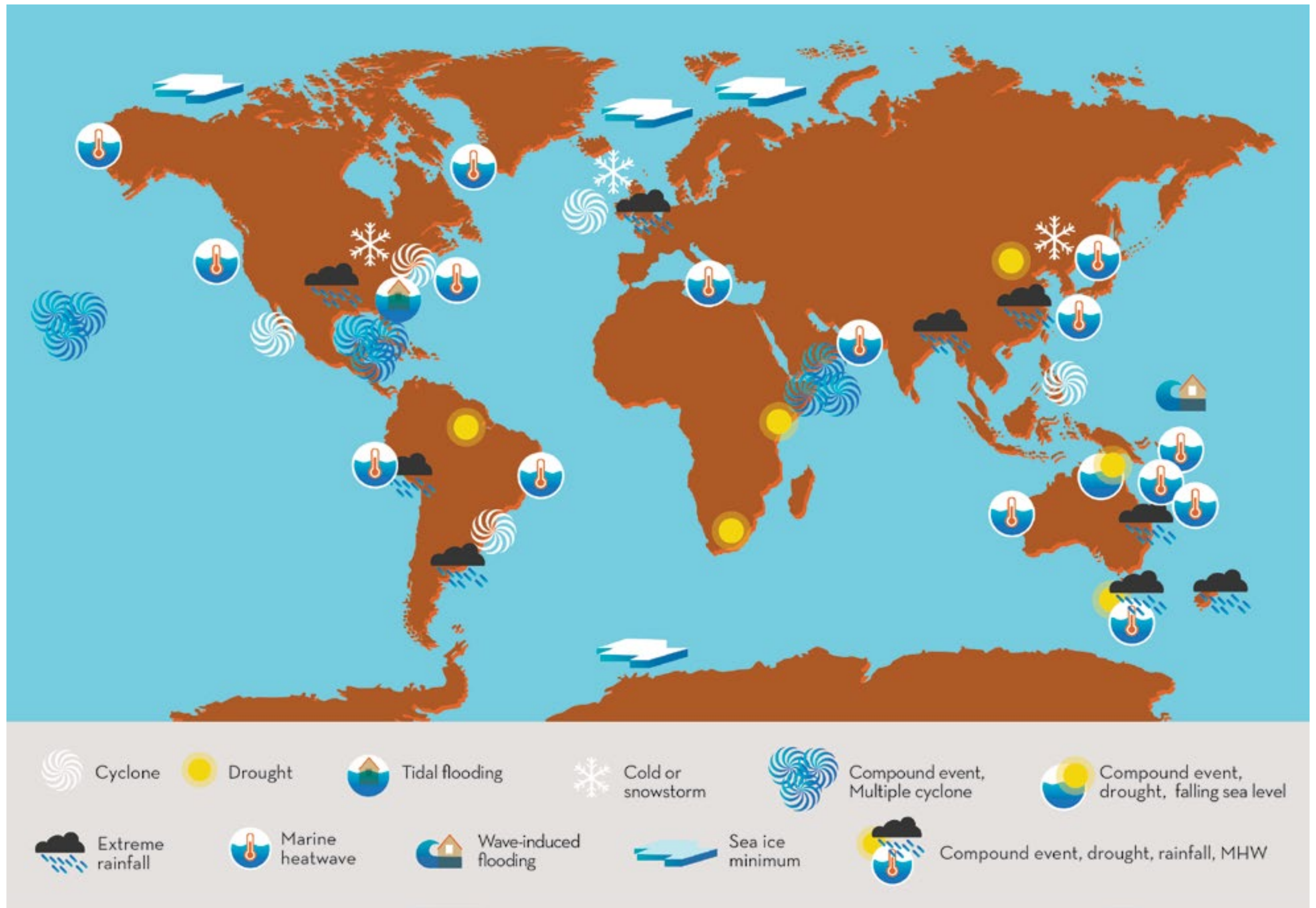


***Figure 2: Location of areas where extreme events have occurred in connection with changes affecting the ocean (selection of events that took place between 1998 and 2017).***
*Source: IPCC, SROCC, 2019. Chapter 6*

**KEY**

- *The ocean has absorbed more than 90% of excess heat and 30% of human-induced carbon dioxide emissions*

- *The ocean will continue to absorb heat in the course of this century. According to scientific models, the ocean will store between 3 and 6 times the amount already absorbed since 1900, i.e. between 1,500 ZJ (1 Zeta Joule = 1,021 Joules) and 3,000 ZJ by 2100.*

- *Ocean pH (i.e. measure of acidity) has decreased by ~0.02 pH units per decade since measurements began.*

- *Global forecasts indicate that the decrease in oxygen levels in the ocean will be 3.5% by 2100 (medium level of confidence).*

- *Mean sea level rise is correlated with the rate of greenhouse gas emissions. Its value will be between 0.43 m (likely range between 0.29 and 0.59) and 0.84 m (likely range between 0.61 and 1.10) in 2100 according to the emission scenarios.*

*FACT SHEET*
*2*

# THE OCEAN IS WARMING UP

*Christine Causse, Nausicaa*

Having absorbed 93% of the excess heat associated with global climate change, the ocean is warming up at all depths, with regional variations. This phenomenon will continue during the 21st century and for several centuries to come.

- On a global scale, ocean warming is more pronounced near the surface. From 1971 to 2010, the temperature of the first 75 meters of the water column rose by 0.11°C per decade.

- Ocean heat waves and increasingly frequent extreme events will have consequences for marine and coastal ecosystems, altering their functioning and causing a decrease in biodiversity.

- Implementation of adaptation and mitigation measures can limit the impacts on human communities (safety, health, resources and economic activities).

## ① WHAT PHENOMENON IS INVOLVED?

The global ocean covers 71% of the planet's surface and contains approximately 97% of all the water on Earth. It plays a key role in regulating the global climate by continuously exchanging heat with the atmosphere, storing and redistributing it from the equator to the poles and from the surface down to the sea floor through marine currents. Since 1950, the ocean has absorbed more than 90% of the excess heat accumulated in the climate system due to the greenhouse effect (high level of confidence). The ocean thus mitigates climate fluctuations and limits global warming.

Global warming leads to an increase in ocean temperatures. The average temperature of the ocean surface –between 0 and 75 m in depth – has increased by 0.11°C per decade since the 1970s (high level of confidence). Between 2004 and 2016, the upper (0 down to 700 m in depth) and intermediate (700 down to 2,000 m) ocean layers warmed up (almost certain),as did layers deeper than 4,000 m in the southern hemisphere (high level of confidence). Air temperature at the surface of the Arctic Ocean is increasing about twice as fast as the global average temperature. Even a slight rise in temperature can potentially unbalance and rapidly melt large surfaces of sea ice. As seawater warms up, it expands and occupies more space, contributing to the rise in mean sea levels.

In the ocean, various layers of water overlap: the first few hundred meters are composed of warm and salty waters, lying above colder, denser and saltier waters. Warming of surface waters accentuates the stratification phenomenon in the ocean. Mixing between surface and deep waters decreases, limiting their heat, carbon and oxygen exchanges. This stratification phenomenon is very likely to grow significantly during the 21st century in the first 200 m of the water column.

On the Earth's surface, solar energy is transformed into heat, thus evaporating water and influencing atmospheric movements, sea currents and the climate. Since the 1950s, the atmosphere and the ocean have warmed up under the influence of human activities.

Approximately 84% to 90% of the ocean heat waves observed in the ocean during the last decade can be attributed to human-induced climate warming (high level of confidence).

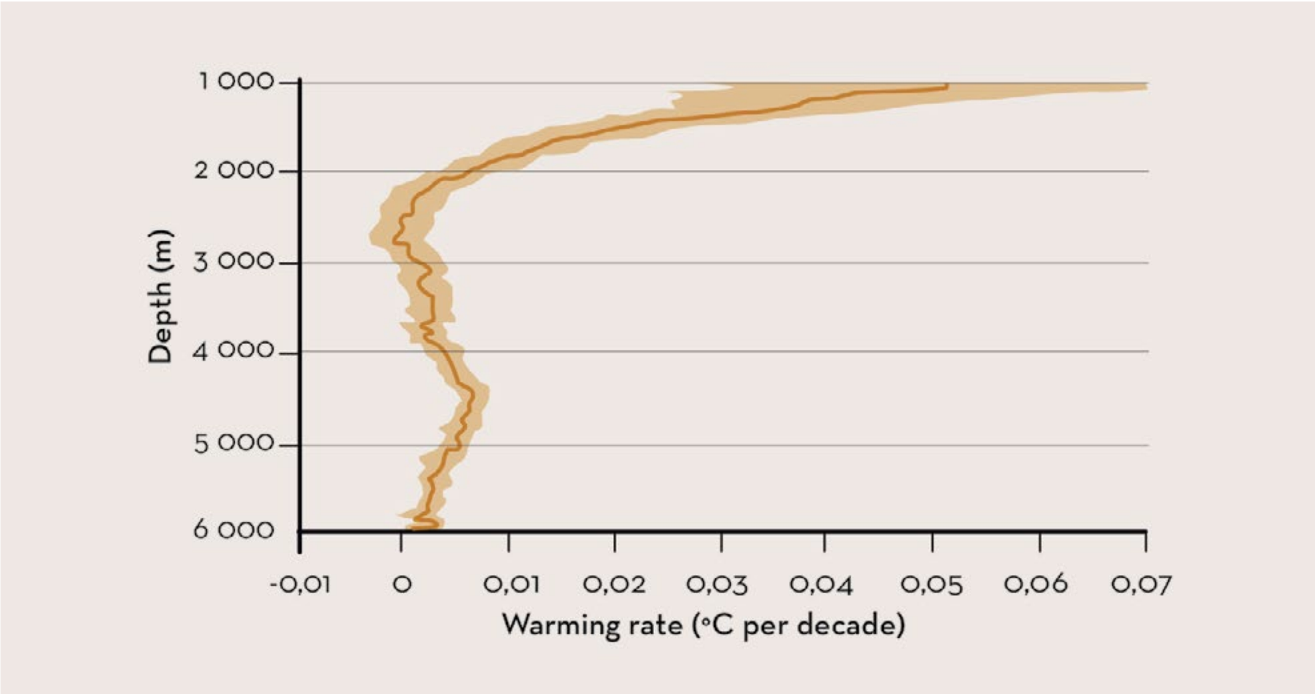


*Figure 1: Warming between 1981 and 2018 as a function of depth, with confidence intervals of 90%.*
*Source: IPCC, SROCC, 2019. Chapter 6*

# 2 CONSEQUENCES FOR NATURAL SYSTEMS

## What can we observe today?

Ocean heat storage increases the risk of heat waves and other extreme events. Marine heat waves are abnormal episodes of warming of sea surface temperatures, lasting from a few days to several months, likely to affect thousands of square kilometers. These heat waves and the resulting large masses of unusually warm water can be observed in several marine regions. The first marine heat waves were studied in the Mediterranean Sea in 2003 with summer temperatures between 1 and 3°C above seasonal averages. Then, in 2011, off the west coast of Australia, where sea temperature reached + 5°C above the seasonal norm for 10 weeks.

From 2013 to 2015, the Pacific Northwest region experienced the most intense heat waves ever recorded (+ 6.2°C). The frequency of these heat waves has most likely doubled since the 1980s. Extreme events, such as marine heat waves or storms, accentuate ecosystem changes (very high level of confidence).

