THE CLIMATE IN OUR HANDS

OCEAN AND CRYOSPHERE

Teacher's guide book for primary and secondary school

United Nations
Educational, Scientific and
Cultural Organization

Office for Climate Education
UNDER THE AUSPICES OF UNESCO

4 QUALITY EDUCATION
13 CLIMATE ACTION
14 LIFE BELOW WATER

THE CLIMATE IN OUR HANDS

Ocean and Cryosphere

This document should be cited as follows: **"The climate in our hands – Ocean and Cryosphere, a teacher's handbook for primary and secondary school"**, Office for Climate Education, Paris, 2019.

Coordinators:
Mariana Rocha (OCE, France)
David Wilgenbus (OCE, France)

Authors (in alphabetical order)
Lydie Lescarmontier (OCE, France)
Nathalie Morata (OCE, France)
Mariana Rocha (OCE, France)
Jenny Schlüpmann (Freie Universität, Berlin)
Mathilde Tricoire (OCE, France)
David Wilgenbus (OCE, France)

The scientific overview was written by Eric Guilyardi (Institut Pierre Simon Laplace, France) and Robin Matthews (IPCC Group 1 Technical Support Team, United Kingdom).

Layout and cover design: Mareva Sacoun
English proofread: Niamh O'Brien

A full list of the many people who contributed to this book, through their critical reviews, proposals, classroom tests, etc., is provided on the "Acknowledgements" section, page 190.

Date of publication
January 2020

Information
Information on the Office for Climate Education work, as well as extra copies of this document (English, French, German and Spanish versions in 2020), can be obtained at the following address:

Office for Climate Education
Fondation La main à la pâte, 43 rue de Rennes, Paris – France
e-mail: contact@oce.global
website: www.oce.global

The digital version of this publication can be viewed and downloaded at: www.oce.global

THE NEED FOR CLIMATE EDUCATION

There is an urgent need for collective action to mitigate the consequences of climate change and adapt to unavoidable changes. The complexity of climate change issues can pose educational challenges. Nonetheless, education has a key role to play in ensuring that younger generations have the required knowledge and skills to understand issues surrounding climate change, to avoid despair, to take action, and to be prepared to live in a changing world.

The Office for Climate Education (OCE) was founded in 2018 to promote strong international cooperation between scientific organisations, educational institutions and NGOs. The overall aim of the OCE is to ensure that the younger generations of today and tomorrow are educated about climate change. Teachers have a key role to play in their climate education and it is essential that they receive sufficient support to enable them to implement effective lessons on climate change. The OCE has developed a range of educational resources and professional development modules to support them in teaching about climate change with active pedagogy.

THE CONTENT OF THIS EDUCATIONAL PROJECT

In 2019, the United Nations' Intergovernmental Panel on Climate Change (IPCC) published a Special Report[1], which emphasized the importance of the ocean and cryosphere (ice and snow all over the planet) to mankind and how strongly they are being impacted by climate change.
The four key messages in this report are:

- The ocean and cryosphere sustain us.
- The ocean and cryosphere are under pressure.
- Their changes affect all our lives.
- The time for action is now.

This OCE teacher handbook has been researched and written by the OCE team and the OCE's scientific and education partners. The aim of this guide is to support teachers in implementing a range of activities on climate change and the ocean and cryosphere in their classrooms.
This resource:

- Targets students from the upper end of primary school to the end of lower-secondary school (ages 9 to 15).
- Includes scientific and pedagogical overviews, lesson plans, activities, worksheets, and links to external resources (videos and multimedia activities).
- Is interdisciplinary with lessons covering disciplines such as natural sciences, social sciences, arts and physical education.
- Promotes active pedagogies: inquiry, role-play, debate and project-based learning.

The lessons are divided into two parts.

PART 1 WE UNDERSTAND
This section contains five sequences with core and optional lessons, aimed at helping students understand the impacts of climate change, induced by human activities. They also highlight the importance of the ocean and cryosphere in regulating climate and how they provide essential resources and services to humans. The lessons outline how these services are at risk as a result of climate change. Finally, it provides students with opportunities to reflect on and consider the importance of urgent action.

PART 2 WE ACT
This section contains three detailed projects that students / schools could implement so that they can take tangible action in mitigating climate change, as well as ideas for other projects. Details on possible designs and methodologies for those projects are also outlined in this section.

The sequences of lessons in this resource are written so that teachers can select lessons that are suited to their particular needs or contexts. However, we advise teachers to maintain a certain balance between the two main parts: students will not usually be capable of intelligent, effective actions without a proper understanding of the issue; understanding without taking action is not insufficient, given the urgency of adaptation and attenuation.

Our hope is that this resource will inspire teachers and support them in adopting a creative and effective climate education programme in classrooms.

1 www.ipcc.ch/report/srocc

CONTENT

Background for teachers

Lesson plan

Around this book

SCIENTIFIC OVERVIEW

BACKGROUND FOR TEACHERS

SCIENTIFIC OVERVIEW

Introduction

This background document draws upon the Special Report on the Ocean and Cryosphere in a Changing Climate (SROCC) prepared by the UN's Intergovernmental Panel on Climate Change (IPCC) of scientific experts, and released in September 2019 (www.ipcc.ch/report/srocc). It aims to provide a broad overview of the core themes and concepts explored in the accompanying lesson plans. Unless otherwise specified, the information in this summary comes from the SROCC report.

The ocean and cryosphere (ice and snow on the planet) stretch from the highest mountains to the bottom of the sea, and from the warm, humid tropics to the cold, dry poles. These realms were once considered too vast and remote to be affected by humans.
Today, we are witnessing rapid changes in the ocean and cryosphere, driven by human greenhouse gas emissions and other human-caused factors, and impacting both humans and ecosystems.

This document provides an overview of these changes across six key themes:
1. What the climate is and why it varies.
2. Why the ocean and cryosphere are important to us.
3. How the climate is rapidly changing due to human activity.
4. How the ocean and cryosphere are changing due to climate change.
5. What impacts this has on us.
6. How we can act to mitigate and adapt to climate change.

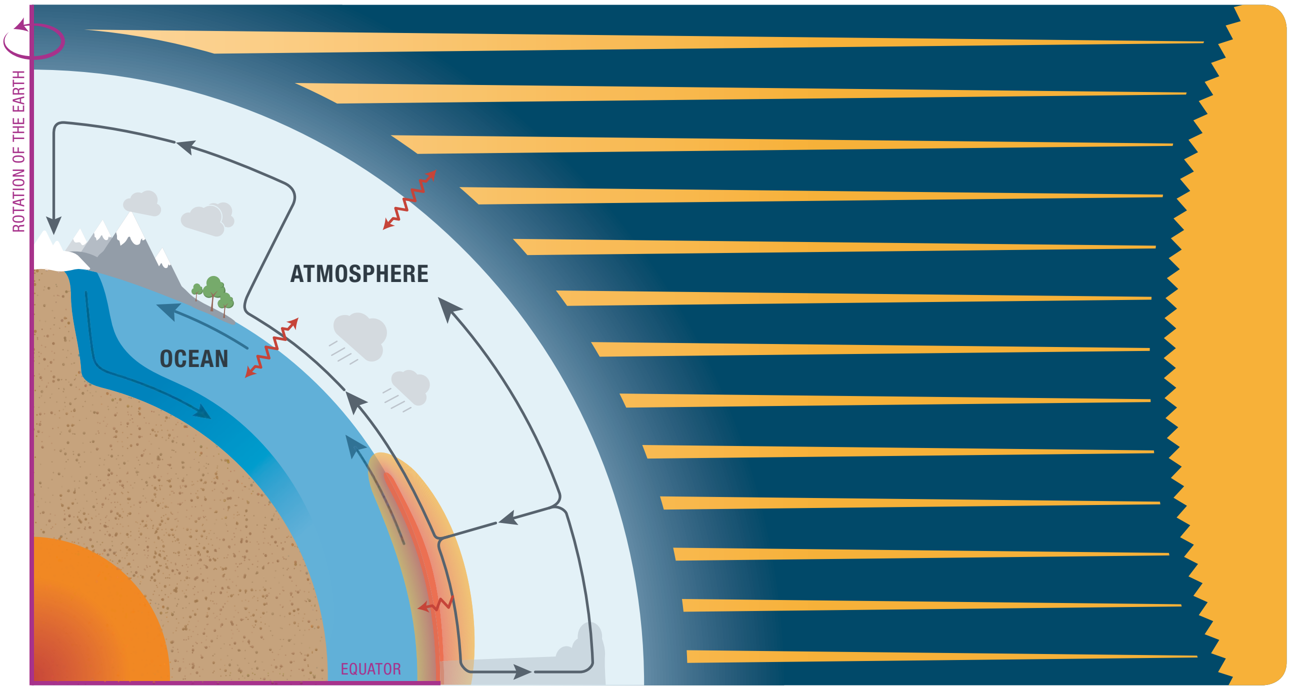

Diamond Beach, Iceland.

What the climate is and why it varies

THE CLIMATE AND ITS VARIATIONS

The climate is the time average of weather over months, years, decades, centuries or more. In the tropics, we expect it to be warm and humid (a tropical climate), although the conditions on any given day will still vary (the weather) around this "average condition". Beyond geography, which explains the different climates present on Earth, the global climate system is a dynamic entity in which energy, water, carbon and other elements are continuously exchanged between the atmosphere, ocean, cryosphere, land surface, and life forms.

The Sun's energy is the main driver of the climate system. Because the Earth is a sphere, the Sun's rays distribute this energy unequally across the planet, with the tropics receiving more energy on average than the poles (figure below). The atmosphere and the ocean maintain a stable climate by transporting this additional energy from the tropics towards the poles, acting as climate regulators.



The climate system receives energy from the sun. The Sun's rays distribute the energy unequally on Earth.

Although they both contribute to this energy transfer, the ocean and the atmosphere do so with marked differences:

- Slow but powerful currents in the ocean, together with the thermal inertia of water (water does not give up its heat easily), drive energy transfer in the tropics.
- The atmosphere gives up its heat more easily but its currents (the winds) are faster, and particularly efficient at transporting energy outside the tropics and towards the poles. In the atmosphere, the energy received from the Sun is finally returned to space through infrared radiation, ensuring a global balance between incoming (the Sun) and outgoing (infrared radiations) energy. The infrared radiation is the radiation emitted by a warmed body (the Earth's surface, warmed by the Sun).

To detect changes in the climate and determine their causes, scientists first have to understand the mechanisms that affect it. **The climate varies due to both external and internal causes.**

EXTERNAL CAUSES

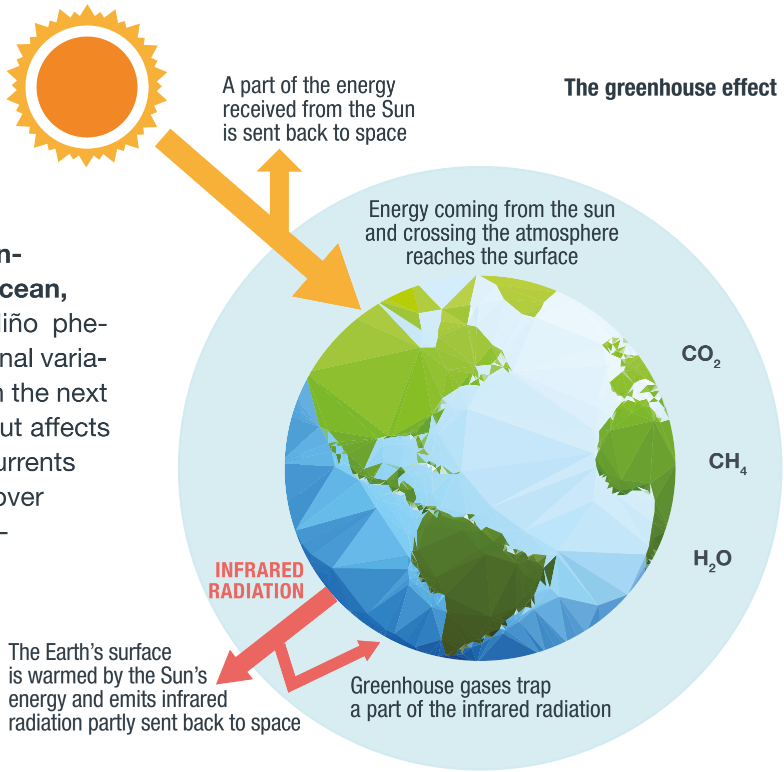
There are three main sources of external climate variations:

- **Changes in the energy received from the Sun** (related to sunspots or variations in Earth's orbit); For example, the seasons we experience are climate variations from changes in the amount of sunlight received at a given location during the year.
- **Volcanic eruptions** occurring on Earth. Massive eruptions release aerosols – small particles – into the upper atmosphere, which act as an umbrella blocking the sun's rays and cooling the planet for up to a few years.
- **Greenhouse gases** (GHG) emissions.

Greenhouse gases are gases in the atmosphere that have the property of being mostly transparent to visible sunlight, but not to the infrared radiation emitted by the Earth's surface. These gases (including water vapour, carbon dioxide, methane and nitrous oxide) **trap the infrared energy and send a part of it back to the surface, thus warming the lower atmosphere and the planet's surface.** This phenomenon is known as the **greenhouse effect**. It occurs naturally and is essential to life on Earth – without it, global mean temperature would be around -18°C, instead of +15°C. Humans are raising greenhouse gas levels in the atmosphere, mostly by releasing carbon dioxide, methane and nitrous oxide, causing human-made (anthropogenic) climate change. This is defined as a cause external to the climate system.

INTERNAL CAUSES

The climate also undergoes internal variations of its own accord. **These variations involve energy exchanges between the ocean, atmosphere and cryosphere.** The El Niño phenomenon is the most active source of internal variations from one year to the next (see box on the next page). It originates in the tropical Pacific but affects most of the planet. Changes in ocean currents can also drive changes in regional climate over decades. For instance, a colder North Atlantic Ocean in the 1970s and 1980s led to severe droughts in the Sahel (south of the Sahara Desert).



SPECIFIC ROLE OF THE OCEAN

The ocean plays a central role in the climate system. It can store a very large amount of heat. The top 2 or 3 meters of the ocean's depth contain as much thermal energy as the entire atmosphere. This is why the ocean exerts a strong influence on the climate system over seasons and centuries, regulating the planet's heat and causing slow internal variations in climate.
Ocean circulation and currents play a major role in regulating the climate and supporting marine life by transporting heat, carbon, oxygen, and nutrients throughout the ocean.

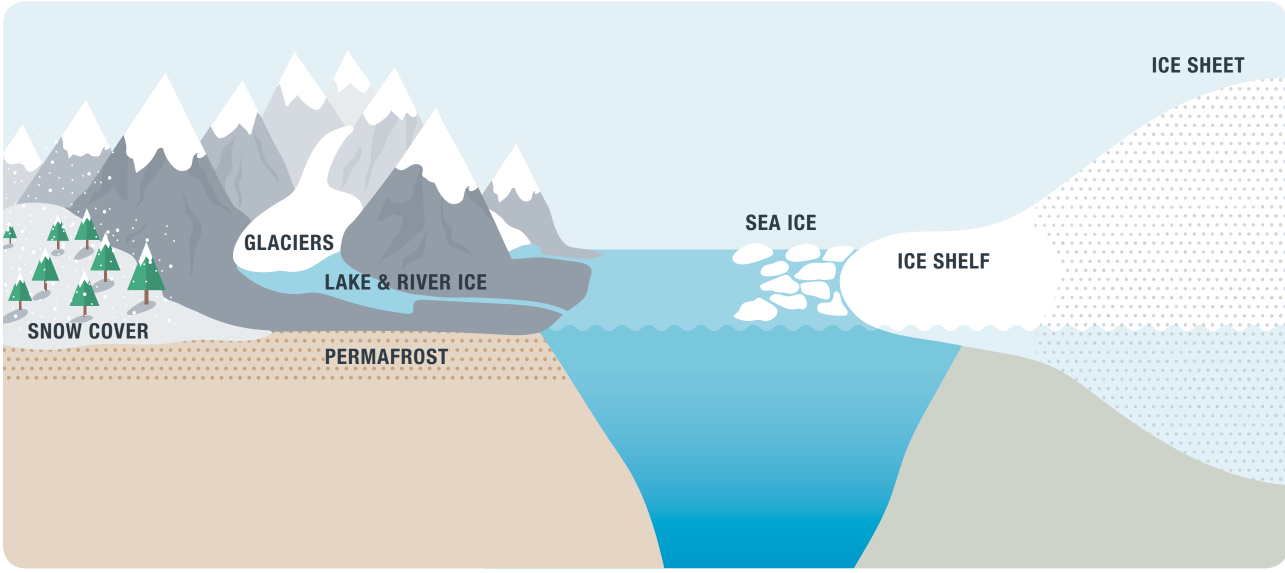
The ocean also stores a very large amount of carbon. Today it stores about 38,000 gigatons (Gt) of carbon (1 gigaton = 1,000,000,000 tons): about 16 times as much as all plants on land and underlying soils, and around 60 times as much as the atmosphere. The ocean exchanges very large quantities of carbon with the rest of the climate system: about 100 Gt of carbon are exchanged every year across the air-sea interface. In the ocean, the distribution of carbon is controlled by two carbon "pumps", which transfer carbon from the surface into the deep ocean. The physical pump relies on the facts that ocean water absorbs carbon dioxide (CO_2) from the atmosphere and that cold water masses sink to great depths. The second pump involves biology: marine plants (such as phytoplankton) absorb CO_2 by photosynthesis, like plants on land. Some of the organic matter formed by this process sinks down to the ocean's depths.

SPECIFIC ROLE OF THE CRYOSPHERE

The cryosphere consists of ice and snow in different forms:

- In the ocean: **sea ice** (ice floating on the ocean, made of frozen seawater).
- On the continents: **glaciers** on land, the two **ice sheets** (on Greenland and Antarctica), **permafrost** (permanently frozen ground), and **seasonal snow** on land and **frozen lakes and rivers**. Glaciers and ice sheets are formed by the slow accumulation of snow, which, over time, compresses into ice and then flows very slowly downhill. The Greenland and Antarctic ice sheets are several kilometres thick in some places. When ice sheets flow down to a coastline and then onto the ocean, they form thick floating platforms of ice attached to the land, called ice shelves.

The cryosphere influences the climate in several ways. First, it is **part of the global water cycle** and holds three quarters of the fresh water on the planet. Second, due to their **highly reflective nature** (or "albedo"), ice and snow act as "mirrors" and reflect a large fraction of the solar radiation they receive back to deep space. Third, formation and melting of sea ice at the poles **contributes to ocean circulation** by modifying the seawater salinity. Finally, **permafrost is an important component of the planet's carbon cycle.**



The components of Earth's cryosphere. Adapted from Fig. 4.25 of the IPCC WG1 AR5 report (2013).

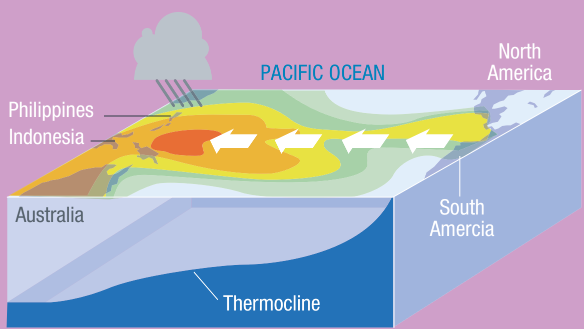
EL NIÑO, THE "WILD CHILD OF THE PACIFIC"

Every few years, an anomalous warming occurs in the central to eastern tropical Pacific, known as an El Niño event. Several such events have occurred in recent decades, such as the very large event of 1997-1998 and, more recently, 2015-2016.