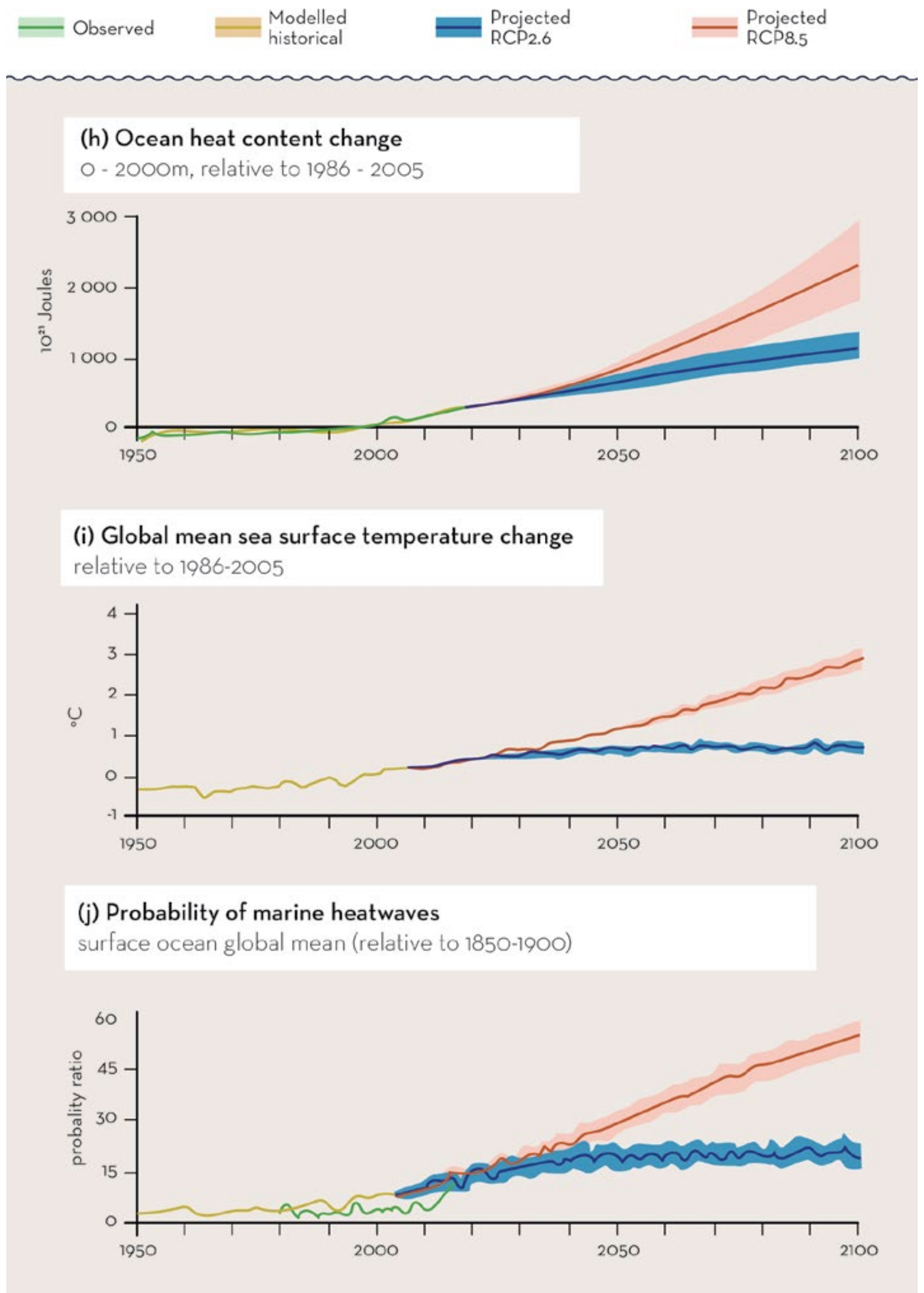
New environmental conditions in the ocean will have consequences for the physiology, distribution and ecology of marine organisms, from plankton to whales, and therefore for biodiversity and ecosystem functioning (high level of confidence).

Changes affecting polar oceans and the cryosphere have an impact on marine primary production (medium level of confidence) and as a result, on food chains and ecosystems (high level of confidence). In turn, this affects the abundance, species composition and geographical distribution of zooplankton, crustaceans, fish and predators that feed on them. Subarctic species will migrate northwards and compete with Arctic species (medium level of confidence). Furthermore, some marine organisms will become rarer locally.

In addition, coral reefs are affected by bleaching episodes (during which they expel their symbiotic algae, ultimately leading to coral death), caused by an increase in water temperature and marine heat waves. According to scenarios based on the lowest greenhouse gas emissions (+1.5°C), 90% of coral could be impacted by climate change.

## What do the different scenarios predict in the long term?

In the course of the 21st century, heat will continue to be absorbed by the ocean for several centuries, progressively warming the water column from the surface down to the sea floor. This is expected to continue for several centuries. Over the same period, water stratification linked to the warming of surface waters is very likely to grow significantly.



*Global change in the ocean surface temperature (°C) compared with the 1986- 2005 period, with an interval of 5-95%.*

*Probability of occurrence of ocean heat waves: overall average compared with the 1850-1900 period, with an interval of 5-95%. A probability rate of 10 is equivalent to a tenfold probability of a heat wave occurring compared with what happened in the years 1850-1900.*

*Figure 2: Changes affecting the ocean: Observations and projections of heat content, and probability of occurrence of marine heat waves according to low (RCP2.6) and high (RCP8.5) emission scenarios.*
*Source: IPCC, SROCC, 2019. SPM*

In addition, ocean heat waves are most likely to become more intense, last longer and spread over a wider area. Once rare, extreme events (ocean heat waves, major cyclones) are expected to become more and more frequent over the century, according to all emission scenarios.

Furthermore, some Atlantic currents are likely to slow down. According to all emission scenarios, the large marine circulation loop that flows through the Atlantic Ocean (i.e. Atlantic Meridional Overturning Circulation - AMOC) is most likely to weaken during the 21st century (high level of confidence). However, this current is very unlikely to collapse or undergo a sharp transition. If this were to occur, impacts on climate would be significant. Some climate models predict the risk of a sudden slowdown in the Atlantic polar current, called subpolar gyre (SPG), on shorter timescales, but with less significant potential impacts.

Many changes affecting the ocean and cryosphere have a retroactive effect on climate change. For instance, increased evaporation of the ocean surface due to water warming has an impact on the water cycle because it increases the amount of water contained in the atmosphere, thus leading to increased precipitation. Scientists are expecting marine species to decline at low latitudes (medium level of confidence), geographical areas to expand northwards (high level of confidence), biological events to occur at an earlier stage (high level of confidence) and a displacement of biomass and species composition (very high level of confidence). The combined effects of seawater warming, deoxygenation, acidification and changes in nutrient availability are expected to exacerbate the loss of species biodiversity in coastal ecosystems. Deep ocean benthic communities (species living on the sea floor) will undergo structural and functional changes, impacting the carbon cycle in the course of this century (medium level of confidence).

# 3 SOCIO-ECONOMIC CONSEQUENCES

## Impacts already felt by human communities

Changes affecting the distribution and availability of marine biological resources impact human communities that depend directly on the ocean, such as those living from fishing and aquaculture.
Indeed, these changes have consequences for food and economic security, culture, traditional ways of life and health.

## Impacts expected in the long-term

Ecosystem services provided by the ocean and cryosphere (heat and carbon storage, provision of food and water, renewable energy resources, trade, transport, tourism, leisure, culture, health, etc.) will be modified, altered or disappear with climate change (high level of confidence). Increased threats impacting the services provided by marine ecosystems will then appear, including risks to human health and risks of conflict over changes.
In addition, changes in rainfall pattern associated with rising ocean temperatures will threaten the security of water supply, including increased risk of severe storms and floods in some areas and droughts in others.

# 4 HOW DO WE RESPOND?

## Adaptation

Actions must be considered to adapt to water risks (floods or droughts), such as implementing infrastructure aiming at managing rainfall, retrieving melt water and regulating river flow in order to secure water supply for the populations depending on it. In terms of agriculture, adaptation strategies could include the development of crops better adapted to future climatic conditions.

Investing in prevention strategies (deploying observation systems at sea, such as floating buoys, weather forecasting equipment, warning systems, etc.) in response to extreme events is less expensive than repair costs following a climate disaster (medium level of confidence).
Adapting to threats includes improving coastal infrastructure, relocating essential services and implementing a faster and more effective response from emergency and health services, and, in extreme cases, relocating populations.

Coastal ecosystems (swamps, mangroves, seagrass beds, kelps, coral reefs, oyster and mussel beds) offer protection and reduce risks to coastal communities. Measures for the preservation and restoration of these ecosystems can provide many benefits (including economic advantages) to coastal populations (high level of confidence).

In addition, relying on indigenous and local knowledge would also complement scientific knowledge to implement effective contextspecific responses.

## Mitigation

Ambitious carbon-reduction policies are needed. Urgent action to mitigate global warming represents the best option to limit changes affecting the ocean and cryosphere and find effective adaptation and sustainable development solutions.

Ecosystems, such as mangroves, marshes, coastlines and seagrass beds can represent a nature-based solution (blue carbon). Indeed, carbon storage per unit area achieved by these marine ecosystems is much more significant than that of vegetated lands (high level of confidence).

Moreover, strengthening legal tools and international conventions, such as the UN Convention on the Law of the Sea (UNCLOS), can facilitate the implementation, monitoring and enforcement of appropriate measures to address the challenges of climate change affecting the ocean (provisions on the control of pollution at sea or the protection of living resources and ecosystems, etc.). International cooperation on governance of the ocean, coasts and cryosphere is essential to tackle these climate challenges.

FACT SHEET
3

# THE SEA IS RISING INCREASINGLY FASTER

*Gabriel Picot, Aquarium tropical du Palais de la Porte Dorée*

**The IPCC Special Report on the Ocean and Cryosphere, published on September,2019, issues warnings, especially on problems caused by rising sea levels. As observed in many regions, with sometimes perceptible impacts, sea level rise is expected to accelerate sharply in the centuries to come, thus threatening many coastal and low-lying areas.**

## 1 SEA LEVEL RISE IS ACCELERATING

In the early years of the industrial era, tide gauges were installed in European ports to measure and record sea level variations. Their original purpose was to measure tide-related variations. The records allowed scientists to calculate that the mean sea level rose by 17 cm in a 100 years during the 20th century, at the average rate of 1.4 mm per year.

Since the 1990s, satellite measurements have revealed that, from 1994 to 2018, the ocean rose by 8.5 cm, at an average rate of more than 3.6 mm/year. Sea level rise has therefore accelerated between the mid-20th century and the past few decades (high level of confidence).
This increase can vary by ffl30% depending on the region of the world. In Southeast Asia, for instance, the ocean is rising very rapidly, up to 15 mm/year in some areas. However, the rate decreases near the coasts of Alaska. This is explained by the fact that ocean heat is not uniformly distributed by ocean circulation, causing water expansion to vary from region to region.