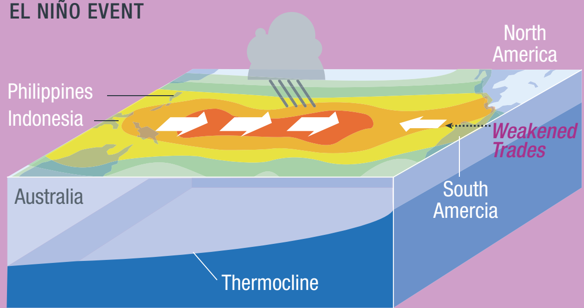
El Niño arises due to an anomalous energy exchange between the ocean and the atmosphere (see figures): the west-ward flowing trade winds that usually maintain the warm tropical waters around Indonesia suddenly weaken. As a result, the waters of the eastern Pacific warm up, further weakening and even reversing the trade winds. The name El Niño was coined by Peruvian fishermen who noticed an annual warm current that usually only occurred around Christmas time (hence El Niño, the child) would sometimes last the entire year.

El Niño has major human and environmental global impacts. As it changes wind and rain regimes, it is feared in many regions in or near the Tropical Pacific. On the coasts of Peru and Chile, usually abundant fish catches stop during El Niño as the nutrients associated with deep cold water are no longer present at the surface to feed the fish. In the western Pacific, the usually intense rains move further east, generating devastating droughts in Indonesia, the Philippines and Australia. Summer monsoons, on which half of the planet's population depend, are disrupted, especially in China, India, Australia, the Sahel and Brazil. These major impacts can now be anticipated because we can predict El Niño months in advance, using seasonal forecasts.

NORMAL CONDITIONS



EL NIÑO EVENT



Why the ocean and cryosphere are important to us

The ocean and the cryosphere are both expansive and resource-rich, and are fundamental to human society. **They provide a wide range of both material and immaterial services to us,** ranging from food to recreation.

GEOGRAPHY OF THE OCEAN AND CRYOSPHERE

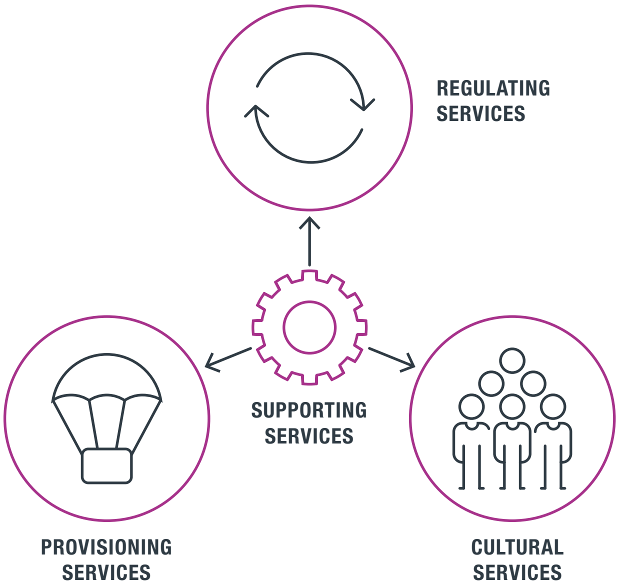
The ocean covers around two thirds of Earth's surface – it has been suggested that our planet should be called Ocean rather than Earth. While the surface of the ocean may seem homogenous, its temperature, salinity, colour and ecosystems vary geographically. Coral reefs and mangroves are found in the warm coastal waters of the tropics, while sea ice and associated ice-dwelling algae are found near the poles. Seagrasses (grass-like plants) are found along coasts everywhere but the polar seas [1].

The cryosphere is also vast, with the great ice sheets of Antarctica and Greenland together covering around 10% of Earth's land surface [2]. There are also nearly 200,000 glaciers worldwide [3], including those at high altitude in the tropics (where it is cold high up, despite being tropical). Even less known is the fact that around a quarter of land in the northern hemisphere is underlain by permafrost (permanently frozen ground) [4]. Some components of the cryosphere vary seasonally. For instance, each winter, snow covers around a third of northern hemisphere land ("seasonal snow"), while sea ice in the Arctic and Antarctic expands each winter and retracts each summer.

People and wildlife live in conjunction with the ocean and cryosphere. Many of the world's megacities, including Tokyo, Bangkok and New York, are located on the coast, and in 2010 about **30% of the global population lived less than 100 km from the ocean. Around 10% of the world's population lives in high mountain regions,** while around 4 million people, including indigenous peoples, live in the Arctic. Unlike the Arctic, the Antarctic, protected by an international treaty, can only be visited (by scientists, explorers and tourists) and has no permanent residents.

SERVICES OF THE OCEAN AND CRYOSPHERE

The resources and services the ocean and cryosphere provide can be classified into different **ecosystem services,** of which there are four main types: **regulating, provisioning, cultural** and **supporting** services.



REGULATING SERVICES

We have already seen how the ocean and cryosphere **help regulate the global climate** through their interactions with Earth's energy budget and carbon cycles. These are regulating services, which also include things like the coastal protection functions provided by coral reefs and mangrove forests.

PROVISIONING SERVICES

The ocean and cryosphere also provide provisioning services, including **food, water and energy.** Fisheries provide a key global food source, with fish and shellfish accounting for over 50% of the animal protein consumed in many least developed countries [5]. The ocean also provides renewable energy in the form of wave and tidal power, along with oil, gas and minerals from the seafloor. Glaciers supply river basins with water for drinking, irrigation and hydro-

1 Short et al. (2007). Global seagrass distribution and diversity: a bioregional model.
2 Chapter 4 WG1 AR5 IPCC Report: https://www.ipcc.ch/report/ar5/wg1/
3 Pfeffer et al. (2014). The Randolph Glacier Inventory: a globally complete inventory of glaciers.
4 Gortnitz, V. (2019). Vanishing Ice: Glaciers, Ice Sheets and Rising Seas.
5 http://www.fao.org/fishery/topic/16603/en

Healthy coral reef ecosystems are sustained by interactions between numerous animal and algal species.

power. Around 800 million people[6] are partly reliant on run-off from Himalayan glaciers alone. **Transport** is another type of provisioning service. Frozen rivers in the Arctic in winter provide a transport network (ice roads), while the vast majority of goods is moved across the planet by ocean-traversing ships.

CULTURAL SERVICES

Cultural services comprise a third category of ecosystem services. In an ocean and cryosphere context, these include **jobs in fishing and recreation** (such as water sports and beach jobs), **local traditions and cultures, and religious beliefs** regarding, for example, high-mountain glaciers.

SUPPORTING SERVICES

Finally, there are the supporting services that **contribute to the provision of the three preceding types.** These include **primary production** (such as the food source that ocean phytoplankton provides in marine food webs), **nutrient cycling and soil formation.**

BIODIVERSITY

Like supporting services, biodiversity, or the diversity of organisms (from micro- to macro-) and their networks, also cuts across ecosystem services, since it aids ecosystem functions. **Biodiverse ecosystems are also more resilient to climate change**[7].

The ocean is highly biodiverse with hotspots found, for instance, in coral reef ecosystems. Microscopic single-cell algae called phytoplankton form the base of most marine food webs and are consumed by (mostly microscopic) animals called zooplankton. At the top of these food webs are sharks and marine mammals, such as seals and whales, some of which migrate long distances across the ocean. Species diversity maintains ecosystem functions, but each ecosystem has its own specific key organisms at play. For coral reefs these includes algae, worms, molluscs, sponges, urchins and fish in addition to the corals. Kelp forests are a type of cold-water coastal ecosystem structured by kelps (macroalgae), which also provide food and habitat to a myriad of organisms. While our knowledge of ocean biodiversity is rapidly growing with thousands of new species discovered every year[8], it is also limited, and marine biologists estimate that hundreds of thousands of species still remain unknown.

6 https://www.aaas.org/news/spy-satellites-reveal-himalayan-ice-loss-has-doubled-2000
7 Epple and Dunning (2014). Ecosystem resilience to climate change: What is it and how can it be addressed in the context of climate change adaptation? UNEP – WCMC.
8 World Register of Marine Species – http://www.marinespecies.org/index.php

How the climate is rapidly changing due to human activity

HUMAN ACTIVITY EMITS GREENHOUSE GASES WHICH LEAD TO GLOBAL WARMING

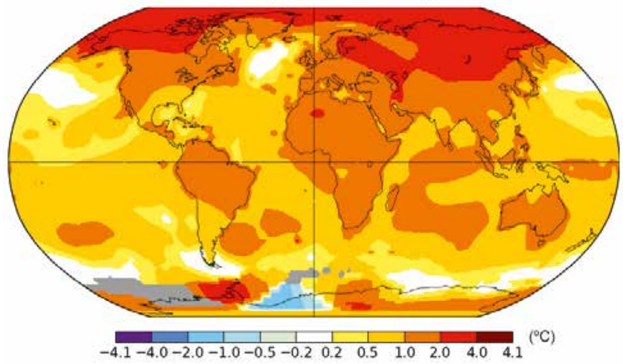
The physics of greenhouse gases has been well understood for decades: **if we increase the concentration of these gases in the atmosphere, more energy remains near the surface of the planet, leading to the warming we are experiencing.** Human actions have altered GHG concentrations in two ways:

- Through extraction of ancient (fossil) carbon fuels from underground (coal, oil and gas) and their subsequent combustion ($C + O_2 \rightarrow CO_2$).
- Through deforestation, reducing the natural CO_2 storage provided by forests, and other changes in land use.

Over the last million years, CO_2 levels in the atmosphere have varied from 180 to 280 parts per million (ppm)[9], the lower value corresponding to glacial periods (colder periods) and the upper value to interglacials (warmer). The planet has been in an interglacial period for about 10,000 years and, in a mere 150 years, the CO_2 concentration in the atmosphere has risen by more than 40% and is now around 410 pm (2018)[10]!

Most of this extremely rapid increase is **directly due to the burning of fossil fuels,** which began on a large scale with the advent of the industrial revolution in the 1800s. The methane concentration has increased by 160% over the same period, and the nitrous oxide concentration by 20%. Human-caused sources of methane include cattle digestion, paddy fields, and leaks occurring during oil and gas exploitation. Nitrous oxide is mainly emitted when using synthetic nitrogen fertilizers and manure in agriculture.

As a consequence of these GHG increases, **the global temperature has risen by about 1°C,** from pre-industrial times until 2018[11]. Scientists estimate that our direct CO_2 emissions, methane emissions and land use changes (such as deforestation) account for roughly 70%, 20% and 10% of global warming, respectively.



Annual surface temperature anomaly 1950 – 2018. Observed global warming in degrees Celsius: change of surface temperature from 1950 to 2018. Source: NASA-GISS: https://data.giss.nasa.gov/gistemp/maps/index_v4.html

THE OCEAN AND CRYOSPHERE SLOW DOWN GLOBAL WARMING

Today, out of the 40 billion tons of CO_2 emitted each year by human activity, less than 50% stays in the atmosphere[12]. The rest is absorbed in roughly equal parts by land vegetation (which grows faster) and by the ocean. Without these two carbon "sinks", global warming would already be much higher than 1°C. In addition to removing human-generated CO_2 from the atmosphere, the ocean also slows down global warming in another way. Thanks to its huge heat capacity, **it has absorbed more than 90% of the extra heat generated by global warming,** taking it out of the atmosphere. While beneficial in some ways, both of these ocean services have other adverse consequences. As described in more detail in the next section, they come at the price of increased ocean temperature and acidity, along with sea level rise.

ALBEDO CHANGE IN THE CRYOSPHERE ENHANCES GLOBAL WARMING

In the seasonally ice-covered Arctic, faster warming is due to the following **positive feedback:** as temperature rises, ice and snow melt away, hence re-

9 https://climate.nasa.gov/climate_resources/24/graphic-the-relentless-rise-of-carbon-dioxide/
10 https://www.esrl.noaa.gov/gmd/ccgg/trends/
11 IPCC Special Report "Global warming of 1.5°C": https://www.ipcc.ch/sr15
12 https://www.globalcarbonproject.org/carbonbudget/ & IPCC Special Report "Global warming of 1.5°C"

ducing the "mirror" effect (reflection of sunlight back to space), such that more heat can be absorbed, accelerating warming and the melting. This feedback also operates in glacier areas and snow-covered mountainous areas.

The change in moisture levels, another consequence of melting sea ice, further increases Arctic Ocean warming. **Around 1% of the extra heat from global warming goes into melting glaciers and ice sheets,** removing this heat from the atmosphere.

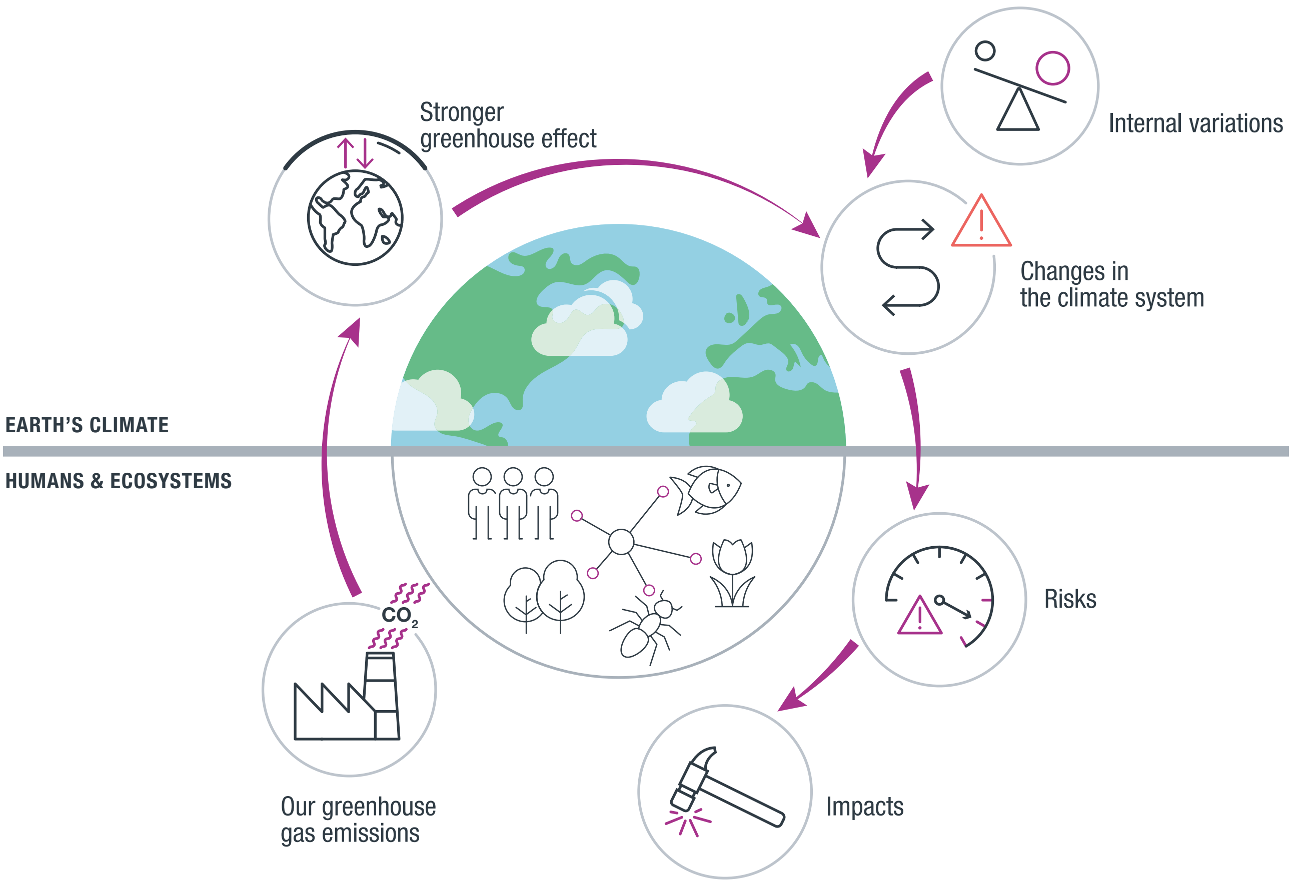
WARMING IS NOT THE SAME EVERYWHERE

As seen in the distribution of global warming across the planet (figure on the previous page), the regions outside the tropics warm more – the Arctic is warming twice as fast as the global average. Land has a smaller heat capacity than the ocean and is not very efficient at transporting energy downwards away from the surface. It therefore warms more. We experience this effect in temperate latitudes in summer where coastal regions (oceanic climate) tend to be cooler than those inland (continental climate).

How the ocean and cryosphere are changing due to climate change

Human-generated greenhouse gas emissions are enhancing the planet's natural greenhouse effect. The resulting **warming of the ocean and atmosphere can be enhanced or reduced by mechanisms operating in the climate system, known as feedbacks** (as previously seen with the albedo effect).

For instance, as global temperatures rise, more water from oceans and lakes evaporates into the atmosphere. This is an amplifying feedback that generates further warming, because water vapour is a major greenhouse gas.



Flow diagram of human greenhouse gas emissions and the impacts of climate change

CHANGES IN THE OCEAN AND CRYOSPHERE

The flow diagram on the previous page illustrates the multiple interactions between human activities and the climate system. The top half of the diagram (above the grey line) shows changes to Earth's climate system, while the bottom half shows factors relating to humans and ecosystems. Following the black arrows takes us from our greenhouse gas emissions (which can be "mitigated", i.e. avoided) on the left over to the risks and impacts they cause through global warming on the bottom right. In between are the so-called "climate hazards", which are the physical and chemical changes in the climate system, including the warming of the atmosphere and ocean, the melting of glaciers and ice sheets, and sea level rise. Their magnitude depends on the amount of global warming, and therefore the amount of greenhouse gases we release. Taking steps to reduce our greenhouse gas emissions is called mitigation.

Partly due to the internal variations in the climate system discussed previously, we cannot say for sure what the exact impacts of climate change will be for a specific location. For instance, a given location may or may not experience an extreme storm that has been altered by climate change – although the nature of storms will change as the planet heats up. Instead, we can take a risk-based approach, coming up with a best estimate of how likely and how consequential such a storm would be. We can then take steps to reduce the level of risk (and thus the impacts if the storm does occur) through adaptation, which we will discuss in the final section.

In the remainder of this section, we will consider each of the components of the ocean and cryosphere in turn, **exploring how climate change is already affecting them and what may lie in store in the future.**

MELTING OF GLACIERS AND ICE SHEETS

As atmospheric temperature rises, the surfaces of ice sheets and glaciers are increasingly exposed to melting conditions (loss of ice mass), which the accumulation of fresh snow (gain of mass) cannot always compensate for. Ice sheets and glaciers generally respond slowly to temperature (they have high **thermal inertia**). For this reason, and also due to the feedbacks discussed above, **ice sheets and glaciers will continue to melt for hundreds or thousands of years after global temperature stops rising.** With a few exceptions, glaciers worldwide are losing mass and shrinking in size. Between 2006 and 2015, the Greenland ice sheet lost mass at a rate of 278 gigatons (Gt – billions of tons) per year and the Antarctic ice sheet at a rate of 155 Gt/year. This corresponds to a global sea level rise of 0.77 and 0.43 mm/year respectively. Worldwide, glaciers lost mass at the same rate as the Greenland ice sheet.

PERMAFROST MELTING

Permafrost is permanently frozen ground – soil, rock (etc.) with a temperature below 0°C – which is usually encased in ice. **Permafrost temperatures are rising across the Arctic and in the world's mountainous regions** in response to the warmer atmosphere. If permafrost temperature rises above 0°C, the ground thaws. This has two consequences:

- It destabilizes the ground, potentially damaging buildings and roads in the Arctic and causing landslides in mountain regions.
- It leads to the decay of organic matter previously locked in the permafrost, resulting in the release of greenhouse gases (CO_2 and methane) and potentially, viruses and bacteria.

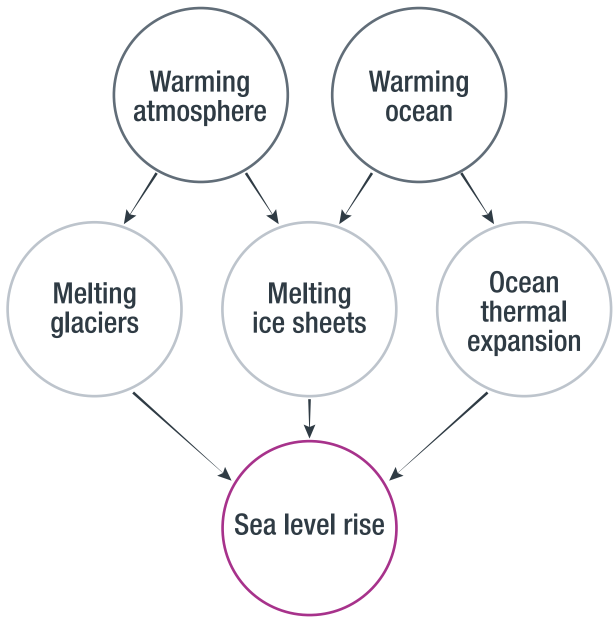
The amount of greenhouse gases released from permafrost in the 21st century will depend on the level of global warming reached, with estimates ranging from tens to hundreds of gigatons. By way of comparison, humans have already emitted around 2,200 Gt of carbon dioxide since the industrial revolution.

SEA LEVEL RISE

Global mean sea level has risen by around 15 cm since 1900, and the rate has accelerated (from 1.5 to 3.6 mm/year over that time). Sea level rise results from an increase in the ocean's volume. As illustrated on the next page, there are two main drivers:

- **The addition of water** to the ocean due to the melting of continental glaciers and ice sheets.
- **The expansion of seawater** as the ocean warms (thermal expansion) – warmer water occupies more space.

About half of the sea-level rise seen since the 1990s has been caused by thermal expansion, and the other half by the melting of ice on land, although this second factor is now dominant. **The sea level will continue to slowly rise for centuries after global warming stops.** Global mean sea level is projected to rise by a further 20 cm to over 1 m by the end of this century, depending on how much greenhouse gases we emit and how quickly the polar ice sheets respond.



How a warming atmosphere and ocean causes sea level rise. Note that some glaciers discharge into the ocean, so an extra arrow could be drawn between "warming ocean" and "melting glaciers".

On a local scale, additional factors come into play. First, there are extreme sea-level events like storm surges and changes in wind regimes. Shifts in the land surface – up or down – can also alter the height of the waterline relative to the land. This later can have a major impact: in Jakarta, groundwater extraction and sediment compaction have caused parts of the city to sink by several metres since 1980.

SEA ICE

Although summer sea ice does not contribute to sea level rise (as it is already in the ocean), rapid summer sea ice loss has been observed in the Arctic in recent decades [13]. Sea ice cover in the Arctic is subject to natural seasonal variations, reaching its maximum in March and its minimum in September. However, **ice cover in September has declined by around 40% since 1980** [14]. In addition to changes in ice cover, the **average age and thickness of ice has decreased.** In winter 1980, around 30% of the ice was five or more years old (having survived several summer melt seasons) – today, this figure is only 2%. Also, **sea ice in the central Arctic is now only a quarter as thick as it was in 1975** (1.25 m vs. 3.5 m). This Arctic sea ice reduction is affected by the positive ice-ocean albedo feedback discussed previously. In contrast to the situation in the Arctic, **Antarctic sea ice cover has remained stable over the past 40 years.**

OCEAN STRATIFICATION, MARINE HEATWAVES AND OXYGEN LOSS

Rising temperatures are altering the physical structure of the ocean and affecting sea life. As the ocean is being heated from the top down, the (less dense) ocean surface is warming faster than deeper, denser layers. **This increases the density contrast between surface waters and deeper layers** (a process called **stratification**), making it harder for nutrients from deeper waters to reach the nutrient-poor surface layer. With less mixing between surface and deeper waters, there is also a **decline in the supply of oxygen to deeper layers** from the oxygen-rich surface waters (**deoxygenation**). The upper 1000 m of the ocean has lost 0.5-3% of its oxygen content since 1970.

In addition to these gradual changes, extreme ocean temperature events, known as **marine heatwaves, are increasingly being observed.** These warm water events can lead to **mass coral bleaching and coral death,** as witnessed between 2014 and 2017 when a global event affected 75% of reefs. This is set to continue, with 75% of coral reefs expected to be lost if global temperature rises by only a further 0.5°C, and if local stressors due to human activities, which can also influence coral mortality, are not minimized.

OCEAN WARMING

In addition to contributing to increasingly frequent marine heatwaves, **a warmer ocean surface also reduces the efficiency of the ocean's physical CO_2 pump, which could affect its central role in slowing down atmospheric warming.**

OCEAN ACIDIFICATION

The uptake of human-induced CO_2 is causing the ocean to become more acidic (ocean acidification). This is sometimes called "the other CO_2 problem". Upon dissolving in seawater, CO_2 forms carbonic acid, which then separates into various ions through a series of chemical reactions. The net effect of these reactions is to raise the concentration of hydrogen ions (and thus ocean acidity), and lower the concentration of carbonate ions (saturation state of carbonates). The latter are a key building block used

13 https://nsidc.org/arcticseaicenews/charctic-interactive-sea-ice-graph/
14 http://nsidc.org/arcticseaicenews/2017/10/arctic-sea-ice-2017-tapping-the-brakes-in-september/

by marine calcifying organisms such as molluscs and corals to construct their shells and skeletons of calcium carbonate. Global mean pH has dropped by around 0.1 units since the industrial revolution to around 8.05 today (the greater the acidity, the lower the pH)[15]. It should be stressed that the acid / alkaline boundary of pH = 7 has little relevance in seawater – **any drop in pH can affect marine calcifiers during their various developmental stages** (pH does not have to drop below 7 to have an impact).

OCEAN CIRCULATION

Ocean circulation is driven both by winds (surface currents) and by density changes (thermohaline circulation). Warm surface currents, such as the Gulf Stream or the Kuroshio, affect the climate downwind, contributing to a climate that is milder in the western side of continents, at mid-latitudes (e.g. western Europe or western North America), in comparison to that of eastern coasts.

The thermohaline circulation, also known as the global overturning circulation, is a global loop: in the Atlantic basin, warm surface waters travel northwards, crossing the Equator from the south to the north Atlantic, before cooling and sinking to the bottom of the ocean, at high latitudes. Then, returning south at depth, the deep waters cross once again the Equator towards the south, reaching the Southern Ocean around Antarctica, before coming back up to the surface, centuries later, and joining the surface Atlantic currents again.

The strength of this circulation contributes to climate regulation around the world, and it affects in particular Europe's climate, by delivering heat to the north Atlantic. The Atlantic branch of this circulation is expected to weaken in the 21st century (by around 10 to 30%) due to climate change, but not to shut down entirely. This weakening will increase the sea level along the east coast of North America and cause more winter storms in Europe. In many other regions of the world, it is not yet known how global warming will affect ocean circulation, both at the surface and at depth.

SHIFTING SPECIES

Species on land and in the ocean are shifting their geographic ranges in response to global warming. They are moving uphill (on land) or to higher latitudes, so they can remain in their preferred temperature range. Glacier melt, along with loss of snow and permafrost in mountain regions, is creating new habitats for some species and destroying habitats for those dependent on snow and ice. In the Arctic, the boreal forest is expected to expand northwards into the treeless Arctic tundra. In the ocean, a range of creatures, from phytoplankton to marine mammals, are all moving towards the poles, by an average of 5 km / year. With the loss of Arctic sea ice, we expect to see increasing movement of fish between the Pacific and Atlantic oceans via the Arctic. Monitoring biological changes is particularly challenging in the Antarctic.

What impacts this has on us

CLIMATE CHANGE CREATES RISKS FOR HUMANS AND ECOSYSTEMS

As climate change alters the ocean and cryosphere, this creates risks for humans and ecosystems, which can affect resources, jobs, livelihoods, culture and health. Humans and ecosystems are exposed to multiple climate-related ocean and cryosphere threats, including higher storm surges, marine heat waves, sea ice loss and permafrost thaw.

- **As global mean sea levels rise, more areas are exposed to flooding** – either from recurrent tidal flooding or from extreme events like storm surges. Extreme sea levels, which are currently historically rare (for example, today's hundred-year floods), will become increasingly common this century. Low-lying areas, like Bangladesh and small islands, are particularly at risk. Many low-lying megacities and small islands will experience what are currently hundred-year floods every year by 2050. In the absence of strong adaptation efforts, this will lead to increased occurrences of severe flooding. Impacts include saltwater intrusion into groundwater and wetlands, which degrades water quality and can lead to health

15 Summary for Policy Makers of the IPCC WG1 AR5: https://www.ipcc.ch/report/ar5/wg1/

issues and destroy harvests. **Some low-lying Pacific Island nations and Arctic communities are already making plans in case they need to migrate** and resettle their populations elsewhere in the future.

- **Cryosphere loss affects humans in the Arctic and high mountain areas** in predominantly negative ways, impacting freshwater supplies, hydropower, infrastructure, transportation, food supplies, tourism and recreation, health and wellbeing, and culture and social values, with challenges and opportunities unequally distributed across populations. As glaciers melt, annual runoff initially increases, up to a peak, before declining. The seasonal timing of runoff can also change. In some areas, glaciers' ice loss is already reducing crop yields (e.g., in the tropical Andes), especially where other stressors are also present.

- As the climate changes, **ecosystems and landscapes are altered in complex ways, affecting ecosystem services.** In the Arctic, sea ice loss is expected to enhance growth of ocean phytoplankton due to greater light availability. On a global scale, fish are expected to generally shift polewards as the ocean warms, reducing species richness in the tropics and increasing it at mid to high latitudes. At the same time, global fishery catches, already affected by overfishing practices in some areas, are projected to decline overall.

- In addition to negative impacts, **there can also be opportunities.**
  For instance, melting sea ice in the Arctic is opening up the possibility of new marine transportation routes (a cruise ship, the *Crystal Serenity*[16], went through the Northwest Passage in summer 2016) and access to mineral resources, even if these activities also create new environmental risks.

The village of Shishmaref in Alaska is an island community of Iñupiat Eskimo. Although the village has some protective structures to combat coastal erosion, residents have voted to relocate to the mainland.

CLIMATE CHANGE IMPACTS MAKE IT HARDER TO ACHIEVE THE UNITED NATIONS SUSTAINABLE DEVELOPMENT GOALS

The UN has established a set of 17 Sustainable Development Goals that target, among other outcomes, improvements in global food and water security, livelihoods and education.

There are many intersections between this sustainable development agenda and climate change. For instance, declining fish catches due to climate change will affect income, livelihoods, and food security for fishing-dependent communities. In the tropics, 500 million people depend on coral reef ecosystems and will be severely impacted if they are permanently damaged[17]. Changes in the ocean and

16 Gortnitz, V. (2019): Vanishing Ice: Glaciers, Ice Sheets and Rising Seas
17 https://www.iucn.org/resources/issues-briefs/coral-reefs-and-climate-change

cryosphere can also affect cultural identity and well-being. For example, glaciers and sea ice can have profound cultural and religious significance.

The challenges and opportunities created by climate change may not be equally distributed. For instance, the poorest populations often live in low-lying areas that are most exposed to sea level rise. However, **tackling climate change can also support sustainable development,** if the burdens of taking action is shared fairly and equitably, in the same way as losses and gains from climate impacts.

The final section of this overview explores how we can tackle climate change – both its root cause (greenhouse gas emissions) and its symptoms (climate impacts).

How we can act to mitigate and adapt to climate change

There are two ways we can act to reduce the risks and impacts of climate change in the coming decades:

- One is to **limit global warming** by acting on greenhouse gases. We can do this by reducing human emissions into the atmosphere or by using methods that actively remove carbon dioxide from the atmosphere (known as CO_2 removal), such as planting trees. Together, these actions are called **mitigation**.
- A second approach is to **tackle the consequences of climate change** by either limiting the number of people, wildlife and property that might be in harm's way, or by reducing the extent to which they are affected. This is known as **adaptation**.

It is not an either / or situation, though: **both mitigation and adaptation are needed to tackle climate change.** Moreover, both should be considered when taking actions. For instance, when designing a new school, we could make the building carbon neutral in both construction and operation (mitigation), while also ensuring it can cope with a range of possible climate futures (adaptation). Or, when adapting to rising sea levels in the tropics, we can plant mangroves, which have the benefit of reducing both wave energy and coastal erosion while also removing CO_2 from the atmosphere (stored in carbon-rich mangrove soils). Preservation of coral reefs can also improve protection of island populations from wave energy from cyclones while providing sustainable food and economic resources.

MITIGATION

The challenge of **reducing humanity's greenhouse gas emissions** is huge. **Rapid emissions cuts are needed** while global population, energy demand and consumption are rising. Meanwhile, as enshrined in the UN's Sustainable Development Goals, we need to tackle other major global challenges, including improving access to food, water, jobs and healthcare care for those most in need, and reducing inequality.

There are many reasons to be hopeful. Not only is there growing public and political awareness of the need to act fast, but in combination with the rapidly falling cost of renewable energy and the landmark Paris agreement on climate change in 2015, all elements that can support rapid emissions reductions are falling into place. There have already been many success stories. In the UK, thanks to a decline in coal use, CO_2 emissions have fallen to levels last seen in 1890 [18], while Germany's use of renewables-based electricity has soared from around 6% in 2000, to about 38%, in 2018 [19]. In March 2018, the renewable electricity production in Portugal accounted for 103.6% of mainland electricity consumption [20]. However, since global warming depends on global emissions, it is not enough for just a few countries to act. It is also not only up to government, businesses and legislation to reduce emissions, even if their role is central. As we explore below, local organizations and individuals also have a role to play.

18 This does not give the full picture since some of the UK's emissions have been "outsourced" overseas.
19 Federal Environment Agency Section V 1.5 (2019). Time series for the development of renewable energy sources in Germany 1990 - 2018
20 https://www.apren.pt/en/march-100-renewable--first-month-of-xxi-century-fully-supplied-by-renewable-electricity-sources/

THE PARIS AGREEMENT

The goal of the UN Paris Agreement[21] is to keep global warming under 2°C while aiming to limit warming to 1.5°C (above pre-industrial levels). To prevent warming exceeding 1.5°C, a 40-60% cut in global CO_2 emissions is needed over the next decade, **to ultimately reach (net) zero emissions by 2050**[22] (see the Office for Climate Education's Summary for Teachers of the IPCC Special Report "Global Warming of 1.5°C"[23] report for further details). This is a huge challenge and all levels of society – governments, businesses, local organizations and individuals – have a role to play in reducing emissions.

The Paris Agreement does not set emissions reduction targets for individual countries. Instead, countries set their own targets in an iterative process in which they periodically report on their emissions and mitigation actions taken to date. This data is then aggregated to assess global progress towards achieving the Paris Agreement goals. Individuals, communities and businesses can contribute to this process by demonstrating that they support scaled-up government action on climate change, such as the implementation of policy measures like carbon taxes. Adopting the Paris Agreement approach on a personal or group level, we can calculate our own carbon footprints and share them, then plan and implement steps to reduce the corresponding emissions. Finally, we can recalculate our carbon footprint to gauge our success. As with countries under the Paris Agreement, we can decide what actions to take given our own circumstances and means.

CARBON FOOTPRINTS

A carbon footprint is usually defined as the total amount of greenhouse gases emitted by a given source of emissions. Carbon footprints can be computed for many different entities, such as a person, country or product – for instance, the total amount created in the production, transport and use of a T-shirt. To account for the release of greenhouse gases other than CO_2, they are measured in terms of "CO_2 equivalent" (CO_2-eq) – i.e. the equivalent amount of CO_2 emissions.

Calculating a footprint will help you, or the group you belong to, identify which of your activities produce the most emissions, and so are the most critical to target. Rather than trying to get a precise estimate of each contribution to this footprint, the aim is to get a rough estimate of their relative sizes, so you can identify which are the largest and therefore the most important to act on. Bear in mind though that there will be limits to what individuals or local groups can do without legislative or other support.

REDUCING YOUR CARBON FOOTPRINT

Here are some ways you can reduce your carbon footprint:

- **Decreasing consumption** of energy and materials by reducing, reusing and recycling. By consuming fewer products and services, you can lower your energy consumption and thus any related GHG emissions. For example, hanging clothes out to dry rather than putting them in the dryer or deciding to use less carbon-intensive transportation or car-pooling. When replacing devices (such as washing machines), you can privilege energy-efficient versions.
- **Prefer devices or vehicles that run on low-carbon energy sources** (e.g. purchase green electricity, or privilege electric cars). When you choose to swap a device or car that uses fossil fuels as energy source, you need to check if it is worthwhile, given the emissions generated in the production of the new device (and the disposal of your old one).
- **Avoid food waste** – a staggering 1/3 of food is wasted globally[24]. If you are a meat eater, you might want to consider eating less meat. Lamb and beef have the highest carbon footprints so avoiding or substituting these would reduce your footprint.
- **Avoid high-emitting activities** or replace them with lower-emitting alternatives. For instance, avoid long-distance travel or, if you have to go, take the train rather than flying (if possible). To get to school or work, cycle, walk or take public transport rather than travelling by car.
- For emissions you cannot avoid, consider **purchasing carbon offsets from a reputable source to compensate for them.** Remember that a very significant fraction of the CO_2 we emit will still be in the atmosphere in 100 years, so only schemes that aim to keep CO_2 out of the atmosphere long-term will achieve an actual offset.

BEST PRACTICES IN MITIGATION

While reducing emissions might seem straightforward on the surface, the full story is more complex.

21 https://unfccc.int/process-and-meetings/the-paris-agreement/the-paris-agreement
22 IPCC Special Report "Global warming of 1.5°C": https://www.ipcc.ch/sr15
23 http://www.oce.global/en/resources/climate-science/ST1.5-EN
24 IPCC Special Report on Climate Change and Land, 2019: https://www.ipcc.ch/srccl/

→ Consider all emissions

To get the best estimate of the CO_2 emissions associated with a product you buy or with your activities, **you need to account for all the emissions involved.** Take the purchase of a cotton T-shirt, for example. You would need to catalogue all the emissions generated across the product's life cycle – from "cradle" (manufacture) to "grave" (disposal). This includes emissions from growing cotton, knitting the T-shirt and transporting the garment to the local store. You could even go a step further, and account for the CO_2 produced by washing and drying the garment over its usage lifetime. A lot of these emissions may be generated in foreign countries. When countries quantify their carbon footprints, they might not account for these "outsourced emissions", so can appear greener than they really are – in fact, all the more so as some emissions, like those from international transport, are currently not attributed to any country.