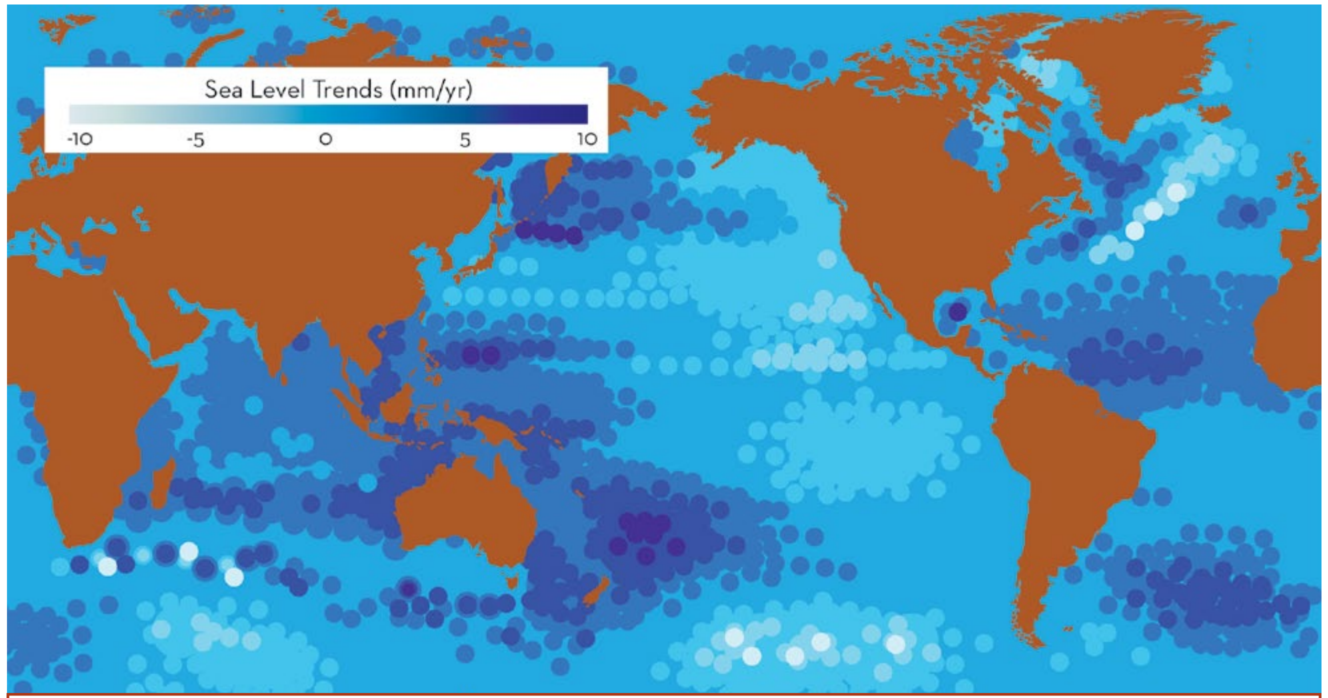


*Figure 1: Sea level rise between 1993 and 2015.*
*Source: ESA*

## 2 WHAT ARE THE CAUSES OF RISING SEA LEVELS?

### Water expansion as a result of rising temperatures

When a body heats up, it occupies more space. As seawater warms up, it expands, so the sea level rises. Scientists estimate that, since 1993 and the beginning of satellite observations, water expansion has caused a global rise in sea levels of 1.1 (+/-0.3) mm/year.

### Glacier melt

Glaciers cover about 730,000 km· of the land surface. Since the end of the Little Ice Age (around 1850), on almost all the mountain ranges, glacier melt has been observed, varying between 10 cm and 2 m equivalent of water per year. Since 2006, ice loss has been estimated at 278 (+/-113) billion tonnes/year. This phenomenon is partly explained by the delayed response of glaciers to natural global warming after the Little Ice Age. Between 2006 and 2015, it is estimated that glaciers contributed 0.77 (+/- 0.31) mm/year to sea level rise.

### Melting of polar ice caps in Greenland and Antarctica

Warming of the atmosphere leads to a significant ice melt in Greenland and on the Antarctic continent. Melt water ends up in the sea. Since 1992, a noticeable ice melt has been observed in the coastal regions of Greenland and West Antarctica. Between 2006 and 2015, the polar ice caps lost each year approximately 433 (+/-30) billion tonnes.
Taken together, these inputs represent a rise in sea levels of 1.12 (+/-0.08) mm/year over the same period.

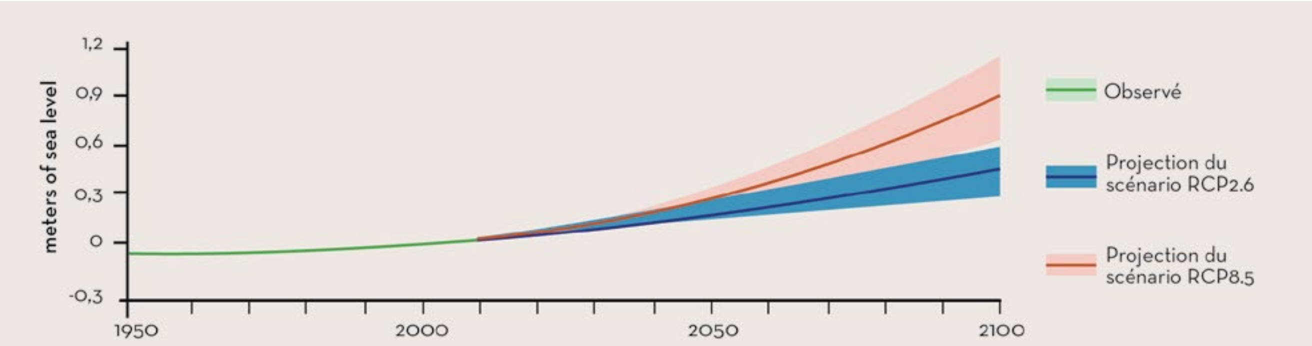


*Figure 2: Overall rise in mean sea levels from 1950 to 2100, compared with the 1986-2005 period.*
*Source: IPCC, SROCC, 2019. SPM*

## 3 CONSEQUENCES FOR NATURAL SYSTEMS

### What can we observe today?

Since 1970, rising sea levels have mainly been the result of human activities.

The IPCC Special Report on the Ocean and Cryosphere, published on 25 September, 2019, shows with a very high level of confidence that sea level rise has accelerated in recent decades due to increased freshwater inputs resulting from continental ice melt. Glaciers and polar ice caps in Greenland and Antarctica are currently the main source of rising sea levels.

Locally, particularly in the deltas of great rivers, human-induced pumping of groundwater causes land subsidence, equivalent to a relative sea level rise. This effect is in addition to the rise in sea levels due to global warming and partly explains large regional variations. However, in these delta regions, the impact of storm waves is likely to be greater than rising sea levels.

### What will happen in the future?

Sea level rise is an irreversible phenomenon on the timescale of centuries and for the foreseeable future.

Due to system inertia and slow heat transport, the additional heat already emitted by human activities will lead to a long-term sea level rise, probably by several meters, on a millennium timescale.

Climate models all predict that, in a context of high greenhouse gas emissions, Antarctica will probably contribute to several tens of centimeters to sea level rise by the end of the 21st century. New predictions taking this impact into account suggest an increase between 29 and 59 cm by 2100 if greenhouse gas emissions are significantly reduced, and between 61 and 110 cm at the current rate of emissions. The rate of rising waters could then approach 19 mm/year in 2100, against 3 mm/year at present.

Beyond 2100, forecasts of rising sea levels are very risky, because current models still do not adequately incorporate the physical processes driving the behavior of polar ice caps. In particular, ice shelf collapses are very difficult to predict and may have a "threshold effect" on the behavior of the entire ice cap.

Near deltas, the expected increased level shows that it is essential to take into account local phenomena, such as waves and land subsidence, to predict the impacts of rising sea levels.

## 4 CONSEQUENCES FOR HUMAN COMMUNITIES AND THE ECONOMY

Sea level rise is a major concern for coastal areas, where 27% of the global population lives and more than half of the world's megacities are built. Low-lying islands and coasts are at high risk of climate change impacts. Indeed, various studies show the impacts of rising sea levels.

They may affect ecosystems, as well as the services they provide to the economy, coastal infrastructures, the habitability of the region, community livelihoods, and cultural and aesthetic values.

However, attributing locally observed impacts solely to rising sea levels remains difficult because of the combined influence of other factors. Population growth, habitat loss and environmental degradation due to urban development and pollution play a major role in the vulnerability of coastal communities.

Moreover, sustainable development is jeopardized by the increasingly significant impacts of climate change on the ocean. People living along the coasts are particularly threatened, as well as areas whose borders will undergo changes because of rising waters.

These impacts will soon become much stronger, particularly on the most vulnerable populations.

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Effects of local factors unrelated to climate, such as home extensions, degradation of coastal environments or pollution, are very likely to play a key role in the vulnerability of populations facing rising sea levels.

Some environments are extremely exposed and vulnerable to climate change and rising sea levels. These are mainly densely populated and relatively undeveloped areas, such as some small islands, deltas and rural coastal areas, but also areas where people rely heavily on environmental services (tourism, fishing, etc.), such as coral reefs or the Arctic Ocean.

Impacts of rising sea levels will intensify in these places in the future. Highly developed and densely populated cities and coastal megacities will also face increasing risks from rising waters.

Sea level rise is likely to lead to a divided world: on the one hand, rich and densely populated areas protected by expensive, tailored dams; on the other, poor areas, with people facing the impacts of rising sea levels or forced to abandon vast stretches of land reclaimed by the sea.

The combination of rising sea levels and extreme events amplified by climate change, such as cyclones, increases the risks. Indeed, in the future, the proportion of major tropical cyclones (categories 4 and 5) is likely to rise, as is the amount of associated precipitation. It is less certain, however, that the total number of cyclones will increase (medium level of confidence). The combined effects of sea level rise and major hurricanes could cause extremely significant coastal flooding (high level of confidence).

Whatever the scenarios of greenhouse gas emissions considered, floods will become common by 2100 (high level of confidence).

Coastal cities and islands will be particularly affected as of 2050. However, these episodes of significant flooding will show a large regional variability, in both intensity and frequency.

In some regions, such as the Pacific Islands and the west coast of America, historically 100-year episodes will become statistically annual events by 2050, and even monthly events by 2100.

## 5 HOW DO WE DEAL WITH RISING SEA LEVELS?

### Mitigation: Reducing problems at their source by limiting global warming

Sea level rise by the end of the century will depend heavily on greenhouse gas emissions. High emissions will accelerate melting of the Antarctic ice caps (high level of confidence), thus strongly contributing to rising sea levels. A drastic reduction in emissions would significantly mitigate the risk, without eliminating it. However, this scenario would give scientists and policy makers time to develop more varied adaptation solutions.