→ Estimate emissions savings

When coming up with a mitigation action plan, you obviously want to avoid accidentally increasing your emissions! To prevent this, **you can first estimate the emissions reductions you expect from your actions.** Depending on your local context, actions that you might assume will reduce your emissions could have the opposite or little effect, so it is important to calculate your footprint using data for your country/context. For nature-based methods of mitigation, such as conserving and expanding natural carbon sinks like forests and mangroves, you also need to consider how climate change may affect them in the future and what the time scales involved are.

→ Consider all environmental impacts

Carbon footprints only measure one of the ways in which we impact the environment (greenhouse gas emissions). **There are other aspects to consider if you want to reduce your carbon footprint.** For instance, with the cotton T-shirt example, a large volume of water from an unsustainable source could have been used to grow the cotton. We could also consider whether the cotton farmers received a fair price for their crop, or if they used pesticides, thereby endangering biodiversity. Unfortunately, it is often difficult to find out whether the things we consume were produced in a fair, ethical and sustainable manner although some useful information may be found on the packaging. For instance, the country the product has come from, which materials were used (palm oil, for example) and whether the product has a fair-trade label that can be trusted. In any case, it is important to keep a critical mind and consider all the dimensions of a potential solution as, sometimes, it can create unforeseen negative impacts.

→ Climate justice

While the Paris Agreement does not specify how emissions reductions should be distributed across countries, **ethics dictate that this should be done in an equitable manner.** One approach would be to allocate reductions based on which countries' have emitted the most in total, and thus have contributed most to the global warming problem. A drawback is that this does not consider the ability of countries to reduce emissions, given their economic status. The emissions of some populous developing countries, while low per person, can add up to more than the emissions of developed countries with fewer inhabitants. Another aspect that enters into climate justice considerations is the degree of climate impacts experienced. In general, the most severe impacts will fall upon people with few resources in the developing world – those who have contributed least to the problem in terms of emissions.

ADAPTATION

The extent to which climate change affects a place depends not only on how large the changes in climate affecting it are but also on how exposed and vulnerable its population, ecosystems and infrastructure are to those changes. Adapting to climate change involves taking **actions to reduce exposure (things in harm's way) and vulnerability (their susceptibility to harm).** Exposure and vulnerability are often tied to poverty. For instance, the people with less resources might, in addition to having a limited capacity to cope, also be living in the most exposed locations.

REDUCING EXPOSURE AND VULNERABILITY

Depending on the climate change impacts that are expected to affect a given region, different measures can be taken to reduce exposure and/or vulnerability. For example, for sea level rise and storm surges, exposure can be reduced by moving assets, increasing protection (e.g. with sea walls, coral reef and mangrove preservation) or accommodating periodic flooding (e.g. by elevating buildings). In agriculture, farmers can be made less vulnerable to flooding events by planting salt-tolerant crops. On a personal level, we can take steps to reduce our exposure and vulnerability to extreme weather events. During heatwaves, we can seek shade or cool indoor spaces (thus reducing our exposure) and drink lots of water (reducing our vulnerability). Unfortunately, in some cases, there will be limits to how much we can do. With sea level rise, some low-lying areas may ultimately become uninhabitable, with their populations thus forced to relocate.

EDUCATION

Education is a core part of adaptation and can take many forms, such as getting better acquainted with your local environment, passing on your climate change knowledge to friends and family, and undertaking training towards a career that can contribute to adaptation solutions.

BEST PRACTICES IN ADAPTATION

→ **Take an iterative approach**

To plan and implement adaptation, we need a good understanding of all the risks that climate change poses on a local scale. **Since many aspects of how climate change will affect a specific place are uncertain, adaptation has to be an iterative process, with continuous reassessment of how well strategies are working and their continued suitability as scientific knowledge improves.** Involving a spectrum of people and institutions in adaptation efforts can help ensure all perspectives are considered and that the burdens of implementing them, together with their positive and negative outcomes, are fairly distributed.

→ **Tackle other environmental problems**

A good place to start with adaptation is by **identifying and reducing existing environmental problems that could otherwise make the impacts of climate change worse.** For example, human-caused land subsidence is exacerbating sea level rise for some coastal cities. Steps could be taken to slow the rate of subsidence, such as reducing use of groundwater. Pollution (besides greenhouse gases) provides several other examples. For instance, construction and agriculture can increase sediment and nutrient inputs and reduce light levels for coral reefs, making them more vulnerable to climate change. Plastics circulating and accumulating in the ocean, and overfishing, are other ocean examples. In the cryosphere, soot particles from fossil fuel combustion landing on snow can increase climate-driven melting, so reducing these emissions may help slow melting.

→ **Carefully manage opportunities**

Adaptation is not only about dealing with the negative impacts of climate change, but also about **identifying any positive impacts that might arise.** Where sustainable and avoiding new emissions, these could be utilized through careful management.

Wrap-up

We have explored how the ocean and cryosphere are fundamental to both the climate system and human society, how they are rapidly changing due to climate change and other factors, and how this is, in turn, affecting humans and ecosystems. Finally, we have considered how we can tackle climate change, both at its root cause through mitigation, and with regards to its risks and impacts through adaptation.

The lesson plan which follows explores the concepts introduced here in more detail. It also guides students to consider the role they, their local communities and their nations can play in tackling the great 21st century challenge of climate change.

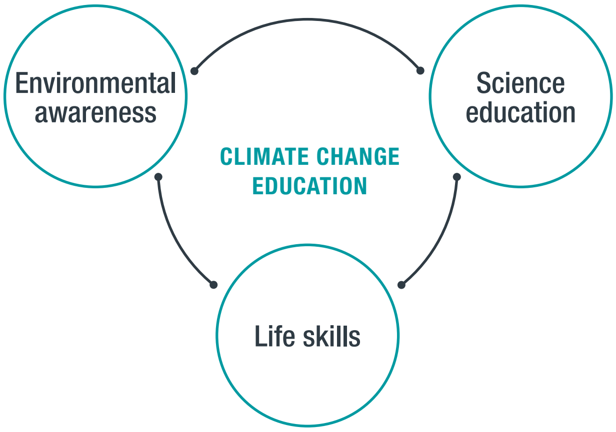
PEDAGOGICAL OVERVIEW

BACKGROUND FOR TEACHERS

PEDAGOGICAL OVERVIEW

Different outlooks on climate change education

This teaching resource is based on the following general approach. It helps students to develop environmental awareness, an understanding of scientific knowledge and life skills. This type of knowledge and skills is necessary for students to understand the causes, consequences and mechanisms of climate change. If a change in the values and motivation of students towards a more sustainable behaviour is achieved, the knowledge and skills developed will be essential tools for the implementation of effective adaptation and mitigation actions.



Effective climate education should address three broad issues[1]:

- **Environmental awareness** (knowledge of the consequences of human activities).
- **Scientific education** (understanding the phenomena and scientific processes at work).
- **Life skills** (critical thinking, creative thinking, decision-making and problem-solving skills, self-awareness and empathy, resilience and ability to cope with stress and emotions, etc.).

We need to establish a balance between these three poles when educating the younger generations. The perfect balance will not necessarily be achieved by developing a programme designed to be at the exact centre of these three poles (the centre of the circle, see figure on the left). Each program must define its ideal balance between the three poles depending on the characteristics, context and local needs of each student considered. It is therefore essential for teachers to have their own critical view of the pedagogical sequences that follow, despite their "turnkey" characteristics.

How to use this teaching resource?

This teacher handbook provides detailed guidelines on how to teach 9-to15-year-old students about climate change in the ocean and cryosphere. The structure of each lesson helps teachers to encourage their pupils to engage with the programme's investigations and activities.

The plan of each lesson specifies its approximate duration and includes: a list of resources required, introductory questions to initiate discussion, suggestions as to how students can carry out the experiments/investigations, potential difficulties that may arise and effective ways to draw relevant conclusions.

All the suggestions of experiments and conclusions that you will find in this lesson plan are provided as examples. They were gathered during class tests and are scientifically correct. Nevertheless, we strongly encourage you to follow the experimental protocols, ideas and conclusions proposed by your own students, as long as they provide the correct answers to the questions asked.

1 Inspired by the work of Rocha, M.L. (2019). Un regard sur l'éducation au développement durable à travers le prisme de l'évaluation. Master thesis.

All of the lessons in this resource have been approved by scientists and educators, and have been tested in a range of classes in different educational settings and countries.

The lessons can and should be adapted to suit the needs of individual classes/schools. Lessons do not need to be followed step by step. We encourage each teacher to adapt the course work depending on his or her personal project and the time available.

Adaptations can be made in order to:
- Make the most of student interest and questions, by discussing opinions, local news, etc.
- Take into account implementation difficulties such as insufficient materials or students' mental blocks.
- Adapt the unit for different age groups.

Choosing lesson content: tips and storyline

"The climate in our hands – Ocean and Cryosphere" consists of **two different parts, of equal importance**: "We understand" and "We act".

PART 1: WE UNDERSTAND

In this part, the lessons are organised in four consecutive sequences, following a coherent storyline (see details below).

These sequences include:
- What climate change is.
- What the causes of climate change are.
- What effects climate change is having on the ocean and cryosphere.
- Why the ocean and cryosphere are important to us.
- What our carbon footprint is and why we need adaptation and mitigation measures.

Each part of the lesson plan contains some "core lessons" and some "optional lessons".

PART 2: WE ACT

This part is not a lesson plan. Instead, the class is encouraged to implement one concrete adaptation/mitigation project. Proposals for projects that the students could carry out are provided.

The sample projects differ in terms of duration (from a few hours to a few months!) and type (adaptation, mitigation, outreach etc.).

IMPORTANT
We strongly recommend that students are given the opportunity to do the activities and investigations in part one "We understand" before commencing an adaptation/mitigation project.

STORYLINE OF THE PROJECT

The storyline below offers a very schematic and summarized view of the project.

PART 1 A — **Climate change vs. weather**
→ Climate is not weather.
→ Climate change is a reality.

PART 1 B — **Origin of climate change**
→ The greenhouse effect is a natural phenomenon.
→ Greenhouse gas emissions (CO_2, CH_4 and others) due to human activities are responsible for climate change.

PART 1 C — **Consequences of climate change on the ocean and cryosphere**
→ Because of climate change, the cryosphere is changing due to ice melt.
→ Because of climate change, the sea level is rising.
→ Because of climate change, the ocean is becoming more acidic, which endangers some marine species.
→ Oceans are important regulators of the climate system (currents, thermal inertia, etc.).

PART 1 D — **Services provided by the ocean and cryosphere**
→ The ocean and cryosphere provide a lot of ecosystem services (oxygen, food, freshwater, energy, etc.) and cultural benefits. Climate change has impacts on these services.

PART 1 E — **The need for action**
→ The most vulnerable people and countries are the most affected by climate change. Acting is also a question of climate justice.

PART 2 — **We act**
→ We can act at the individual level to mitigate climate change, or to reduce its impacts on ecosystems and human societies.

Teaching climate change through active learning: inquiry-based and project-based learning

This teaching resource requires that students actively participate in class, through questioning, experimentation, observation, trial and error, debate, and implementation of local and concrete solutions to address climate change issues.

This “active learning” can take different forms. The two approaches that we strongly promote throughout this resource are inquiry-based learning and project-based learning.

Some activities are aimed at developing students’ scientific education and supporting students in developing their critical thinking. These adopt inquiry-based approaches to learning, which are frequently used in STEM education. Other activities focus specifically on implementing concrete adaptation or mitigation projects, which are carried out by the students, the school, and even local communities. These follow a project-based approach.

WHAT IS INQUIRY-BASED LEARNING?

While it would be oversimplifying to use a fixed model of inquiry-based learning, this approach generally has three phases:

1. **Questioning**: initiated by the teacher or the students, it helps to formulate hypotheses;
2. **Formulating a hypothesis**: research to investigate the hypotheses, which may be carried out through experiments, investigations, observations or documentary studies;
3. **Research and structuring knowledge**, which in turn leads to more questioning, more research, etc.

French students investigating how the dissolution of CO_2 into water leads to an acidification.

PHASE 1: QUESTIONING

The aim of this phase is to provide students with opportunities to ask questions about different phenomena in their environment. The processes of questioning, drawing comparisons and highlighting discrepancies will lead to a problem that the students have to solve. The teacher’s role in this phase is to guide the discussion that will lead the students to become aware of a problem and discuss ways they could address it. The teacher should ask open-ended questions to support students in developing their scientific and critical thinking skills.

PHASE 2: FORMULATING A HYPOTHESIS

Using their experience and/or their knowledge, students are encouraged to provide explanations that they believe to be plausible. These lead to the students’ theories. To enable students to accept or reject their different hypotheses, they are given opportunities to carry out specific experiments and/or documentary research. The research phase commences when the credibility of a theory needs to be tested.

Students can develop ideas or theories (what they think they know, what they think they understand and can explain about a certain phenomenon) either individually or as a group.

PHASE 3: DOING RESEARCH AND STRUCTURING KNOWLEDGE

During this phase, the students work alone or in a group to investigate solutions to the problem raised. This involves testing the hypotheses they have chosen.

If experimenting, modelling or direct observation are not possible, documentary research and even interviewing an expert (which may be the teacher) will enable the students to validate or dismiss their hypotheses.

Sometimes students need to alternate between questioning and research before finding a solution and constructing new knowledge. Class and group discussions play a key role in structuring the students’ knowledge. During discussions, the teacher’s role is to support dialogue between the students.

It is important that students summarize the key findings. We recommend that the teacher allows the students to draw their own conclusions, based on the work they did in class. The class conclusion should ideally be a consensual conclusion. Nonetheless, even if it is consensual, it does not mean that it is correct. We can all be wrong.

An essential step in an inquiry-based approach, which is all too often skipped, is to compare the knowledge created in class (the class conclusions) with established knowledge.

Examples of inquiry-based learning as implemented in the present teaching resource:

→ **Experiment.** In lesson C1, the students carry out an experiment to ascertain that the melting of sea ice does not cause sea level rise, whereas the melting of continental ice does.

→ **Documentary research.** In lesson A1, the students carry out a documentary analysis to understand the differences between weather and climate and the factors that influence each one.

→ **Role playing.** In lesson D2, the students take part in a role play to further their understanding of food webs and to establish that, in ecosystems, all living beings interact with and depend on each other for their survival.

WHAT IS PROJECT-BASED LEARNING?

Project-based learning is a fully-fledged concept of active learning. First described in the early 20th century (initially by John Dewey, who also described inquiry-based learning), it was long confined to primary education before gradually spreading to secondary and higher education. Project-based learning has evolved as a method of instruction that addresses core content through rigorous, relevant and hands-on learning. The projects are typically framed with open-ended questions that push students to investigate, research, or construct their own solutions. For example: How can we reduce our school's carbon footprint?

The second part of this teaching resource has been created, to focus on the implementation of concrete actions to address climate change. It adopts project-based learning so students can engage in real-world problem solving.

Key aspects of project-based learning include:

- Students working on a complex task (a problem that can only be solved through an investigation; a question that can only be answered through research). The purpose of project-based learning is to enable students to manage a project from beginning to end, including a variety of different tasks, to solve a particular problem.
- Students carrying out practical investigations, conducting desk-based research to establish different points of view on a particular issue.
- Sufficient time to enable students to overcome challenges and implement projects in the field.
- Understanding that the project is managed by students as a class group and not the teacher alone.
- Breaking up of complex tasks into more basic tasks, where the students have a high degree of independence and are actively involved.

Cambodian students planting mangroves.

The main benefits of project-based learning are that students learn in contexts which are meaningful to them. Moreover, the practical and real-world aspect of the project usually motivates them. They acquire cross-functional skills – such as decision-making or planning, for example. They realise that making errors and failed attempts are part of the learning process, and that cooperating and pooling together the different skills of each student is key to success. And, finally, the outcome of the project can inspire other classes, families and the community.

THE TEACHER'S ROLE IN PROJECT-BASED LEARNING

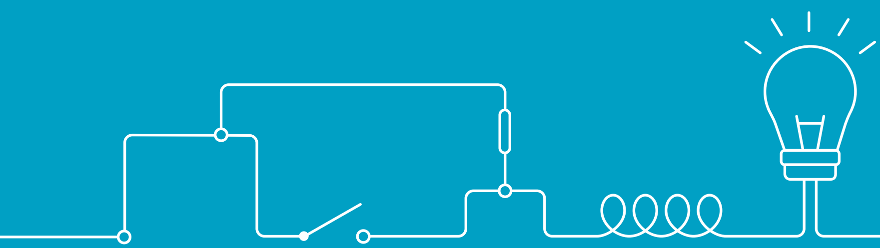
Like inquiry-based learning, project-based learning focuses on student activity. The teacher's role is to help define the project and make sure that its objectives are attainable. He/she refocuses the activity or discussion if necessary, supervises the discussions and may act as an expert if asked by the students.

SCIENTIFIC AND LANGUAGE PROFICIENCY

Oral and written communication is a central element of inquiry-based and project-based learning. Writing helps to create distance, to clarify and formulate thoughts, making them comprehensible to all. Students that are new to the inquiry-based approach often do not write naturally. This activity therefore requires practice, which will be effective if the students understand its usefulness.

All forms of writing (drawing, figure, legend, descriptive or explanatory text), contribute to the learning process. It is important that the teacher does not play an authoritative role in the student's personal writings (by correcting mistakes, for example). The teacher can, however, gradually help students to structure their writing.

- **Students write for themselves.** Writing helps the students to take action (select an experiment, make decisions, plan, anticipate results), memorize (keep a record of observations, research and readings, look back on a previous activity) and understand (organize, sort, structure, compare to previous writings, reformulate collective writings).
- **Students write for others.** Writing lets the students share what they have understood, question the other students and also people outside the class (other classes, the family, etc.), explain what they have done or understood, recap, etc. Written notes can have two parts: individual writings and collective writings.
- **Individual writings** represent the student's personal space, where they record their initial answers to the questions raised, describe the activities that will enable them to answer these questions, jot down what they anticipate, and draft their reports. For the teacher, reading individual writings is one way of monitoring each student's personal progress.
- **Collective writings** are a summary of the students' ideas and suggestions – following discussions, experiments and research. These writings are then checked: they must follow spelling and grammar rules, and sometimes use a specific vocabulary.



WE UNDERSTAND

LESSON PLAN – PART I

WE UNDERSTAND #LESSONS

The first part of this lesson plan is called "We Understand". As its name indicates, it is aimed at providing the students with the **essential knowledge** necessary to understand:

- The **basis and evidence** of climate change.
- The **physics** involved in climate change and the role of greenhouse gases.
- How **oceans, the cryosphere and the climate system** are interconnected, and consequently how climate change is affecting these systems.
- The impacts of the observed changes on the ocean and cryosphere **ecosystems and human communities** that depend on them.
- Each person's/people's role in climate change and their different degrees of **exposure and vulnerability** to the consequences.
- The **possible measures** for mitigating and adapting to climate change.

All the concepts proposed are based **on scientifically sound and up-to-date knowledge** provided at a **primary – and/or secondary – student-level of understanding.** The sequences were designed to correspond to the **student mind and how they think** and the lessons include a wide range of activities: experimentation, documentary analysis, role-playing games, debating, use of interactive activities and short videos. The overall progression follows an inquiry-based teaching method. As climate change issues are intrinsically multidisciplinary, so are the lessons proposed, which include subjects from natural sciences (such as physics, chemistry, biology and geology), social sciences (such as history, geography, economics, and sociology) and visual or performing arts.

The order of lessons proposed is one among many possible orders, and **you can adapt it** depending on your students' needs, ages, backgrounds, etc.

Some lessons, called the "core lessons" are those we consider to be essential for students to acquire a comprehensive and easy-to-understand picture of the phenomena explored. If you have limited time to work on this education project, we suggest you start by working on the core lessons.

"Optional lessons" are aimed at delving further into the students' understanding of the different issues and getting a wider view of the overall issue of climate change impact on the ocean and cryosphere. Some of these "optional lessons" are suggested for advanced students only.

Some of the "core lessons" also include variations (very often the last part of the lesson, or specific worksheets) in order to facilitate their adaptation to students at different levels of advancement. In both cases, you, as the teacher, are best equipped to know how to adapt this lesson plan to your students.

SEQUENCE A – WHAT IS CLIMATE CHANGE?

◉ Core lesson ○ Optional lesson

SEQUENCE B – WHAT IS THE ORIGIN OF CLIMATE CHANGE?

SEQUENCE C – WHAT ARE THE CONSEQUENCES OF CLIMATE CHANGE ON THE OCEAN AND CRYOSPHERE?

SEQUENCE D – WHY ARE THE OCEAN AND CRYOSPHERE IMPORTANT TO US?

SEQUENCE E – WHAT CAN WE DO?

SEQUENCE A

WHAT IS CLIMATE CHANGE?

In order to teach and to understand climate change, two essential aspects must be addressed: the difference between climate and weather, and the mechanisms of climate change. The first one is fundamental to understand the time and spatial scales of the climate system and its changes, and the second one is paramount in the acknowledgement that human-induced climate change is happening.

The two lessons in this sequence constitute the basis for all of the following sequences. Without this prior knowledge, the contextualisation of all the other lessons will be much harder for the students.

→ **The first lesson** will allow students to understand that there are **different climatic regions** on Earth, and that climate and weather are different things.

→ **The second lesson** is aimed at providing the students with clear and **undeniable scientific evidence that climate change is happening,** while developing critical thinking and awareness regarding different information sources. Both lessons are mainly based on documentary research and analysis.

LESSON LIST

◉ Core lesson ○ Optional lesson

◉	A1	**Climate vs weather** Social sciences / Natural sciences The students carry out a documentary analysis to understand the differences between weather and climate.	page 35
◉	A2	**Evidence of climate change** Natural sciences The students collect various evidence showing that the world climate has been changing over the last decades (global warming, sea level rise, melting of glaciers and sea ice, extreme events, species distribution).	page 41

LESSON A1
CLIMATE VS WEATHER

MAIN SUBJECTS
Social sciences / Natural sciences

DURATION
- Preparation: 5 - 10 min
- Activity: 1 h

SUMMARY
Students carry out a documentary analysis to understand the differences between weather and climate.

KEY IDEAS
- The climate is an average of the prevailing weather pattern for a particular region. It depends in primarily on latitude, altitude and distance from the ocean.
- The weather is the state of the atmosphere at a particular place and time. Temperature and humidity are among the variables that condition the weather.

KEYWORDS
Climate, weather, latitude, altitude, temperature, humidity

INQUIRY METHOD
Documentary analysis

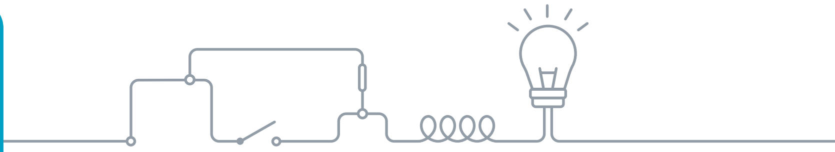
PREPARATION 5 -10 MIN

MATERIALS
WORKSHEETS A1.1, A1.2, A1.3 (one for each group)

LESSON PREPARATION
Print copies of **WORKSHEETS A1.1, A1.2, A1.3** (one for each group of 3-4 students).

If possible, use colour copies. Note that you can also use electronic versions of the documents, to be projected in the class. The PDF versions of all the worksheets are available on the OCE's website. See page 182.

TEACHER TIP
As a prerequisite, students should have a basic grasp of geography (for example, latitude, altitude, precipitations).



INTRODUCTION 5 MIN

→ **Case 1: If you live in a region of the world that has a seasonal climate (summer / winter or wet / dry):** Start by asking the students: *How are you dressed today? Are you wearing a t-shirt or a sweatshirt? Shorts, skirts or trousers? Sandals or shoes?* Then ask them *Were you wearing the same type of clothes yesterday? What about the week before, last month, or during the last holidays? What guides your choice of clothes?*

They will probably state that it depends on whether the day is sunny or rainy, cold or warm: It depends on the weather. Lead them to the conclusion that two of the most important variables to describe the weather are temperature and humidity, and that these parameters change throughout the year. *What about different regions of the world? What temperature and humidity prevail there?*

→ **Case 2: If you live in a place without a seasonal climate:** *Is the weather the same all year round? Is the weather the same as everywhere else in the world? Do other regions have the same temperature and rainfall?*

PROCEDURE 40 MIN

1. Split the class into groups and give each group the world map and the photos of **WORKSHEETS A1.1, A1.2, A1.3.**

2. Give the following instructions: *Each number on the map corresponds to a photo. Observe each photo carefully and place it on the corresponding number. Write down which features of the pictured landscape made you decide that it corresponds to this number on the map rather than to another.*

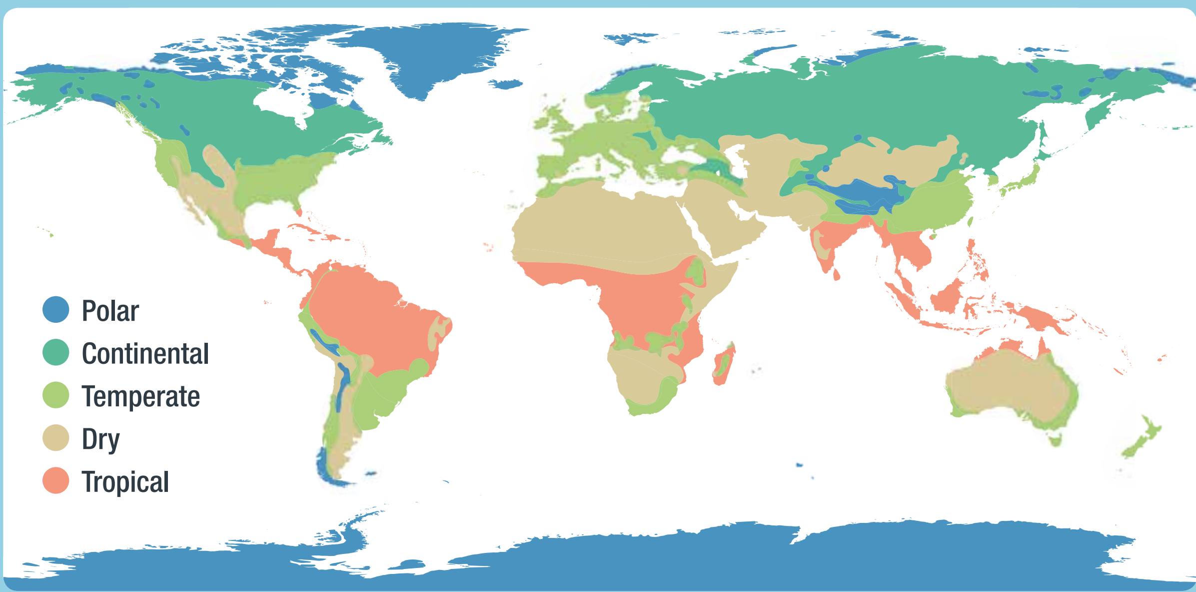
This activity requires students to describe the picture, and explain why they think they are related to one specific climate zone. Example, for a picture

BACKGROUND FOR TEACHERS

Weather is the state of the atmosphere at a particular place and time. It has many components, such as sunshine, rain, cloud cover, wind, hail, snow, thunderstorms, heatwaves, etc. The weather is frequently defined using different parameters, such as **temperature, humidity,** precipitation, cloudiness, wind and atmospheric pressure. In most places in the world, it can change hourly, daily, or, on average, from one season to another.

The difference between **climate** and **weather** has to do with the length of the period considered: climate is the average weather over a “long time”. Climate is therefore the average state of the atmosphere over months, years, decades, centuries or more. For each place on Earth, geographic factors, such as **latitude, elevation, topography, distance to a large water body** (ocean, lake) and location on a continent (east or west, for example) shape the climate (further details can be found in pages 8-11 of the Scientific Overview).

Different climate classification systems can be used to describe the climate of a region. One of the most popular is the Köppen climate classification, which defines five main climate types: tropical, dry, temperate, continental and polar.



Köppen climate classification

with a desert: dry landscape, lack of vegetation (or presence of a specific type of vegetation), etc. The aim is to identify two of the key factors that drive climate (temperature and precipitation, which depend on altitude, latitude, distance from the ocean).

3. After approximately 15 minutes, ask a representative of each group to go to the whiteboard. Have him/her place two of the photos on the world map and explain why the group thinks that these landscapes should be placed on that number. Write the main reasons mentioned by the student on the whiteboard.

At the end of the exercise, each choice is discussed with the whole class. If they disagree, the students can consult appropriate books – a geography book, for instance – or the internet.
Emphasize the key factors that crop up during the discussion, such as **temperature, precipitation, distance from the ocean, wind, latitude, altitude** (geography in general). All of these factors shape the climate.

Solution of Worksheet A1.1

1. Flowing glacier, polar climate, Antarctic Peninsula

2. Mountain, continental climate, Canada

3. Mangrove, tropical climate, Dominican Republic

4. Rice field, tropical climate, Java, Indonesia

5. Mediterranean coast, temperate climate, France

6. Deciduous forest, temperate climate, Vermont, USA

7. Sea ice, polar climate, Svalbard, Norway

8. Savanna, tropical climate, Tanzania

9. Pasture field, temperate climate, Ireland

10. Rainforest, tropical climate, Thailand

11. Small island, tropical climate, Tuvalu

12. Desert, dry climate, Australia

TEACHER TIP
If you have internet access, you might want to check the current and / or average temperatures for all marked locations and let the students guess them. This requires the students to look at latitudes, climate zones, seasons, altitudes and time shifts (day / night).

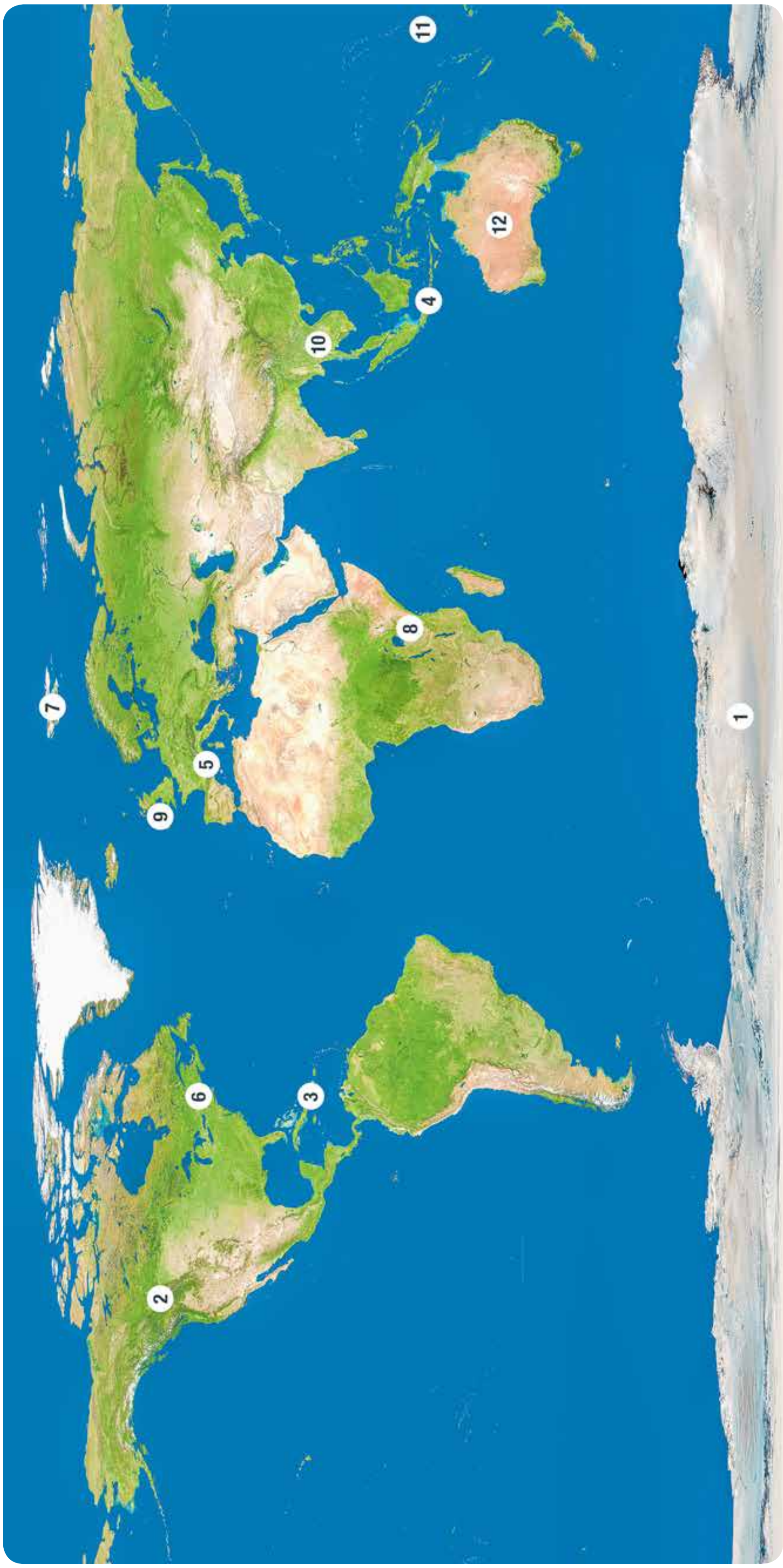
4. Help the students to draw up a summary that connects the different features of the photos to the diversity of climates and their geographical distribution. Emphasize the diversity of climates on Earth. Ask the students: *What is the climate like in our region?*

WRAP-UP 15 MIN

Help the students draw a group conclusion such as, for example: *The climate is an average pattern of weather for a particular region, while the weather is the state of the atmosphere at a particular place and time. There are a lot of different climates on Earth, characterised by specific patterns of temperature and humidity which depend on latitude, altitude, location on the continent (e.g. east or west coast) and distance from a large water body (e.g. the ocean or a lake).*

WORKSHEET A1.1

Each number in the world map corresponds to a photo on **WORKSHEETS A1.2** or **A1.3.**



WORKSHEET A1.2

Each photo corresponds to a number on the world map of **WORKSHEET A1.1.**






WORKSHEET A1.3

Each photo corresponds to a number on the world map of **WORKSHEET A1.1.**

LESSON A2
EVIDENCE OF CLIMATE CHANGE

MAIN SUBJECTS
Natural sciences

DURATION
- Preparation: 5+10 min
- Activity: 1 h

SUMMARY
Students collect various evidence showing that the world climate has been changing over the last decades (global warming, sea level rise, melting of glaciers and sea ice, extreme events…).

KEY IDEAS
- The climate has a natural variability that includes variations from years to millions of years.
- The temperatures of both the atmosphere and the ocean are increasing.
- The frequency and/or intensity of natural events – such as heatwaves, storms, tropical cyclones and floods – are changing.
- Not all sources of information are reliable. We must always check our sources.

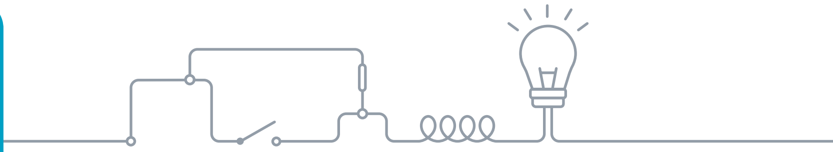
KEYWORDS
Global warming, extreme weather events, gradual change, long timescales, scientific data

INQUIRY METHOD
Documentary analysis

PREPARATION 15 MIN

MATERIALS
WORKSHEETS A2.1, A2.2, A2.3, A2.4, A2.5, A2.6, A2.7, A2.8 (one of the case examples for each group)

LESSON PREPARATION
1. **To be done at the end of the previous lesson.** Ask the students to collect "evidence" of what they consider to be "proof" that the climate is changing: opinions of older people (parents, grandparents or other community members) on how the climate has changed since they were young, interviews, newspaper articles, social media posts, other media resources that in their opinion reflect climate change, etc.



2. Print copies of **WORKSHEETS A2.1, A2.2, A2.3, A2.4, A2.5, A2.6, A2.7, A2.8.** You may print more than one copy of each worksheet, to be able of providing each group with the graphics/articles that are the most relevant for their "evidence".

TEACHER TIP
During this lesson, you should take into account two potential obstacles to student understanding:
- → The timescale of climate change: The large timescales involved with climate change can be difficult to conceive for a young student, for whom 50 years may seem an eternity. For them it is not easy to comprehend the idea of change on these timescales. Moreover, some changes will be gradual and thus difficult to perceive.
- → The fact that climate change is a worldwide phenomenon: Even in the era of globalization and social media, young (and often old!) people will tend to merely perceive events that are directly related to their personal life. Changes and events that occur in other parts of the world are too far away to be real. As a teacher, you can start with events that the students can relate to, events that occur locally and today. Subsequently, you can progressively introduce more global and long-lasting changes. This is why starting with concrete examples brought by the students may help.

Some documents require basic skills in the interpretation of graphs. Do not hesitate to spend more time if the students are confronted with this kind of task for the first time.

INTRODUCTION 5 MIN

Start this lesson by asking each student to briefly present his/her "evidence" to the class. Then, group students according to the "evidence" they brought: students that brought "evidence" related to the same climate change issue should be grouped together.

PROCEDURE 40 MIN

1. Choose from the **WORKSHEETS** provided and give each group of students one or more articles/graphics that reflect the "evidence" they have brought themselves.

Example: One student brings a story his grandfather told him/her about the town he lived in as a child, where it used to snow every year; nowadays, there is only snowfall higher up the mountains – this student should be in a group where "evidence" is related to global warming and to which you will give graphics/articles on temperature change or glacier retreat.

2. Ask each group to analyse the "evidence of climate change" they have brought into school, and to decide, in view of their newly acquired knowledge, whether the events/information relates to climate change or to weather.

3. A representative of each group then informs the class about his/her group's view and explains their decision. Create a table on the whiteboard, one column listing the "proof", the other one stating whether the proof relates to weather or to climate. In the end (and building on the knowledge from the previous lesson), the students should have understood that **weather is a state of the atmosphere, at a particular place and time, whereas climate is an average pattern.** For a given climate, the weather varies daily

BACKGROUND FOR TEACHERS

As explained pages 8-11 of the Scientific Overview, Earth's climate varies naturally. The term **"climate change"** is thus now commonly employed as a synonym to anthropogenic climate change, meaning the changes of the climate system resulting from human activities since the industrial revolution (see pages 14-15 of the Scientific Overview and the Background for Teachers of lesson B3 for further details on anthropogenic climate change). Climate change manifests itself in a number of ways and on different timescales: through **changes in the nature of single, short-lived extreme weather events**, like hurricanes, and through **incremental changes** that build up over decades, such as sea level rise. These can interact and reinforce one another (e.g. extensive flooding due to a storm surge, made more damaging by long-term sea level rise).