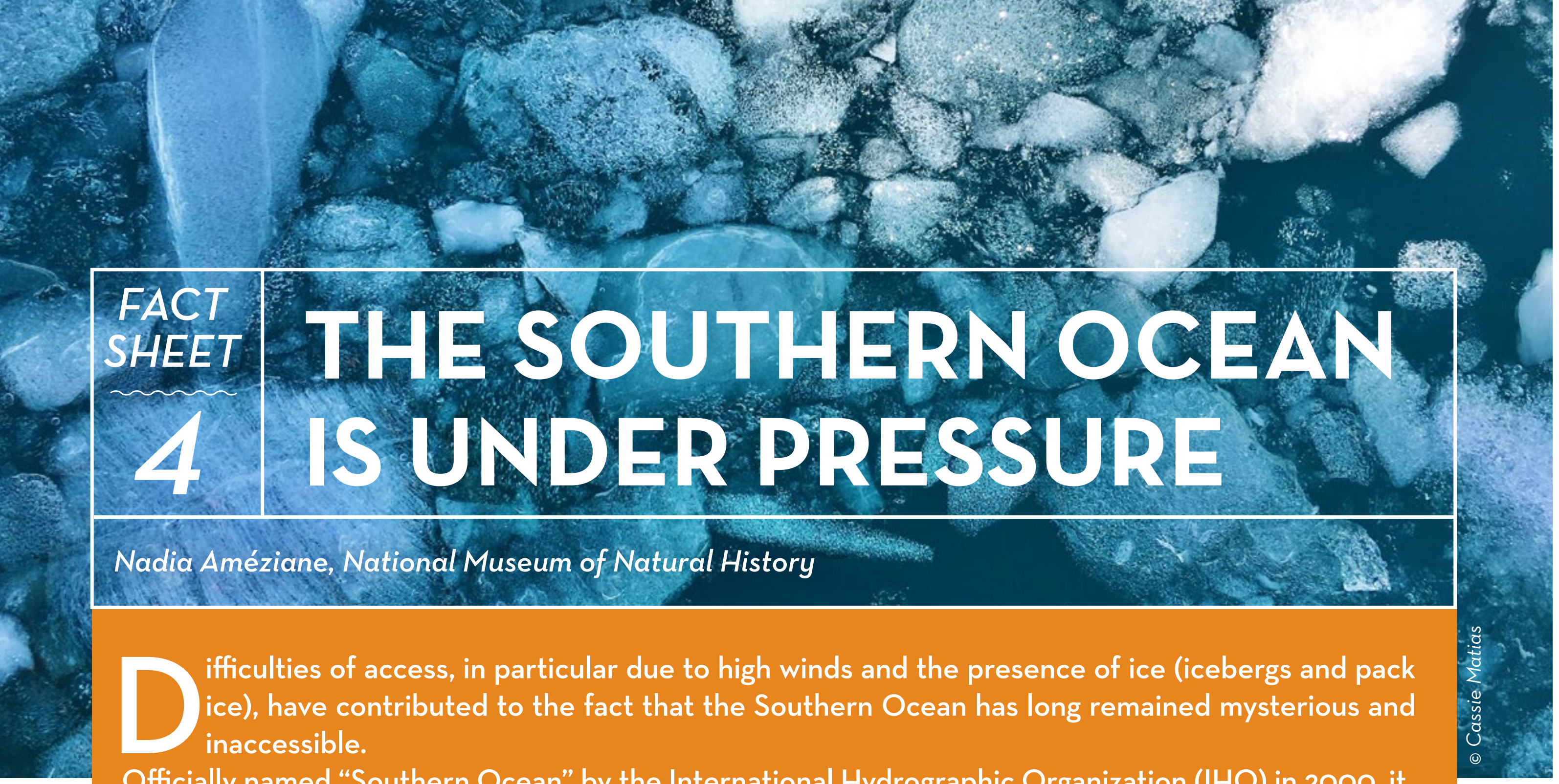
For the first half of this century, the differences between the various emission scenarios remain small, but they are likely to increase significantly in the second half of the century.

### Adaptation: Adjusting infrastructures and preparing populations to deal with new risks posed by sea level rise

There are a variety of methods to adapt to the risks associated with rising sea levels, ranging from conventional engineering solutions (constructing dikes, raising buildings, replenishing beaches, etc.) to ecosystem-based adaptation (floodplain development, maintenance of natural protection, etc.).

To be more effective, infrastructure adaptation must be accompanied by social adaptation measures, such as the development of warning systems, emergency management, relocation of residential areas or economic activity areas, or even abandonment of entire areas. However, resettlement, migration and relocation have both positive and negative effects on those who move, but also on host communities.

These development and protection efforts will reduce risks in the short and medium-terms, and give policy makers more time to make social and economic choices to mitigate global warming. However, it should be noted that the costs and benefits of such measures may not be shared equally between populations, and may even increase the risk exposure of some of them. To prevent this situation, efforts at the local level must be part of broader efforts at the global level.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FACT SHEET
4

# THE SOUTHERN OCEAN IS UNDER PRESSURE

*Nadia Améziane, National Museum of Natural History*

Difficulties of access, in particular due to high winds and the presence of ice (icebergs and pack ice), have contributed to the fact that the Southern Ocean has long remained mysterious and inaccessible.
Officially named "Southern Ocean" by the International Hydrographic Organization (IHO) in 2000, it covers 35 million KM2, representing approximately 10% of the world ocean. Acting as an effective CO2 sink, this ocean absorbs several billion tonnes of carbon each year. It is crossed by the Antarctic Circumpolar Current (ACC), the largest, fastest and most powerful ocean current in the world. 20,000 km long, 200 to 1,000 km wide, it can reach depths of 4,000 m, and carries 130 million m3 of water per second, at a speed of 0.9 to 3.7 km/h on the surface.

Unlike other oceans, defined as bodies of water bounded by continents, the Southern Ocean is the only one encircling a continent. It extends from the coast of Antarctica north to 60 degrees south latitude and encompasses 360 degrees of longitude. Because of its geographical position, the Southern Ocean plays a major role in global ocean circulation, climate and carbon cycle regulation, and atmospheric CO2 concentration. Water temperatures vary from -1.8°C near the continent to 3.5°C further offshore. These very low temperatures promote oxygen dissolution. As a result, O2 concentrations are higher there than in other oceans. Currentology is therefore complex in the Southern Ocean.

## ① SOUTHERN OCEAN CIRCULATION: WHAT PHENOMENON IS INVOLVED?

The Southern Ocean is bounded to the north by a system of predominant currents and fronts called the "Antarctic Convergence", and to the south by the Antarctic continent. The northern boundary is composed of the ACC, bordered to the north by the Subantarctic Front and to the south by the Polar Front. The ACC flows from west to east. It is not uniform, but composed of a series of fronts and eddies. It forms a physical barrier that hinders heat exchanges between the warm waters flowing further north and the very cold waters of the Southern Ocean. This current is the main source of deep-water formation in the world ocean and mixes waters from the Atlantic, Indian and Pacific Oceans. It absorbs warm currents and redistributes cold and dense (rich in salt) waters.

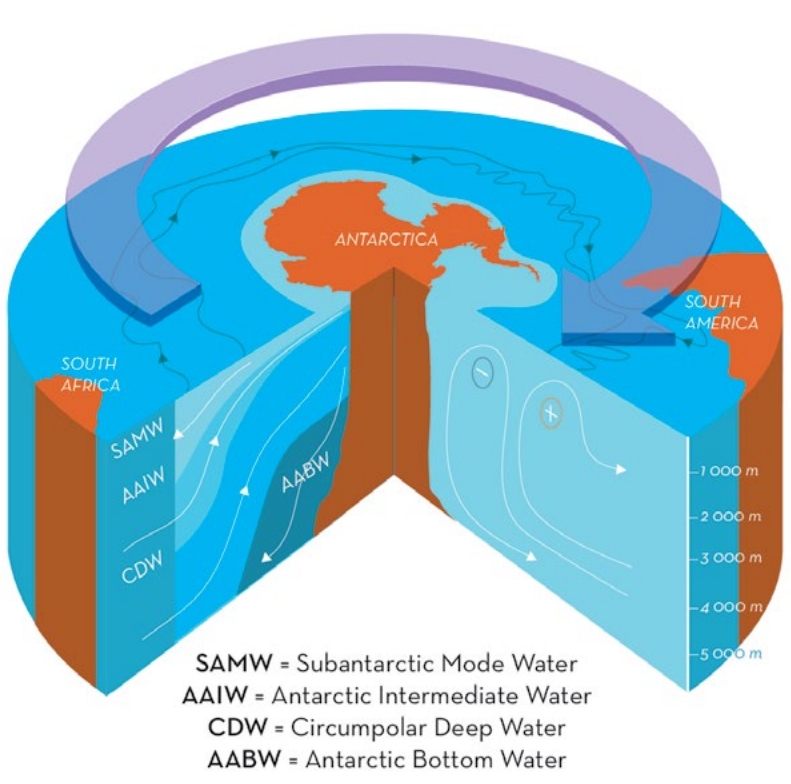

***Figure 1: Ocean circulation in the Southern Ocean***
*Source: IPCC, SROCC, 2019. Chapter 3*

The "overturning" circulation of the Antarctic Circumpolar Current (ACC) (which can be observed in Figure 1) has several actions:

- it influences climate regulation by exchanging heat and carbon with the atmosphere;
- it plays a role in water oxygenation, by promoting the development of nutrients, many of which supply a large part of the primary production of other oceans;
- it impacts the extent and concentration of sea ice;
- it influences the structure and function of pelagic (in the water column) and benthic (on the sea bottom) ecosystems by determining habitats.

## ② WHAT ARE THE CAUSES?

Temperature and salinity drive the Southern Ocean circulation (thermohaline circulation). Winds also play a crucial role in setting up this circulation. Tides and/or the interaction with submarine relief are also involved in the development of the Southern Ocean circulation. All these factors shape the overturning circulation of the ACC.

## ③ CONSEQUENCES FOR NATURAL SYSTEMS

The warming of the Southern Ocean is not homogeneous and varies depending on geographic regions and depth. For instance, warming is significant in the first 2,000 meters of the water column at latitudes between 40°S and 50°S.

In contrast, surface waters located south of the ACC have warmed up by only 0.02°C per decade on average, while the overall warming trend of sea surface temperatures has been of 0.08°C since 1950 (high level of confidence).
This warming results from the overturning circulation and mixing of the upper ocean (high level of confidence). However, within the ACC, temperature rise is primarily related to changes in air-sea fluxes.

Salinity is key factor determining the Southern Ocean density and an important driver of water circulation, exchange and stratification. Changes in salinity are caused by freshwater inputs flowing into the ocean and/or by salting out when seawater freezes.
The changes in salinity observed between 1950 and 2010 indicate a persistent softening of surface waters across the Southern Ocean (medium level of confidence).
Furthermore, the Southern Ocean's ability to absorb CO2 has varied over the decades.
These fluctuations are linked to changes in wind patterns and temperature. Currently, the CO2 sink is increasing.
In recent decades, westerly winds have increased in the Southern Ocean. However, nothing indicates that this increase has modified ACC transport, the average annual value of which appears to be stable (medium level of confidence).

In addition, the volume of Antarctic bottom waters exported to other oceans has decreased (medium level of confidence).

The dynamics of the Southern Ocean's marine ecosystems are closely linked to the ACC and its frontal systems, subpolar gyres, polar seasonality of primary production and ice cover. Krill, which is highly dependent

on ice cover, plays a major role in the food web of the Southern Ocean. Declines in abundance reported in some areas might be episodic and as yet, there is no evidence of a trend towards a continued decline in krill biomass.
However, a change in the composition of these populations has been observed (medium level of confidence).