When talking about climate change, people also refer to one of its consequences for our planet, **global warming**. By global warming we mean the increase of the average surface temperature of the whole planet. Another measure is the rate of temperature increase (or the rate of warming) observed since the industrial revolution, which is constantly increasing.

Scientists use different types of **evidence** to track climate change and its consequences. In this lesson, we provide a few examples. The reduction of sea ice and glacier surface can easily be seen from visual record, such as satellite imagery and photographs. Sea level can be measured both with tidal gauges (instruments that measure the local sea level) and with altimeters (from satellites); thermometers and rain gauges allows us to measure temperature and precipitation locally. The change in the spatial distribution of animal and plant species, which need specific climate conditions to thrive, also provides a way of tracking climate change. For example, an animal needing cooler temperatures may move further north, or higher up the mountains, in order to survive. New species that were previously unable to survive during winter in a certain region may now be able to (e.g. the Asian tiger mosquito in Europe). The change of flower blossoming dates and harvest dates are also indicators of change. Changes in tree ring thickness also follow climate changes. Ice cores (samples of ice) are used to evaluate changes in the gas composition of the atmosphere by analysing the composition of air bubbles from past climates that are trapped in the ice's layers. Sediment cores are used to evaluate changes in climate by studying the differences in organisms and pollen trapped in sediment layers.

The examples above are just some of the different types of evidence that tens of thousands of scientists from all over the world and from all disciplines use to observe, measure and understand climate change and conclude that it is due to **human activity**, and in particular the release of CO_2, a greenhouse gas (see lesson B1, page 53).

(even during the day!), whereas the weather on a given day does not describe a given climate.

4. The students are now given scientific evidence, demonstrating that the climate is changing in many places around the world. Hand out one example of climate change evidence on WORKSHEETS A2.1, A2.2, A2.3, A2.4, A2.5, A2.6, A2.7, A2.8 to each group. **Select the examples that relate to the proof written on the whiteboard.**

Ask the groups to analyse the documents:

- *What type of changes are shown (temperature, sea level, etc.)?*
- *Why are they related to the climate and not the weather (look at the time scale of the data)?*
- *What are the sources of those documents (IPCC, NASA, etc.)? Are these sources reliable?*

5. After each group has analysed and discussed its document(s), one member of each group presents the findings to the other groups. The students should notice that the various articles/graphics they analysed were provided by different kinds of information sources.

WRAP-UP 15 MIN

Conclude that there is solid scientific evidence that the global climate is changing. The impacts of climate change on various regions of the world are different (sea level rise, animal migration, shrinking snow cover, higher temperatures, etc.). Discuss the importance of verifying the reliability of sources of information. Mention the IPCC as one of the most reliable sources of information on climate change.

TEACHER TIP
You can find teacher-friendly summaries of the latest IPCC reports on the OCE's website (see page 182).

Students analysing data showing the change in annual precipitation.

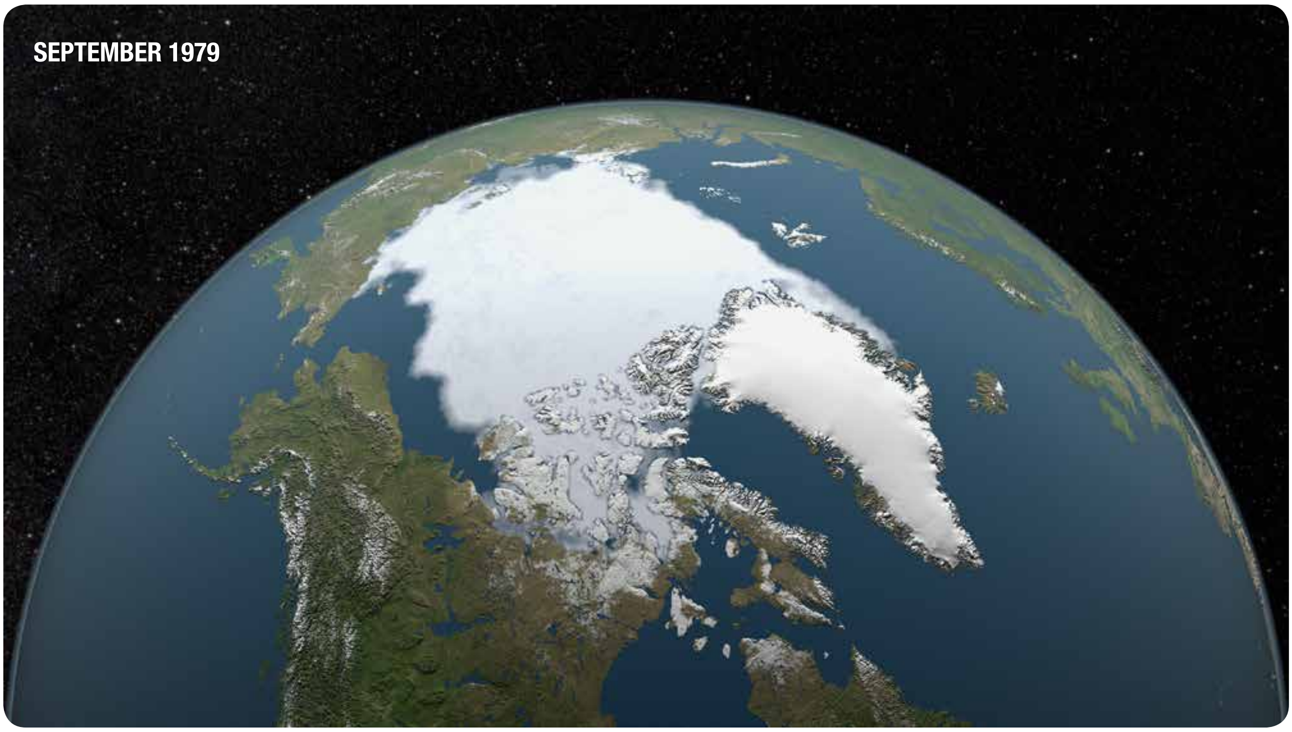
OPTIONAL EXTENSION 1 (1 H) – BUILD YOUR OWN EARTH
To extend this lesson, students can use the "Build your own Earth" online software (http://www.buildyourownearth.com) that will enable them to explore different greenhouse gas emission scenarios and their impacts on the Earth's climate and systems (atmosphere, ice, land and ocean). If you are working with high school students, you can also use the C-roads software (https://www.climateinteractive.org/tools/c-roads/).

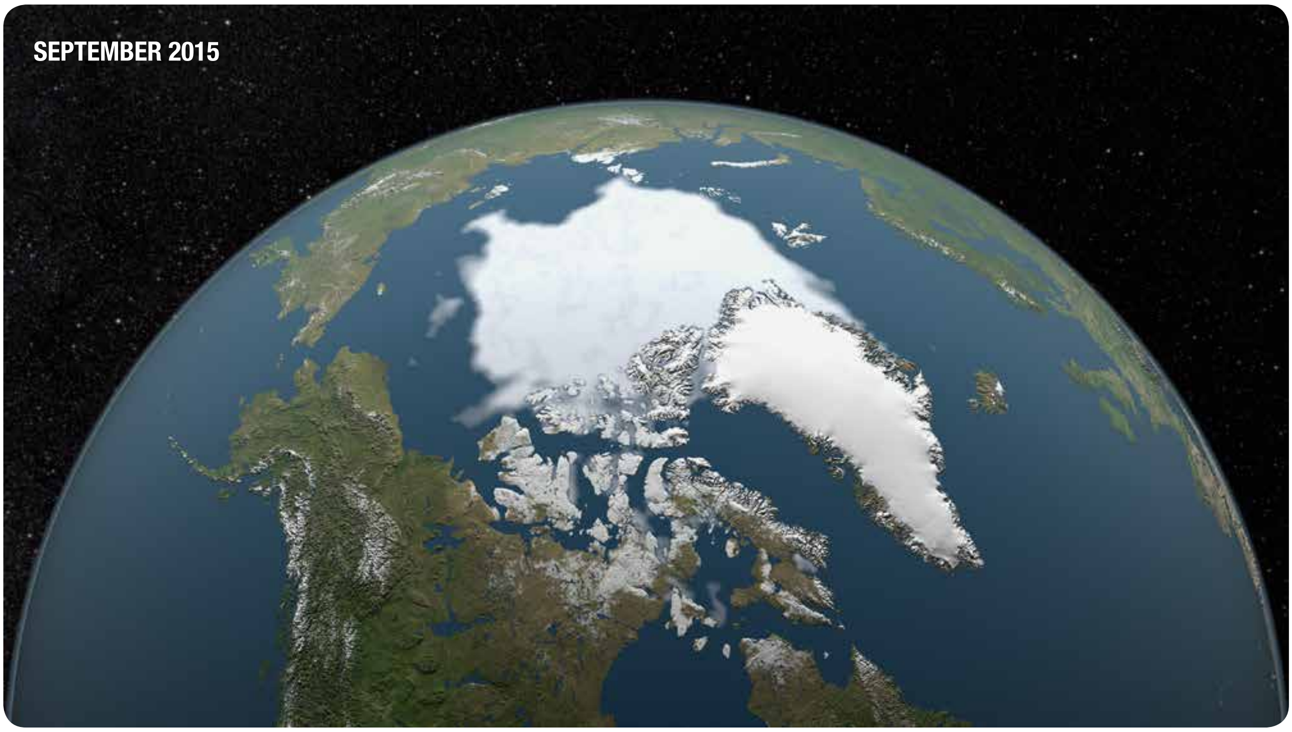
OPTIONAL EXTENSION 2 (1 H) – FAKE NEWS AND CRITICAL THINKING
Conduct a lesson during which students learn how to check the reliability of a source of information. As regards climate change, the IPCC reports – which have been thoroughly reviewed by a large scientific community – are among the most reliable sources of information.

WORKSHEET A2.1

The two images show the Arctic sea ice extent during the month of September (the end of Northern Hemisphere summer), in the year 1979 and in the year 2015.

➔ **What can you observe?**





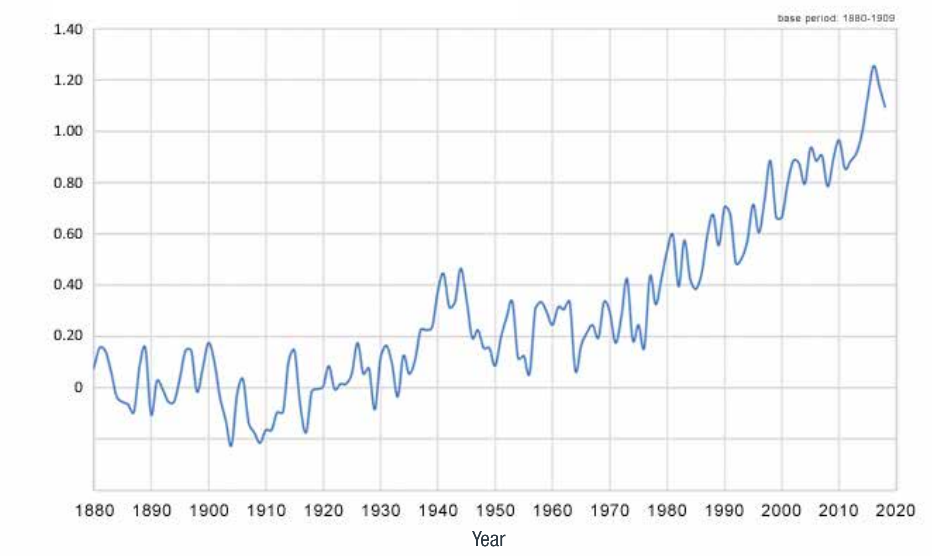
Source: NASA – https://svs.gsfc.nasa.gov/4435

WORKSHEET A2.2

These two figures show global warming and the change in sea level with respect to a reference value.

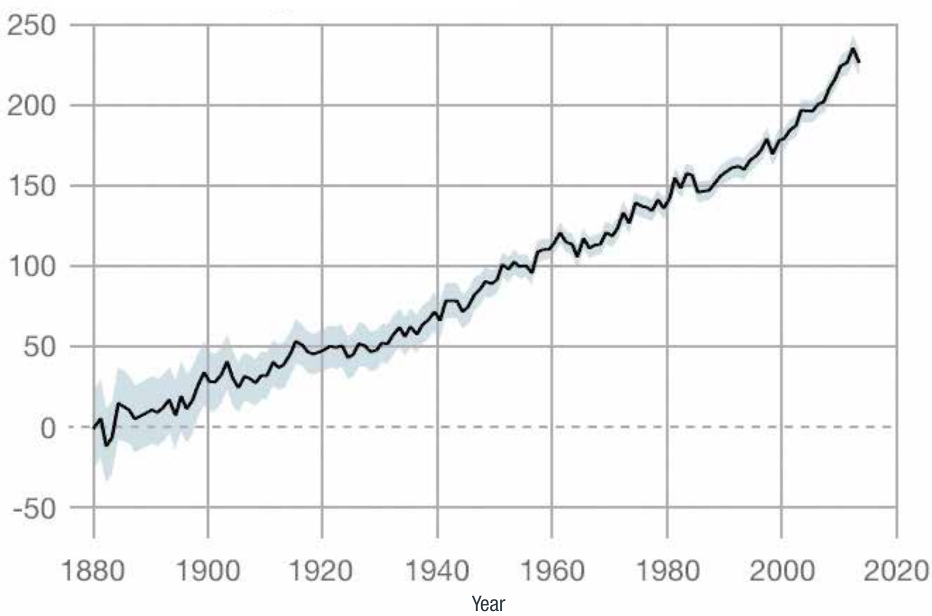
➔ What do you notice?

GLOBAL WARMING IN °C



Source: data from NASA – https://data.giss.nasa.gov/gistemp/tabledata_v3/GLB.Ts+dSST.txt

SEA LEVEL CHANGE IN MM



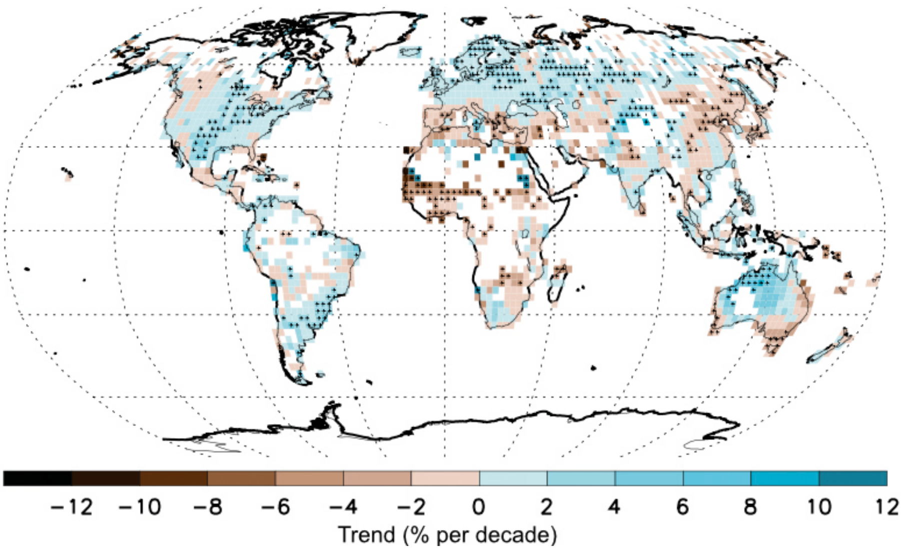
Source: data from NASA – https://climate.nasa.gov/vital-signs/sea-level/

WORKSHEET A2.3

These two figures show the change in mean precipitation (between 1951 and 2010) and temperature (between 1950 and 2018).

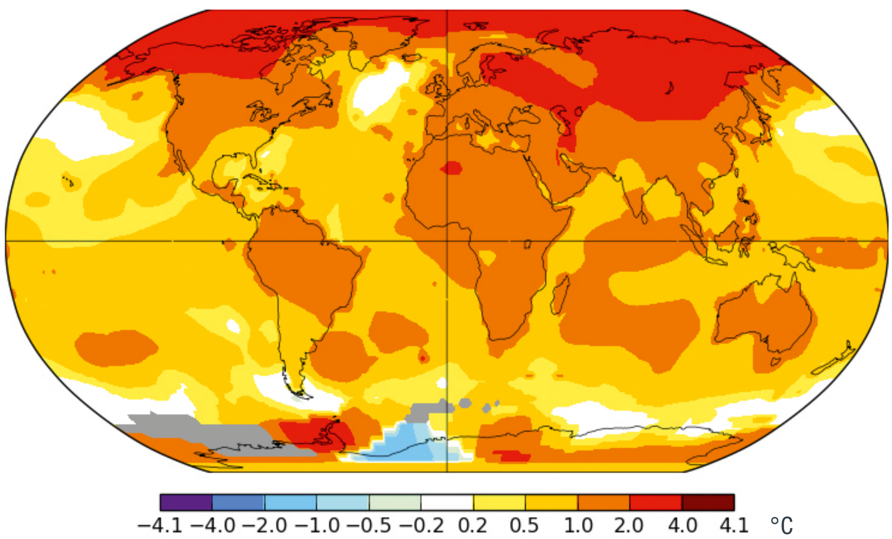
➔ **What do you notice?**

TRENDS IN PRECIPITATION OVER LAND BETWEEN 1951 AND 2010



Source: IPCC Assessment Report 5 – WG1

CHANGE IN MEAN ANNUAL SURFACE TEMPERATURE FROM 1950-2018



Source: NASA – https://data.giss.nasa.gov/gistemp/maps/index_v4.html

WORKSHEET A2.4

Observe the two documents and answer the following questions:

- What do they tell you about the change in glaciers?
- Is it a local or a global phenomenon?

Muir glacier, Alaska. August 13, 1941 and August 31, 2004.
Source: NASA - https://climate.nasa.gov/climate_resources/4/graphic-dramatic-glacier-melt/

Source: NASA - https://climate.nasa.gov/climate_resources/125/infographic-sea-level-rise/

WORKSHEET A2.5

Read the following article published in The Conversation, an online non-profit news organisation, and answer the following questions:

- Where is the “Mer de Glace” located?
- What happened between 1909 and 2017?
- Do you think it is a local or a global phenomenon?

THE CONVERSATION

Academic rigour, journalistic flair

Dundee University, Author provided

What a century of climate change has done to France’s biggest glacier

March 15, 2018 2.16 pm GMT

Like a one-man Google Earth, Swiss aviation pioneer **Eduard Spelterini** flew a gas-filled balloon from the French town of Chamonix to Switzerland on August 8, 1909 – a distance of 100 miles over the Alps. While the flight was extraordinary for being the first aerial crossing of the central Alps from west to east, it now holds a special significance of which Spelterini was unaware. The balloonist was also a photographer who captured a series of **glass-plate images** of the **Mer de Glace** (“sea of ice”) glacier that descends from the **Mont Blanc Massif** in a dramatic sweep.

Spelterini’s interest in recording the alpine landscape was both scientific and aesthetic, and the results are striking. This **collection** of images survives today as a record of the glacier that is unique in its detail and antiquity. But crucially, they can be used to measure how much this landscape has changed in the intervening years. In 1909, no one could have guessed how significant these glaciers would become to environmental science, or just how rapidly they would be affected by **rising temperatures** in the century that followed.