Many Antarctic fish species – both benthic (bottom dwelling) and endemic (living only in the Southern Ocean) – have very low thermal tolerance due to their physiological adaptation to cold water (antifreeze protein, loss of hemoglobin, etc.), making them vulnerable to a temperature rise.
For instance, *Pleuragramma antarcticum*, a pelagic fish that is an important prey in some regions of the Southern Ocean, has an icedependent life cycle. *Dissostichus*, or *toothfish*, is important for southern fisheries. To date, there is no evidence of the impacts of climate change on the two toothfish species living in the Southern Ocean (medium level of confidence).

Benthic fauna consists of many endemic species, the majority of which are suspension filter feeders (feeding on plankton).
Communities living in shallow water habitats covered with ice are composed mainly of invertebrates adapted to darkness. Benthic fauna primarily depends on ice conditions (pack ice and icebergs), the availability of primary production and mixed layer depth.

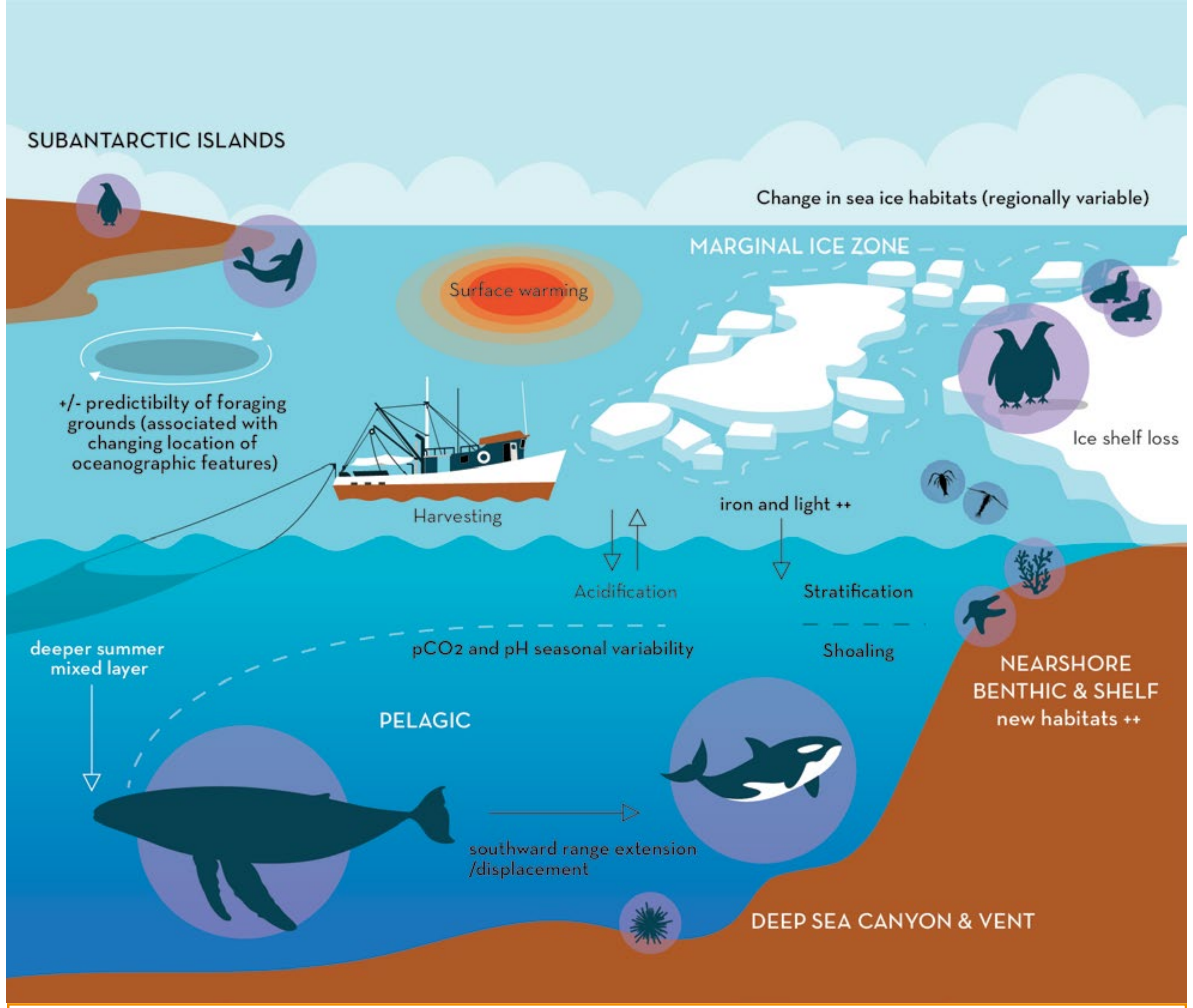

***Figure 2: Concise diagram of major global change processes affecting the different Southern Ocean's ecosystems.***

Marine birds and mammals are all migratory species, coming to the Southern Ocean either to reproduce or to feed. These animals are highly dependent on ice conditions and food
availability (high level of confidence). Thus, the biological parameters (breeding success, mortality, fertility), life history traits, and morphological, physiological and behavioral characteristics of the main predators of the Southern Ocean are changing as a result of climate change (high level of confidence).

## 4 WHAT COULD HAPPEN IN THE FUTURE?

Models indicate that the warming trend observed in the Southern Ocean will continue, leading to a temperature rise of 1 to 3°C by 2100, mainly in the upper ocean.

Water masses in the high seas will also become much softer (decrease in salinity of about 0.1 units), with overall increased stratification and depth of the mixed layer (changes to robust model, low level of confidence in values). Formation and exports of Antarctic bottom waters are expected to keep decreasing due to warming and softening of surface water near the continent (low level of confidence).

Models predict that the Southern Ocean's CO2 absorption capacity will increase by 2100, with absorption ceasing around 2070. This stop is related to a reduction in the Southern Ocean's buffering capacity and increased upwelling of deep circumpolar deep waters (medium level of confidence).

Projections point out a potential continuous strengthening of westerly winds coupled with warming and increased freshwater inputs, resulting from increased rainfall in the Southern Ocean and Antarctic ice melt. If westerly winds continue to increase, vortex flow fields will likely grow in intensity, potentially affecting the overturning circulation of the upper ocean, as well as heat, carbon, oxygen and nutrient transport.

Upcoming changes will also impact krill, which will be subject to further modifications (medium level of confidence). As a result, the spatial distribution of Antarctic krill is expected to change and its biomass to decrease, due to changes in optimal conditions for growth and recruitment (temperature, ice cover, acidification). This decrease in krill biomass will be offset by an increase in biomass of salps (planktonic tunicates), which have no predators in the Southern Ocean.

Rising temperatures will physiologically affect Antarctic benthic fish, which will first move to marginal habitats (low level of confidence). Declining abundance in *Pleuragramma antarcticum* in parts of the western Antarctic Peninsula might affect the associated food webs (low level of confidence). The Antarctic toothfish (*Dissostichus mawsoni*) might face a reduction in its habitat and potential competition with the other species of toothfish, whose distribution area would shift (very low level of confidence).

The number of alien species introductions might increase (very low degree of confidence); however, the ACC is expected to continue to play an essential role as a biogeographical barrier for species living out at sea.

As a result of changes in temperature, ice cover and iceberg scouring, 79% of endemic benthic invertebrate species in Antarctica might face a reduction in their habitat (low level of confidence). The expected reductions in the number of species will be more or less pronounced depending on the Antarctic region.

Marine birds and mammals will continue to be impacted by climate change, changes in ice cover and food availability.

## 5 SOCIO-ECONOMIC CONSEQUENCES

The Southern Ocean's vulnerability is likely to seriously disrupt global ocean circulation, with significant biological and economic impact. Conservation proposals regarding biodiversity loss and resource overexploitation (including krill) are expected and should include geopolitical and socio-economic factors.

FACT SHEET
5

# TOWARDS EXTREME EVENTS

*Corinne Bussi-Copin, Oceanographic Institute, Prince Albert I of Monaco Foundation*

**Global climate change observed over more than a century has modified energy exchanges between the ocean and the atmosphere. Usual weather events are growing in intensity and causing catastrophic socio-environmental and economic impacts.**

**These historically rare extreme events are expected to become more and more common in the course of this century, whatever the scenarios considered. Their increasing frequency, combined with the vulnerability of ecosystems and human communities, will trigger chain reactions in environmental systems and societies.**

**Marine heat waves are very likely to increase in frequency, duration and intensity, affecting marine organisms, ecosystems, and fisheries. The number of category 4 and 5 hurricanes will increase, causing a temporary rise in sea levels which, combined with other effects, will result in catastrophic floods.**

## 1 WHAT ARE OCEAN HEAT WAVES?

As on land, heat waves affect the ocean in the tropical regions. They are characterized by abnormally high temperatures for several consecutive days over a fairly wide area, creating large masses of unusually warm water. The sustained increase in water temperature in the first 60 m causes intense evaporation and moisture transfer from the ocean to the atmosphere. This transfer is at its peak when surface waters reach 28-29°C and causes unstable weather events, such as typhoons, hurricanes and cyclones.

Tropical cyclones, typhoons or hurricanes are vortex phenomena that take place in the atmosphere. These vortexes rotate clockwise in the southern hemisphere and anti-clockwise in the northern hemisphere. They extend over 500 to 1,000 km with wind speeds of 64 knots or more, i.e. 118 km/h (force 12 on the Beaufort scale) and cause intense rainfall. In contrast, their center, called the "eye", typically with a diameter of 30 to 60 km (sometimes up to 150 km) is calm (no rain, low wind speed). Depending on their location, these events are referred to by different names: typhoons occur in the Pacific Northwest, hurricanes in the North Atlantic and the northeast Pacific, and cyclones in the Indian Ocean and the South Pacific.

## 2 TREND IN EXTREME EVENTS OVER THE PAST CENTURY

The frequency of heat waves has most likely doubled since the beginning of the early 1980s. In fact, heat waves have occurred in all ocean basins in recent decades. Compared with the 1925-1954 period, the number of days of ocean heat waves recorded has increased by 50% since 1987.

In 2015 and 2016, one quarter of the sea surface experienced longer and more intense events. On a global scale, about 90% of ocean heat waves observed can be attributed to humans and some are unprecedented compared with preindustrial conditions (high level of confidence).

Furthermore, the 2017 hurricane season in the North Atlantic Ocean was the most active in the last 100 years with major ecological and societal damages (high level of confidence). Increasing frequency of cyclones on a global scale remains unlikely (low level of confidence), but tropical cyclones are likely to be slightly more intense, with a higher precipitation rate and an increase in the proportion of category 4 and 5 tropical cyclones (medium level of confidence).

> Heat waves are climatic and oceanographic phenomena, referred to as Southern Oscillation and El Niño. Combined, they form the El Niño Southern Oscillation (ENSO). The El Niño phenomenon, characterized by a thermal anomaly of equatorial surface waters (over the first tens of meters), takes place in the Central Pacific Ocean. El Niño is known to cause natural disasters (droughts, floods, tropical cyclones) and significantly affect global sea levels.

These extreme events damage marine and coastal ecosystems and impact the associated communities (very high degree of confidence).
Over the past 50 years, major events involving damages caused by cyclones are:

1) ***1965:*** more than 30,000 people affected and 2,500 billion US dollars in damage.

2) ***1979:*** 30,000 people affected and 600 billion US dollars in damage.

3) ***1995:*** more than 30,000 people affected and 500 billion US dollars in damage.

4) ***2007:*** more than 35,000 people affected and less than 500 billion US dollars in damage.

5) ***2015:*** 30,000 people affected and 300 billion US dollars in damage.

The lower number of people affected by major events can be attributed to alert management and implemented evacuation plans.

However, these events still strongly affect marine ecosystems. Adverse and potentially irreversible effects on coral reefs and other marine ecosystems have already been identified. Bleaching episodes, associated with mass coral mortality on a large geographical scale, have increased since 1997-1998, degrading the biodiversity of coral reefs and leading to an ecosystem dominated by algae (high level of confidence).

Seagrass beds and kelp forests (giant algae) 3 show reduced growth, even widespread deforestation. Some areas have lost almost 40% of their original surface area as a result of marine heat waves (medium level of confidence).

A regression of mangroves has been observed over the past 50 years (high level of confidence).

The loss of vegetated coastal ecosystems is likely to increase atmospheric CO2 by 0.15 to 5.35 gigatonnes/year, which would not be stored (high level of confidence).

The coastal populations exploiting the marine resources of these ecosystems will be economically impacted. In fact, the combination of cyclones and rainfall or large-scale waves will cause coastal flooding. Rising sea levels combined with higher storm surges associated with tropical cyclones will be extreme (high level of confidence).

These historically rare extreme events are expected to become more and more common in the course of this century, whatever the scenarios considered (high level of confidence). An event occurring once over a 100-day period on pre-industrial levels is expected to occur every 6 days in the 1.5°C scenario and every 3 days in the event of a warming of 3.5°C (medium level of confidence). The increasing frequency of these events, combined with the vulnerability of ecosystems and human communities, will trigger a domino effect, including severe flooding (high level of confidence).


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# 3 WHAT COULD HAPPEN IN THE FUTURE?

The increase in frequency (medium level of confidence), duration and intensity (high level of confidence) of ocean heat waves will continue to impact not only tropical marine ecosystems, but also those at higher latitudes. Overall, the frequency of marine heat waves is very likely to increase by a factor of 20 (in the RCP2.6 scenario) or 50 (in the RCP8.5 scenario) by 2100. This increase in frequency will occur in the Arctic Ocean and the tropical regions (medium level of confidence).

Even if there is no correlation between the event severity and observed impacts, all marine organisms will suffer great losses, and communities and biogeochemical processes will be modified. Deoxygenation, acidification and changes in nutrient supply are expected to increase biodiversity loss (species richness and spatial heterogeneity) in coastal ecosystems (medium level of confidence). Ecosystems will exceed their resilience limits, including species with reduced mobility, such as reef-building coral (high level of confidence). Mobile species, such as fish, will move from tropical to temperate regions, thus affecting people's food supplies and economic activities, such as fisheries (medium level of confidence).

## What will be the socio-economic consequences?

The role of the ocean in climate regulation, resource supply and human well-being is undeniable. However, a wide range of ecological goods and services derived from marine ecosystems have been seriously affected by recent marine heat waves and other extreme events (high level of confidence). Biodiversity and ecosystem functions are already impacted (medium level of confidence). The quality and quantity of tourist areas are reduced, causing a decline in activity in some regions.

The nutrient cycle has changed and carbon fluxes are influencing the primary production (high degree of confidence), which, in turn, will impact deep-sea biomass (medium level of confidence). Carbon sequestration in ecosystems will decrease.

The deterioration in the ocean's health will have negative impacts on indigenous knowledge and cultures (medium level of confidence). In addition, extreme events increase the vulnerability of communities (high level of confidence).

The ratio between the costs of investing in risk reduction and repairing the damage caused by extreme events varies. Investing in avoidance strategies (for instance, extensive land-use planning) and preparation (such as warning systems) is very useful, and probably less expensive than the impacts of extreme events and disaster recovery (medium level of confidence).

## How do we cope with the impacts of extreme events?

The uncertainty surrounding the frequency and characteristics of tropical cyclones creates delays in the implementation of early warning and evacuation procedures.
Coordination difficulties between disaster response organizations in the event of a disaster persist.

**Mitigation consists of reducing problems at source:**

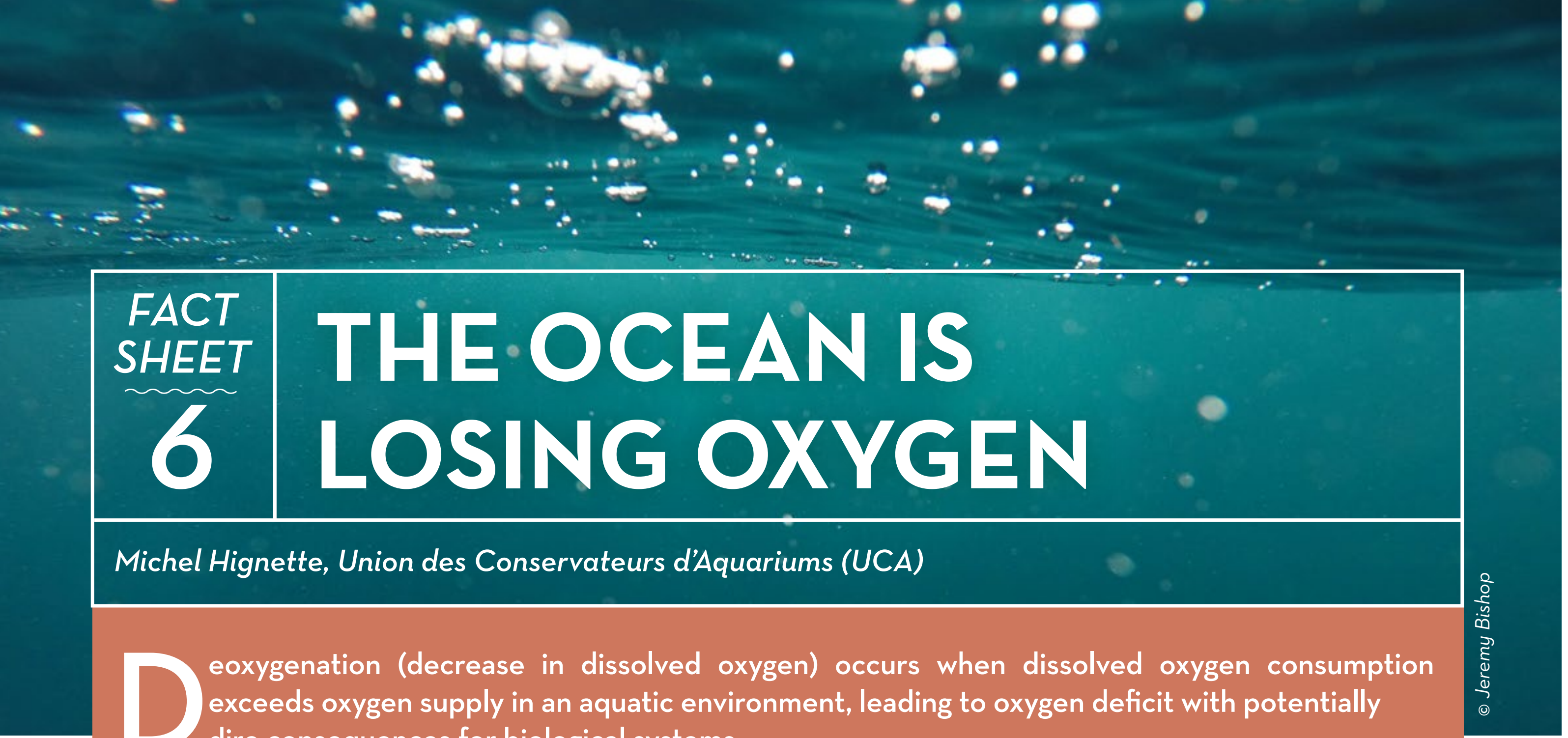
**1)** Limiting global warming to reduce the intensity of marine heat waves and cyclones.

**2)** Maintaining healthy ecosystems to enable them to fulfill their coastal protection role.

**Adaptation consists of adjusting infrastructures and preparing populations to deal with new risks posed by sea level rise:**

**1)** Building dikes and elevated buildings to protect populations in the short term.

**2)** Taking more drastic evacuation and population relocation initiatives in the long term, because building shoreline protection is increasing coastal erosion.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FACT SHEET
6

# THE OCEAN IS LOSING OXYGEN

*Michel Hignette, Union des Conservateurs d'Aquariums (UCA)*

Deoxygenation (decrease in dissolved oxygen) occurs when dissolved oxygen consumption exceeds oxygen supply in an aquatic environment, leading to oxygen deficit with potentially dire consequences for biological systems.

The causes are twofold. On the one hand, a rise in temperature reduces oxygen solubility in water and promotes stratification, resulting in fewer exchanges between the different water layers (those closest to the surface being best oxygenated through gas exchanges with the atmosphere). On the other hand, excessive nitrogen and phosphorus inputs into the marine environment (from water treatment plants and agriculture) promote eutrophication and cause, among others things, a massive growth of microalgae.
In the presence of overabundant mineral salts, planktonic algae multiply rapidly and reach such concentrations that, at night, in the absence of photosynthesis, their respiration depletes the environment of oxygen.

## 1 OCEAN DEOXYGENATION ONLY RECENTLY ADDRESSED

Only briefly mentioned in the 2014 IPCC Special Report, deoxygenation is now regarded as one of the three major ocean issues, along with global warming and acidification.

The threshold value generally used to define deoxygenation is 60 micromoles/kg, i.e. about 2 mg of oxygen per liter of water.