Author

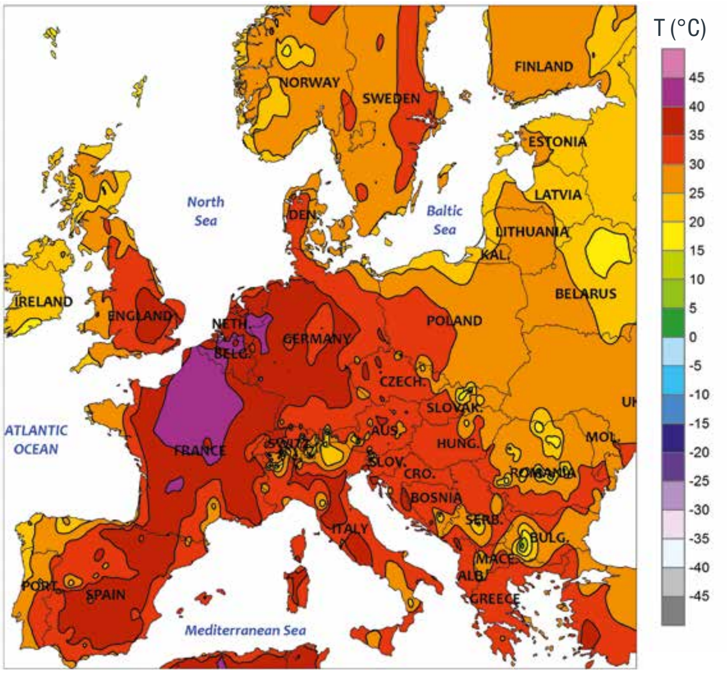
Kieran Baxter

Research assistant, 3DVisLab, Duncan of Jordanstone College of Art and Design, University of Dundee

WORKSHEET A2.6

Look at the two figures below and answer the following questions:

- What is an extreme weather event?
- What kind of extreme weather events can you imagine?
- What happened in Europe in Summer 2019?
- Is it a local or a global phenomenon?



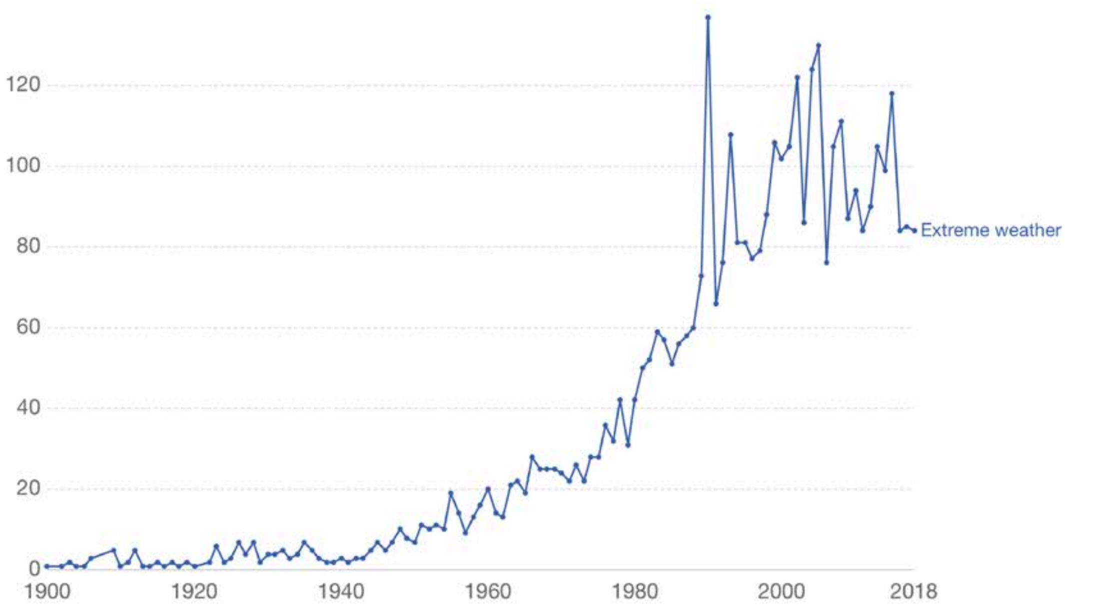
EUROPE – EXTREME MAXIMUM TEMPERATURE (°C) JULY 25, 2019

In July 2019, Europe experienced exceptionally hot weather, setting all-time high temperature records in Belgium, Germany, Luxembourg, the Netherlands, and the United Kingdom, with temperatures reaching up to 9°C above the average temperatures for this season.

Source: Wikipedia & NOAA / National Weather Service
https://www.cpc.ncep.noaa.gov/products/analysis_monitoring/regional_monitoring/

NUMBER OF RECORDED EXTREME WEATHER EVENTS

Extreme weather events are events that fall out of the real of normal weather patterns for a given location (e.g. superpowerful hurricanes, torrential precipitation, droughts, heatwaves). Extreme weather events are themselves, troublesome, but the effects of such extremes, including damaging winds, floods, drought and wildfires, can be devastating.



Source: EMDAT (2019): OFDA/ CRED International Disaster Database, Université catholique de Louvain, Brussels, Belgium.
https://ourworldindata.org/natural-disasters – CC BY

WORKSHEET A2.7

Read the following document and answer the questions:

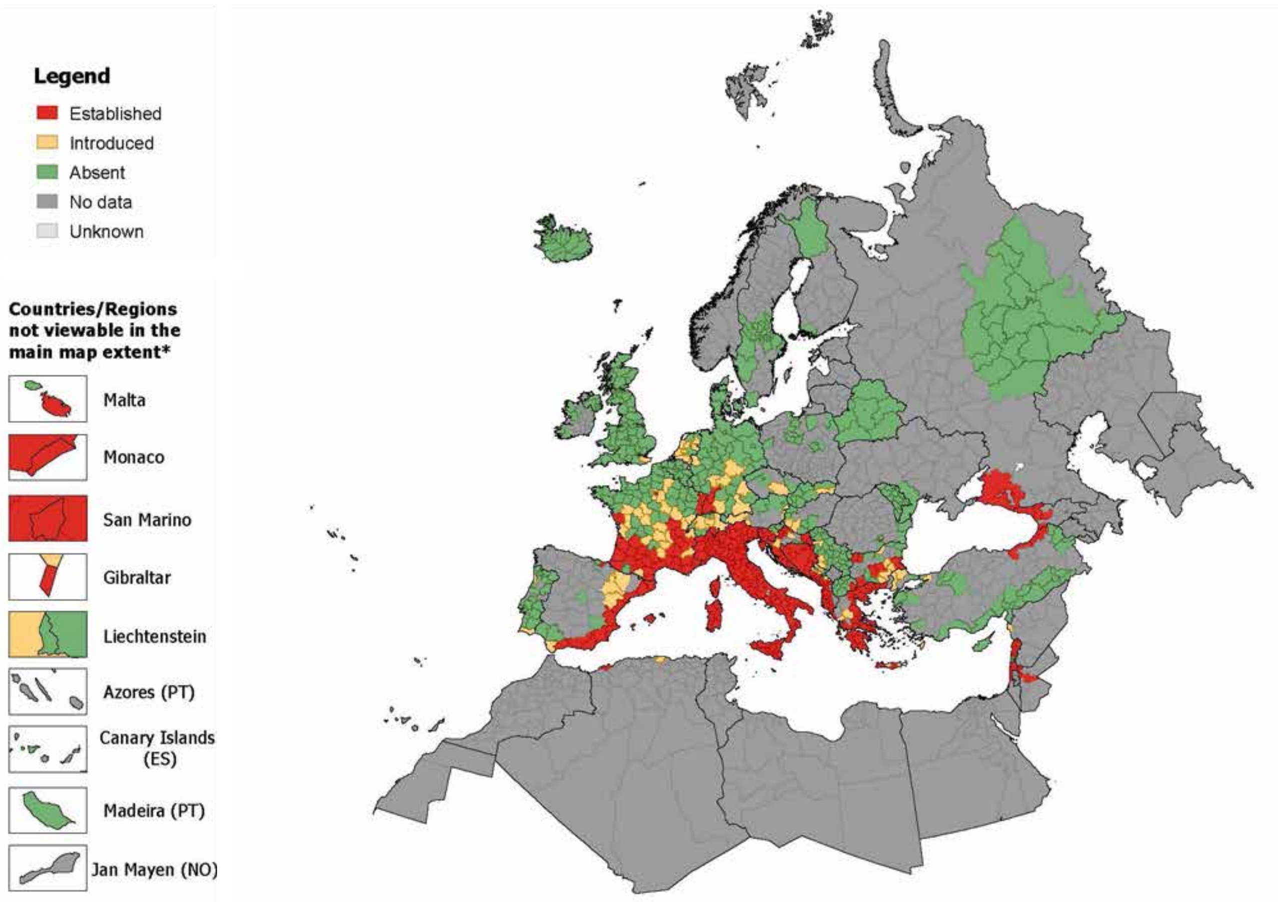
- **Why is the tiger mosquito *(Aedes albopictus)* considered a threat?**
- **Why is it able to thrive in Europe today?**

The tiger mosquito is named thus because of its striking white and black pattern. It measures between 2 and 10 mm in length and is a known vector of viruses affecting human health (such as Chikungunya and Dengue). It originally inhabited the tropical forests of the South-East Asia exclusively. But in the last three decades, it has spread globally through the transport of goods from heavily infested areas. In 2008, the tiger mosquito was considered one of the world's 100 most invasive species according to the Global Invasive Species Database.

The tiger mosquito was first seen in Europe in 1979, the USA in 1985, Latin America in 1986 and Africa in 1990. Previously, European weather was too cold to guarantee the insect's long-term survival. But the climate-induced increase in temperature in Europe in recent decades has made the region more suitable for persistence.

In Europe, the tiger mosquito is now well established in southern Europe, along the Mediterranean coast in Albania, Italy, France, Greece, Spain and the Balkan countries. Furthermore, it has also been reported in other northern European countries, most likely introduced by vehicles coming from southern Europe.

AEDES ALBOPICTUS – CURRENT KNOWN DISTRIBUTION – JANUARY 2018



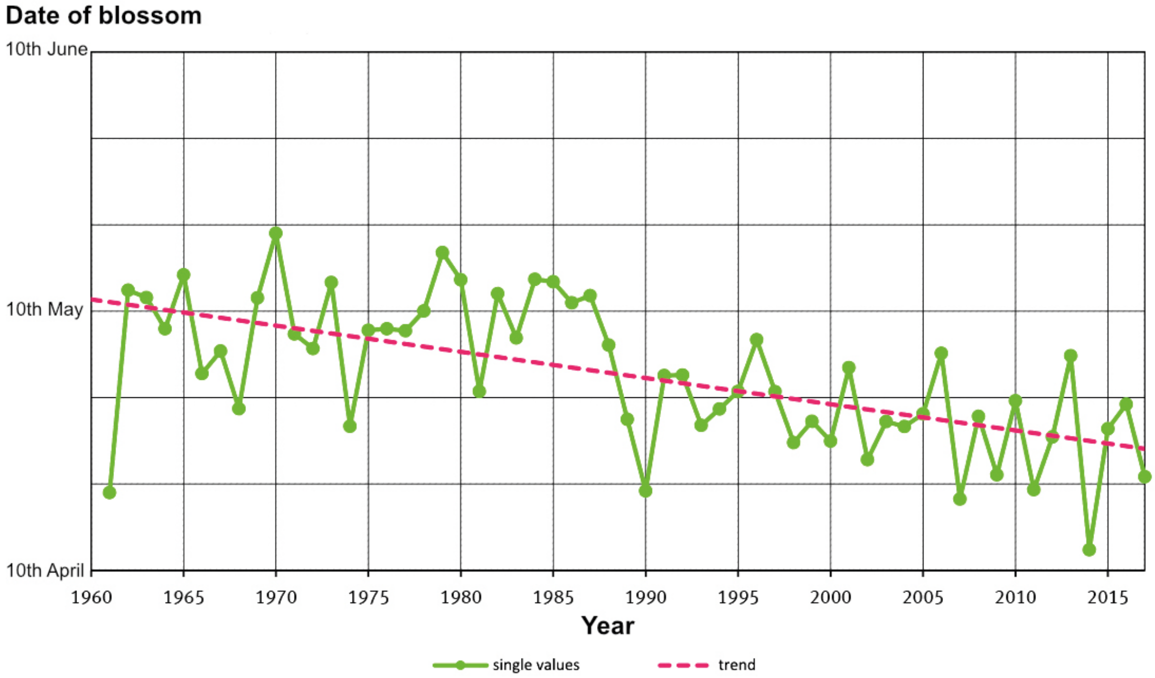
ECDC and EFSA. Map produced on 1 Feb 2018. Data presented in this map is collected through the Vector Net project. The maps are validated by designated experts prior to publication. Please note that the data do not represent the official view or position of the countries.
* Countries / Regions are displayed at differents scales to facilitatet their visualization.
Administrative boundaries: ©EuroGeographics; ©UN-FAO; ©Turkstat

WORKSHEET A2.8

The following graph shows the change in the beginning of apple blossom in Germany in recent decades.

- What do you notice?
- Explain why it is happening.

BEGINNING OF APPLE BLOSSOM IN GERMANY (AVERAGE)



Source: Deutscher Wetterdienst, Germany's National Meteological Service (2018)
https://www.umweltbundesamt.de/daten/klima/veraenderung-der-jahreszeitlichen

SEQUENCE B

WHAT CAUSES CLIMATE CHANGE?

Acknowledging that the climate is changing is the first step in understanding human-induced climate change (sequence A). The second step is recognising human responsibility in today's climate change. The present sequence addresses this issue, providing a preliminary understanding of both the physical mechanisms involved in global warming (in particular, the role of greenhouse gases), and the human activities responsible for it, as well as the links between both. This sequence involves documentary analysis, physical model experimentation and serious games.

LESSON LIST

◉ Core lesson   ○ Optional lesson

LESSON B1
THE GREENHOUSE EFFECT: UNDERSTANDING WITH AN ANALOGY

MAIN SUBJECTS
Natural sciences

DURATION
~ Preparation: 10 min
~ Activity: 1 h 30

SUMMARY
The students learn about the greenhouse effect by building a greenhouse as an analogy with greenhouse gases in the atmosphere.

KEY IDEAS
~ All objects emit infrared radiation; the warmer they are, the more infrared radiation they emit.
~ When the Earth's surface is warmed by the sun, it emits infrared radiation.
~ The greenhouse gases in the Earth's atmosphere absorb infrared radiation emitted by Earth's surface. Only part of this infrared radiation escapes into space and the rest is sent back to the surface.
~ An increase in greenhouse gas concentration results in an increase in Earth's surface temperature.

KEYWORDS
Greenhouse effect, greenhouse gas, infrared radiation, global warming

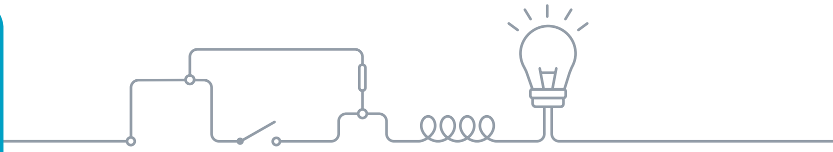
INQUIRY METHOD
Experimentation

PREPARATION 10 MIN

MATERIALS

For each group of 3 to 4 students:

- 1 light bulb (at least 60 W, if possible 100 W; no energy-saving lamps: use incandescent or halogen bulbs), mounted on a stand.
  Note: If the weather is sunny, the light bulbs are optional, and the experiments can be carried out in the sun;
- 2 electronic thermometers;
- 1 transparent container made of glass or transparent plastic (as thin as possible), or a container sealed with plastic wrap;
- (Optional) Modelling clay, which can be useful for sealing the container.



INTRODUCTION 20 MIN

In the previous lessons, the students have learned that the temperature of the atmosphere is increasing, and that this global warming has several impacts on the ocean and cryosphere. This lesson starts by discussing the students' hypotheses as to the causes of the temperature increase. Guide the discussion so that the students come to the conclusion that the cause is some kind of pollution. Depending on the students' age, some may mention greenhouse gases (or at least CO_2, since it has already been introduced). You can ask the students to write down all the concepts they think of when they hear "greenhouse effect" (such as a greenhouse in the garden, greenhouses for flowers, growing plants, protection, warmth, humidity, danger, pollution, gas and the ozone layer).

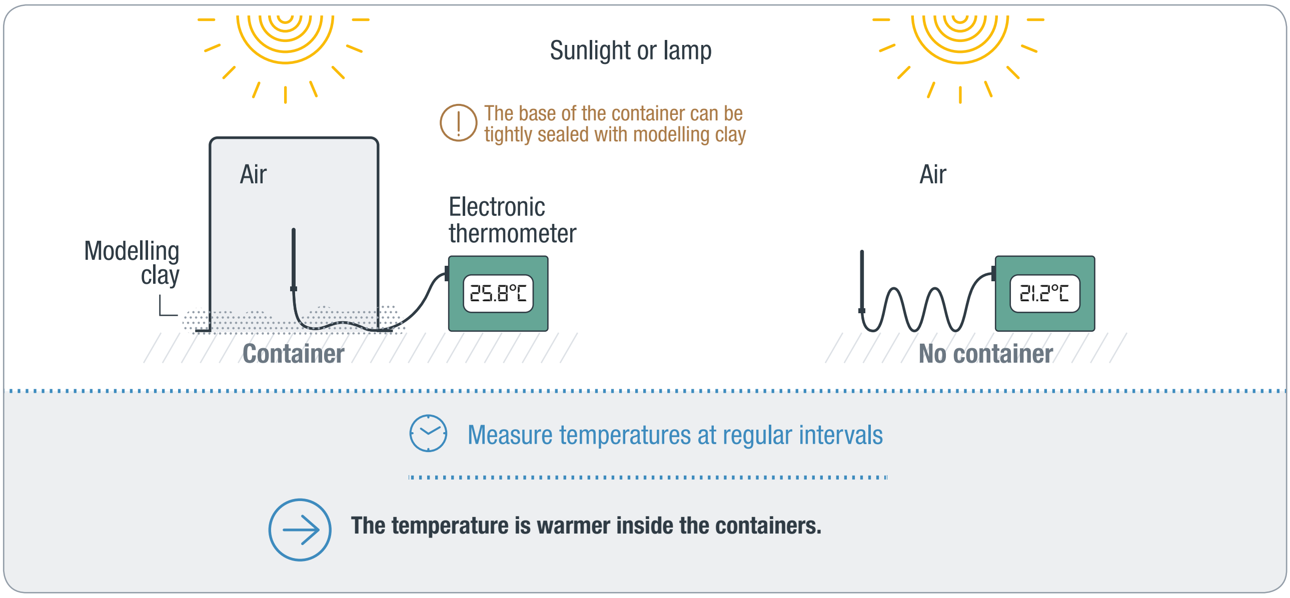
PROCEDURE 50 MIN

1. Ask the students to think of an experiment they could carry out in the classroom to test the greenhouse effect. Building a greenhouse should be the most realistic proposal to emerge (see figures on the following page).

> **TEACHER TIP**
> For noticeable results, do the experiment under the sun and in the middle of the day. You can expect a temperature difference of up to 4 degrees. The use of electronic thermometers is not required, but make sure that your thermometer allows you to notice the change in temperature.