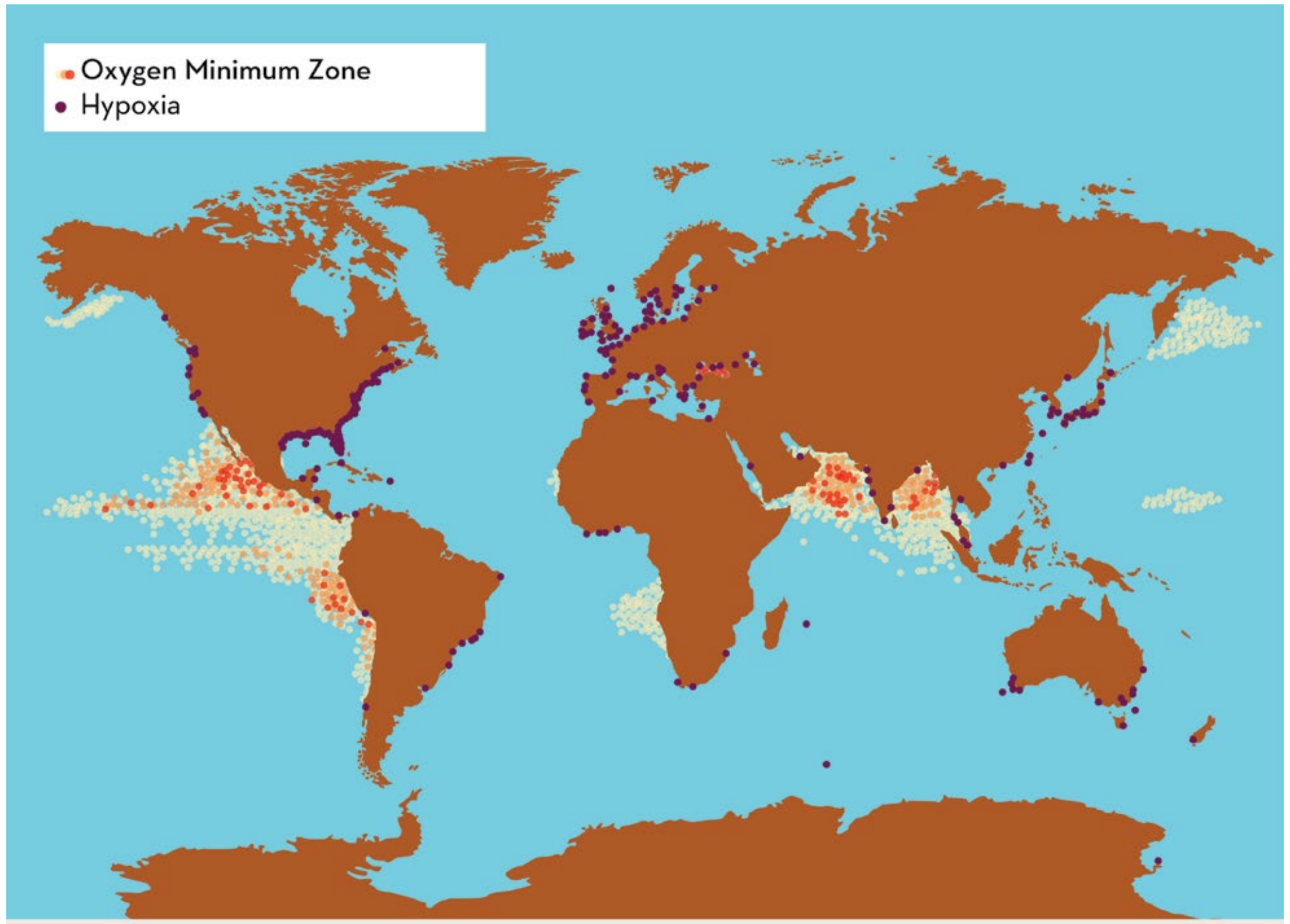
At sea, organic matter decomposition by oxygen-consuming bacteria gradually depletes the oxygen concentration – does not compensate for oxygen consumption by bacteria.

Moreover, thermohaline circulation is characterized by cold oxygen-rich waters sinking in the vicinity of the poles and flowing in the deep ocean. Thus, at great depth, it restores a higher oxygen concentration. As a result, there is an oxygen minimum in waters of intermediate depth (between 100 and 1,000 m).
In contrast, in coastal environments, eutrophication is responsible for deoxygenation.

## 2 OXYGEN MINIMUM ZONES

Oxygen Minimum Zones (OMZs) appear to have increased alarmingly in recent years. However, improvements in data collection may partly explain this apparent increase.

Since 1960, in the high seas, an increase of 4.5 million km2 has been recorded on the open sea, and about 500 estuarine or coastal sites showing a deficit in oxygen have been identified.
The ocean is currently losing about 1 gigatonne of dissolved oxygen per year. Overall, a 3-4% decrease in dissolved oxygen in the ocean is expected by 2100, but with large local variations, especially in tropical areas where high uncertainties remain (medium level of confidence).



*The Millenium Ecosystem Assessment released by the United Nations in 2005 reported that the supply of nitrogen-containing compounds imput to the world's oceans grew by 80% from 1860 to 1990. For individual coastal water bodies the increase has been as high as 100 fold or more..*

*During the past 50 years, the area of low oxygen water in the open ocean has increased by 4.5 million km² The world's oceans are now losing approximately 1 gigaton of oxygen each year (Keeling and Garcia, 2002).*

*Upwelling of low oxygen waters can cause massive fish kills but also brings nutrient-rich waters to the surface to fuel fisheries' production.*

*Over 500 coastal water bodies now report dissolved oxygen concentrations below 2.2 mg/L -1 (Diaz and Rosenberg 2008 and Diaz unpublished update).*

*The Baltic Sea has the largest coastal water hypoxic zone. In 2011, the area of water with dissolved oxygen concentrations &lt;2 mg/L -1 was nearly 80.000 km2. (Carstensen et al., 2014)*

***Figure 1:** Oxygen minimum zones (red) and coastal hypoxic zones (purple) in the global ocean*
*Source: «The ocean is losing its breath. Declining oxygen in the world's ocean and coastal waters», IOC-UNESCO, 2018*

## 3 CONSEQUENCES FOR NATURAL SYSTEMS

In areas already depleted in dissolved oxygen, a further slight reduction may lead to biodiversity loss, changes in geochemical cycles, and a decrease in ecosystem productivity and geographical distribution of species.

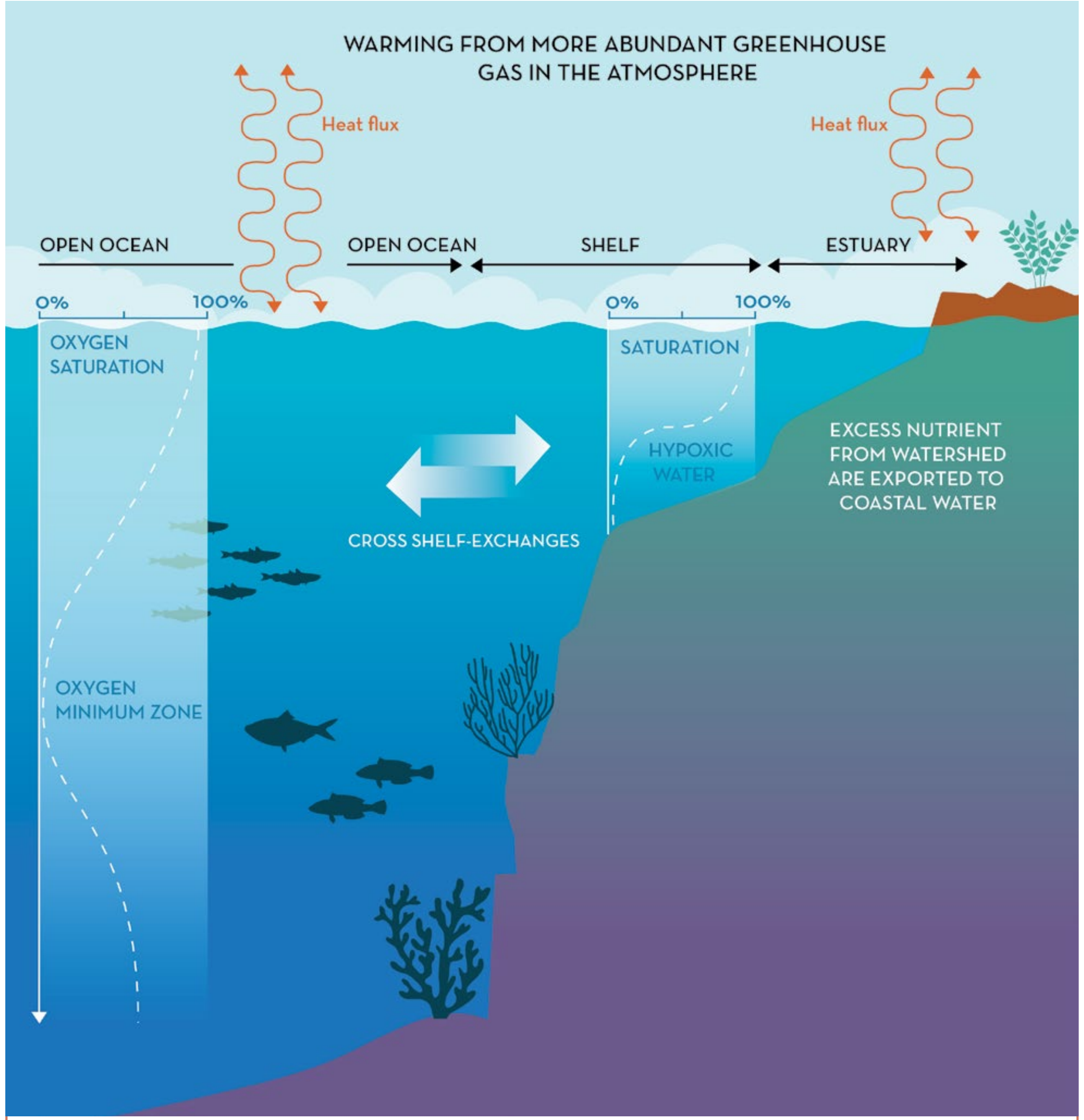


***Figure 2: Ocean deoxygenation: causes and consequences***
*Source: «The ocean is losing its breath. Declining oxygen in the world's ocean and coastal waters", IOC-UNESCO, 2018 (modified)*

## 4 SOCIO-ECONOMIC CONSEQUENCES

The socio-economic consequences are already being felt in the fisheries and aquaculture sectors.

The tonnages caught by fishing fleets and the specific catch composition are already affected by global warming, deoxygenation and changes in primary production (plankton) (high level of confidence). These factors play a role in the growth, reproduction and survival of fish stocks. They increase disease occurrence, particularly in aquaculture, where confined animals cannot escape to more oxygenated zones. Shellfish farms are very sensitive to these changes and to acidification.

Fishermen are already being forced to change their fishing grounds, with consequences for the duration of the fishing trips and fuel consumption.

Tropical regions will be the most impacted in the near future.

With regard to aquaculture, the search for suitable sites, incorporating future changes, is a major challenge at a time when there is growing demand for seafood and fishing tonnages are stagnating, or even declining. Moreover, the low availability of suitable sites hinders aquaculture development because the coastline is highly sought-after for other activities (tourism, etc.).

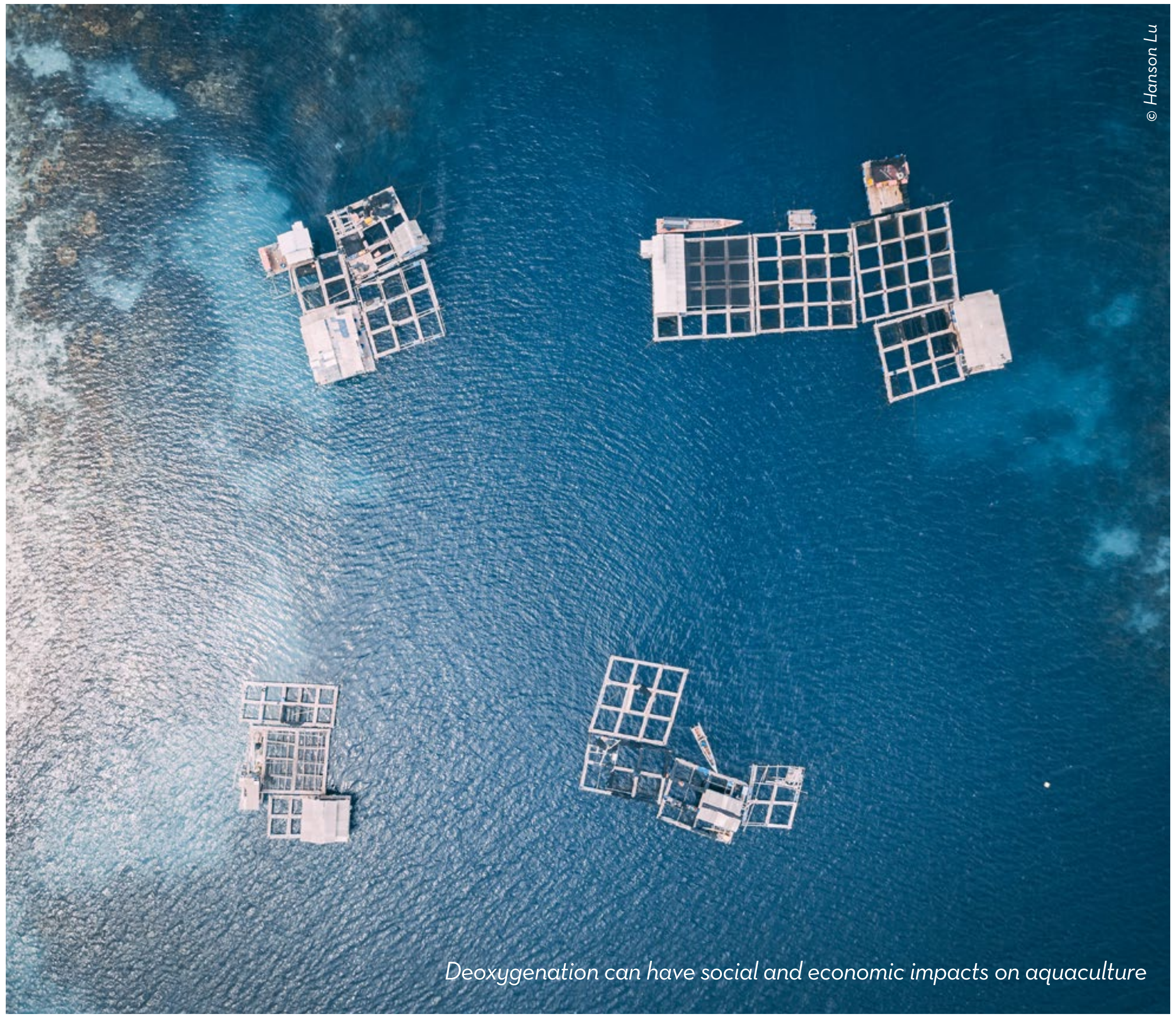
## 5 POTENTIAL CUMULATIVE IMPACTS ON CLIMATE CHANGE

Deoxygenation might also have an effect on climate change by contributing to the greenhouse effect through changes in the nitrogen cycle. When the dissolved oxygen concentration is insufficient for aerobic respiration, some microorganisms use denitrification to meet their energy needs. When incomplete, the conversion of nitrates into inert nitrogen gas can lead to atmospheric emissions of an intermediate, nitrous oxide. This very potent greenhouse gas has an effect 300 times greater than that of carbon dioxide, contributing further to ozone layer depletion. A "vicious circle" could therefore be triggered, where ocean warming would lead, through deoxygenation, to the release of a gas contributing to global warming.

In brief, the "infernal" trio – global warming, acidification and deoxygenation – has the same anthropogenic origin.

## 6 SOLUTIONS FOR THE FUTURE?

Overall, to ensure that the ocean keeps contributing to the well-being of humanity through the services it provides, greenhouse gas emissions, as well as nitrogen and phosphorus discharges from water treatment plants (where they exist...) and unsustainable farming, must be drastically reduced.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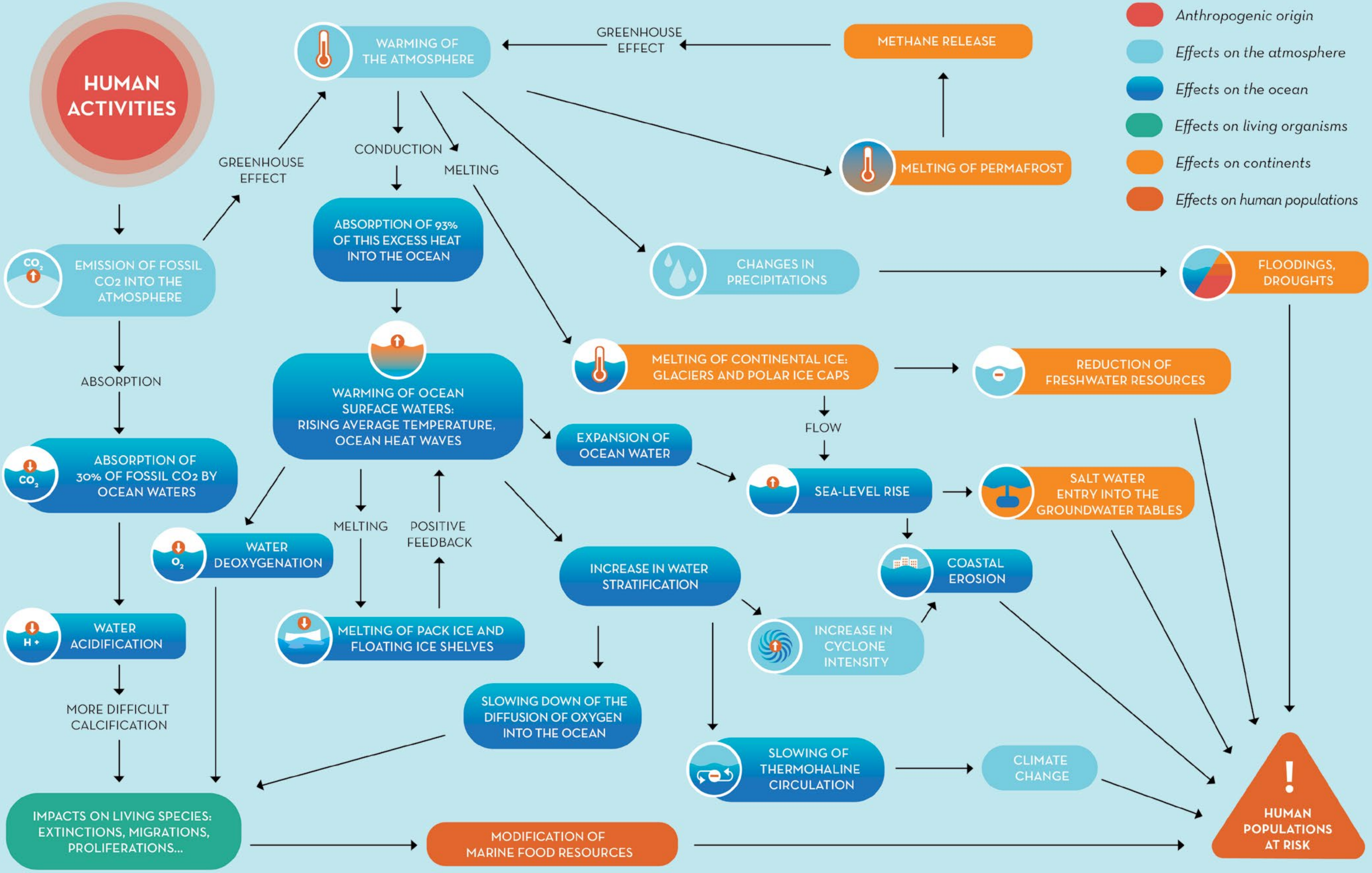
*Deoxygenation can have social and economic impacts on aquaculture*

# *IMPACTS OF HUMAN ACTIVITIES ON THE OCEAN AND CLIMATE INTERACTIONS*

*AUTOR:*
*GABRIEL PICOT,*
*AQUARIUM TROPICAL DU PALAIS DE LA PORTE DORÉE*



**HUMAN ACTIVITIES**

EMISSION OF FOSSIL CO2 INTO THE ATMOSPHERE

GREENHOUSE EFFECT

WARMING OF THE ATMOSPHERE

GREENHOUSE EFFECT

METHANE RELEASE

MELTING OF PERMAFROST

CONDUCTION

MELTING

ABSORPTION OF 93% OF THIS EXCESS HEAT INTO THE OCEAN

CHANGES IN PRECIPITATIONS

FLOODINGS, DROUGHTS

ABSORPTION

ABSORPTION OF 30% OF FOSSIL CO2 BY OCEAN WATERS

WARMING OF OCEAN SURFACE WATERS: RISING AVERAGE TEMPERATURE, OCEAN HEAT WAVES

MELTING OF CONTINENTAL ICE: GLACIERS AND POLAR ICE CAPS

REDUCTION OF FRESHWATER RESOURCES

EXPANSION OF OCEAN WATER

FLOW

SEA-LEVEL RISE

SALT WATER ENTRY INTO THE GROUNDWATER TABLES

WATER DEOXYGENATION

MELTING

POSITIVE FEEDBACK

INCREASE IN WATER STRATIFICATION

COASTAL EROSION

WATER ACIDIFICATION

MELTING OF PACK ICE AND FLOATING ICE SHELVES

INCREASE IN CYCLONE INTENSITY

MORE DIFFICULT CALCIFICATION

SLOWING DOWN OF THE DIFFUSION OF OXYGEN INTO THE OCEAN

SLOWING OF THERMOHALINE CIRCULATION

CLIMATE CHANGE

IMPACTS ON LIVING SPECIES: EXTINCTIONS, MIGRATIONS, PROLIFERATIONS...

MODIFICATION OF MARINE FOOD RESOURCES

**HUMAN POPULATIONS AT RISK**

- 🟥 *Anthropogenic origin*
- 🟦 *Effects on the atmosphere*
- 🟦 *Effects on the ocean*
- 🟩 *Effects on living organisms*
- 🟧 *Effects on continents*
- 🟧 *Effects on human populations*

# OCEAN AND CLIMATE CHANGE: OVERVIEW OF CONSEQUENCES

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**INCREASE IN GHG EMISSIONS INTO THE ATMOSPHERE**
**&**
**INCREASE IN ATMOSPHERIC TEMPERATURE**

## PHYSICO-CHEMICAL CONSEQUENCES

- **Increased melting of ice and glaciers**
  - Sea level rise
  - Changes in marine currents
- **Increased ocean acidification**
- **Increased water temperature**
  - Recession of pack ice
  - Expansion of Oxygen Minimum Zones
  - Changes in marine currents
  - Sea level rise
  - Increased frequency and intensity of marine heat waves and increased intensity of cyclones

## CONSEQUENCES FOR ECOSYSTEMS

- **Deterioration of ecosystem services**
- **Relocation of areas of distribution for some fish species**
- **Changes in the composition of communities**
- **Destruction of coral reef ecocystems**
- **Carbon cycle disruption – Deep habitats**
- **Modification of marine biomass and the food chain**
- **Reduction in marine primary production**
- **Impacts on species other than fish**
- **Contribution to the erosion of biodiversity**

## SOCIO-ECONOMIC CONSEQUENCES

### CONSEQUENCES FOR HUMAN ACTIVITIES

- **Loss of yields for the fisheries and aquaculture sectors**
- **Loss of land due to floodings and/or droughts**

### CONSEQUENCES FOR HUMAN COMMUNITIES

- **Increased water stress**
- **Increased inequalities**
- **Increased food insecurity**
- **Increased phjysical insecurity related to extreme events**
- **Increased migrations of populations**
- **Increased sanitary risks**

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