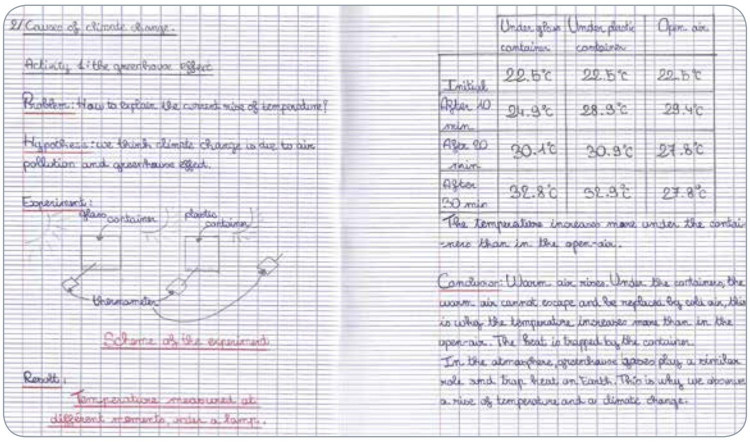
2. Each group builds a basic greenhouse with the provided container, with a thermometer inside. Another thermometer should be kept outside as a control.

3. The students should measure the temperature at regular intervals and write down the measured values in a table.



The greenhouse experiment in a plastic or glass container.

Measuring the temperature inside and outside the greenhouse.



2/ Causes of climate change.

Activity 1: the greenhouse effect

Problem: How to explain the current rise of temperature?

Hypothesis: we think climate change is due to air pollution and greenhouse effect.

Experiment:

Scheme of the experiment

Result:

Temperatures measured at different moments, under a lamp.

	Under glass container	Under plastic container	Open air
Initial	22.5°C	22.5°C	22.5°C
After 10 min	24.9°C	28.9°C	23.4°C
After 20 min	30.1°C	30.9°C	27.8°C
After 30 min	32.8°C	32.9°C	27.8°C

The temperature increases more under the containers than in the open-air.

Conclusion: Warm air rises. Under the containers, the warm air cannot escape and be replaced by cold air, this is why the temperature increases more than in the open-air. The heat is trapped by the container.
In the atmosphere, greenhouse gases play a similar role and trap heat on Earth. This is why we observe a rise of temperature and a climate change.

Student notes of the experiment.

TEACHER TIP

In a greenhouse, two main effects contribute together to the temperature increase: the greenhouse effect and the containment. Without a cover, the hot air rises by convection and is replaced by colder air. This is prevented when you use a cover. The containment effect prevents the warm air from escaping from the greenhouse. The thermometer therefore displays a lower temperature outside than inside.

Moreover, when comparing a glass greenhouse (where, in theory, there is a greenhouse effect, resulting from the absorption of infrared radiation) with a polyethylene (plastic) greenhouse (where there is no greenhouse effect), it turns out that there is no noticeable difference in temperature increase. The dominant effect contributing to warming is the containment.

4. Ask the students what is making the temperature rise. Explain that the greenhouse is used as an analogy.

5. There are gases in the atmosphere that play the same role as the greenhouse roof. These are therefore called greenhouse gases. Such an analogy, if presented and taken as such, is entirely acceptable in the classroom.

6. If you choose not to do lesson B3, give the students **WORKSHEET B3.4** to analyse in groups. Discuss the source of greenhouse gases in the atmosphere.

WRAP-UP 20 MIN

Discuss the link between the experimental results and the greenhouse gas effect that is causing global warming. The greenhouse gases act like a greenhouse, "trapping" the invisible infrared radiation emitted by the Earth's surface (and also directly by the sun) thus leading to warming "inside" the greenhouse (the Earth's surface and the lower atmosphere).

BACKGROUND FOR TEACHERS

GREENHOUSE EFFECT

The sunlight crosses the atmosphere and warm the Earth's surface, generating the upward emission of **infrared radiation** (heat). Some of this heat is trapped on its return to space by **greenhouse gases** in the atmosphere (mainly water vapour, carbon dioxide, methane and nitrous oxide) and sent back towards the Earth's surface. Greenhouse gases thus act like a blanket, trapping heat emitted from below. The temperature of the lower atmosphere is therefore warmer than it would otherwise be. In fact, without greenhouse gases, the average temperature of Earth's surface would be of about -18°C rather than the present average of 15°C.

The concentration of greenhouse gases changes: either because of natural causes, as in the past, or human activities, as in the present. This alters the Earth's energy equilibrium and the average surface temperature (see figure on page 10).

INFRARED RADIATION

Our eyes are only capable of seeing part of the spectrum of the light emitted by the sun: this is visible radiation. **The atmosphere is essentially transparent to visible radiation.**

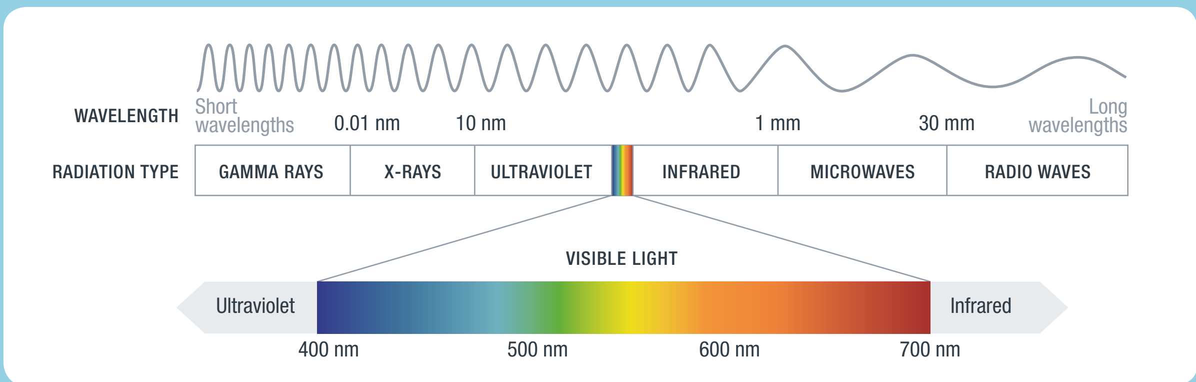
Light is composed of many forms of radiation, of different wavelengths. When using a prism, the rays are deflected to varying degrees according to their wavelength. We then see different colours (which correspond to different wavelengths), but some are invisible to our eyes. The figure below shows the spectrum of light, broken down into different wavelength ranges. Only a very small part of the spectrum, between the 400 and 700 nm wavelengths, is visible to the human eye. Infrared light, with wavelengths longer than those of visible red colour, is invisible to us.

An object that is heated (e.g. Earth heated by the sun) emits radiation of a wavelength that depends on surface temperature. At an average temperature of about 15ºC, the Earth's surface mostly emits radiation in the infrared range. **The atmosphere (due to the presence of greenhouse gases) is not transparent to infrared radiation.**

THE GREENHOUSE EFFECT AND THE "HOLE" IN THE OZONE LAYER: TWO DISTINCT PHENOMENA

The composition of the atmosphere, as well as its temperature, varies with altitude. The lowest layer, in which we live and where most weather events occur, is called the troposphere. It represents more than 80% of the total mass of the atmosphere. It is thicker at the equator than at the poles. Above it, we find the stratosphere, and within it the "ozone layer", located at an altitude of between 15 and 30 km. Ozone is actually present throughout the atmosphere, but its concentration is particularly high in this zone. Ozone absorbs the ultraviolet radiation of sunlight (the radiation responsible for sunburn) and prevents it from reaching the Earth's surface. The massive use of certain refrigerant gases (Chlorofluorocarbons – CFCs) has resulted in a local depletion of this ozone layer, which poses a significant threat to all life on Earth. Since the Montreal Protocol was signed in 1985, the use of these gases has been prohibited, and the "hole" in the ozone layer is gradually closing. The increase in the greenhouse effect and the "ozone hole" are thus two distinct problems: not the same atmospheric gases involved (even though the ozone itself is also a greenhouse gas), not the same issues.

Light spectrum



LESSON B2
THE GREENHOUSE EFFECT: ROLE-PLAYING GAME[1]

MAIN SUBJECTS
Physical education (<12 years)

DURATION
~ Preparation: 5 + 15 min
~ Activity: 1 h

SUMMARY
In a game of catch, the students understand the role of greenhouse gases in “trapping” infrared radiation and stopping it from “escaping” into space so they can link this phenomenon with global warming.

KEY IDEAS
~ When heated, all objects emit infrared radiation.
~ When the Earth’s surface is heated by the sun, it emits infrared radiation.
~ The greenhouse gases in the Earth’s atmosphere absorb infrared radiation emitted by Earth’s surface: only part of this infrared radiation escapes into space and the rest is sent back to the surface.
~ An increase in the greenhouse gas concentration results in a temperature increase of the Earth’s atmosphere.

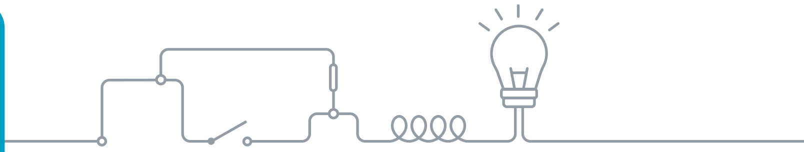
KEYWORDS
Greenhouse effect, greenhouse gas, infrared radiation, global warming, fossil fuels

INQUIRY METHOD
Role-playing game

PREPARATION 5 + 15 MIN

MATERIALS
T-shirts or vests of three different colors. Ideally **HEAT** will be in red, fossil fuels (**FF**) in black (like oil) and greenhouse gases (**GHG**) in blue (atmosphere).

LESSON PREPARATION
1. **To be done during the previous lesson or the day before.** Ask the students to bring a T-shirt of the appropriate color or prepare vests of three different colors.
2. Draw three distinct zones on the floor (see figure on the right) named **EARTH**, **ATMOSPHERE** and **SPACE**.



TEACHER TIP
See “Background for teachers” of the previous lesson (B1).

INTRODUCTION 10 MIN

The teacher starts by explaining that warm objects emit (give off) heat radiation (also infrared radiation); they include the Earth, which is warmed by the sun. The infrared radiation emitted by the Earth’s surface “radiates” into space. Infrared radiation is invisible to our eyes, but is used, for example, in TV remote controls. You can also “feel” infrared radiation when you bring your hands close to a warm object.

PROCEDURE 30 MIN

1. Split the class into three groups: Half of the students, the **HEAT** group, will play the role of infrared radiation leaving the Earth’s surface, in the direction of space; a quarter of the students, the **GHG** group, will play the role of greenhouse gases in the Earth’s atmosphere; and the other quarter, the **FF** group, will

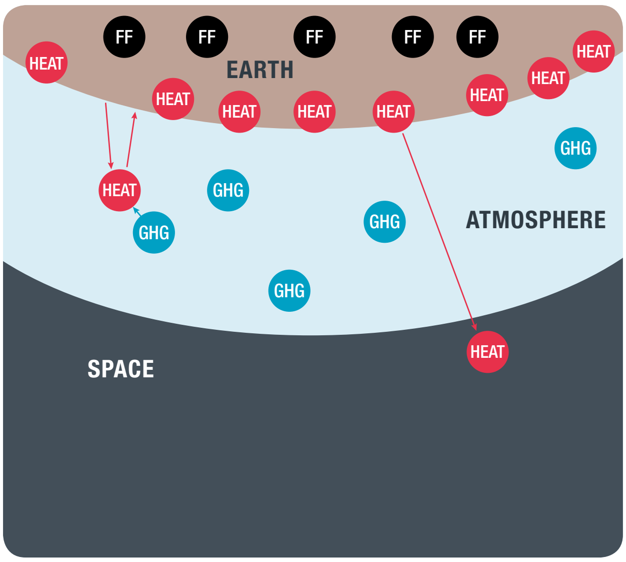


Diagram of the three zones to be drawn on the floor.

1 This lesson was inspired by the activity “Atmosphere-Exploring Climate Science” (https://learning-resources.sciencemuseum.org.uk/) proposed by the UK Science Museum. The OCE is grateful to the authors.

play the role of fossil fuels. The **FF** group remains seated during the first round: the fossil fuels are stored in the Earth's crust. The students in the **GHG** group spread out in the **ATMOSPHERE**. The **HEAT** group starts on one side of the room: they represent the warmed **EARTH** (see figure on the previous page). The game goes as follows:

First round

Measure the time needed to finish a round. If it takes too long, limit the duration of the round to 2 minutes.

- The **FF** group remains seated.
- The **HEAT** group has to cross the room to "radiate" into space, passing the greenhouse gases which try to trap them.
- If a **GHG** traps a **HEAT**, the latter has to go back to the **EARTH** zone and count out loud to five before the student can try escaping again. (This is an analogy to greenhouse gases that do not let infrared radiation escape into space.)
- When all the **HEAT** students have either reached the other side or been trapped by the **GHG** group, the round ends. If you have to end the round at 2 min, count the number of **HEAT** members that managed to escape into space.
- Ask the students to go back to their initial positions for the second round.
- **Before starting the second round,** explain that you (the teacher) represent the inhabitants of the Earth, and that you will take the **FF** out of the crust of the **EARTH**, as an analogy to the exploitation of oil, gas and coal. The **FF** are then transformed into **GHG**: They receive a **GHG** T-shirt or vest and join the other **GHG** students from the first round. Stress the fact that now there are now far more greenhouse gases in the atmosphere. The second round must last as long as the first.

Second round

At the end of the round, observe that in exactly the same time, less **HEAT** students have managed to escape into space.

2. Ask the students to draw the game they played (with a legend and an explanation). Once they are done, draw a version on the whiteboard and discuss the analogy.

3. Ask the students: *What conclusion can you draw from the fact that fewer **HEAT** students managed to escape into space in the second round?* The increased amount of greenhouse gases in the atmosphere makes it more difficult for infrared radiation (**HEAT**) to escape into space.

4. Ask: *What was my role (teacher) in between the two rounds?* The teacher's role was to play humanity exploiting fossil fuels. Discuss (i) the different types of fossil fuels (coal, oil, gas), (ii) how fossil fuels emit greenhouse gases (through combustion), (iii) other human activities that emit greenhouse gases (like meat production and intensive agriculture), (iv) the effects of an increased amount of greenhouse gases in the atmosphere (more infrared radiation is "trapped" and the atmosphere's temperature increases), and (v) what would happen if there were no greenhouse gases at all in the atmosphere. All infrared radiation would escape into space, and the temperature of the atmosphere would be much lower: –18°C in average at the Earth's surface instead of the actual +15°C! The greenhouse effect is essential for life on Earth; the problem starts when the amount of greenhouse gases becomes too high.

WRAP-UP 20 MIN

The students write a conclusion of the lesson. Example: *"When the Earth is heated by sunlight, its surface warms up. The warm surface emits infrared radiation. Greenhouse gases in the atmosphere trap part of the infrared radiation emitted by the Earth. If more greenhouse gases are present in the atmosphere, less infrared radiation can escape into space. The temperature of the (lower) atmosphere and the Earth's surface increases. Human activities that emit a lot of greenhouse gases into the atmosphere are causing global warming."*

OPTIONAL EXTENSION

A possible extension is to use the multimedia activity entitled "The Greenhouse Effect" available on the following website: https://phet.colorado.edu/en/simulation/greenhouse.

The multimedia activity has three different options: the first demonstrates the effect of greenhouse gases on global mean temperature (the concentration of greenhouse gases can be changed) based on the "visible photons" – the sunlight – and "infrared photons" – the infrared radiation – received, emitted or absorbed; the second conceptualizes the phenomenon using the agricultural greenhouse analogy (as in lesson B1): it simulates the concentration of greenhouse gases by changing the number of windows. The last is more advanced, differentiating the radiative effects of the different molecules in the atmosphere.

LESSON B3
HUMANS AND GREENHOUSE GASES [1]

MAIN SUBJECTS
Social sciences

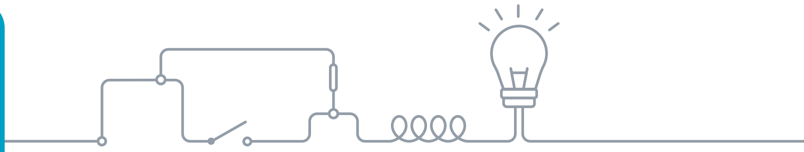
DURATION
- Preparation: 10 min
- Activity: 1 h 30

SUMMARY
Through a mystery-solving activity, the students gain an understanding of the historical causes of climate change. The students analyse different scientific data to learn more about greenhouse gases and the human activities that produce them.

KEY IDEAS
- Anthropogenic climate change – climate change induced by human activities – concerns ongoing and future changes of the Earth's climate.
- In the 19th century, progress in science and technology, alongside socio-economic changes and new forms of production, led to an industrial revolution in Europe. Burning of fossil fuels has been increasing ever since.
- The concentration of greenhouse gases in the atmosphere is increasing. Carbon dioxide (CO_2), methane (CH_4), nitrous oxide (N_2O) and water vapour (H_2O) are greenhouse gases.
- The temperature of the atmosphere is increasing faster than ever before. Since pre-industrial times until 2017, the global mean atmospheric temperature had already increased by approximately 1°C.

KEYWORDS
Industrial revolution, steam engine, fossil fuels, greenhouse gases, anthropogenic emissions, climate justice

INQUIRY METHOD
Debate



PREPARATION 10 MIN

MATERIALS
WORKSHEETS B3.1, B3.2, B3.3, B3.4, B3.5, B3.6 (one of each per group)

LESSON PREPARATION
1. Print **WORKSHEETS B3.1, B3.2, B3.3** (and, for advanced students: **B3.4, B3.5, B3.6**): one copy of each for each group.
2. Place one "Agree" and one "Disagree" sign at two opposite sides of the classroom.

INTRODUCTION 10 MIN

Recap lessons B1 and B2: We have seen excess of greenhouse gases in the atmosphere lead to an increase in the Earth's surface air temperature. In this lesson, the students will find out who/what is responsible for greenhouse gas emissions.

PROCEDURE 1 H

PART 1 (30 MIN): THE HISTORICAL CAUSES OF CLIMATE CHANGE

1. Tell the students that to find out who is responsible for excess greenhouse gases in the atmosphere, they have to start by solving a mystery.

2. Divide the class into groups and give each group a copy of **WORKSHEETS B3.1, B3.2, B3.3**. Ask the students to read and organize the cards in order to be able to solve the following mystery:
"Was James Watt to blame for Ali missing school?"

Organising the cards to solve the mystery.

1 This lesson was inspired by Lesson 5 of the "Creating Futures" resource, produced in the scope of the Education for a Just World initiative, by Trócaire and the Centre for Human Rights and Citizenship Education, DCU Institute of Education (Dublin, Ireland). The OCE is grateful to the authors.

TEACHER TIP

Depending on your students' level, you can choose to give them the highlighted cards to organize first. These are the ones that are essential to answer the question, and the easiest to place in a logical order. When they have finished, you can give them the other cards, which provide extra information on the industrial revolution. If the students struggle to answer the question, even when using only the highlighted cards, you can suggest they can start by choosing which cards are more closely related to James Watt, and which are more closely related to Ali.

3. When the groups think they have found an answer, ask the class to position themselves between the signs to reflect how they feel about the statement. Discuss the mystery with the students on the mystery, asking them to justify their position. They are allowed to move during the debate if they change their minds. Similarly, discuss the following statement with the class:

"The industrial revolution was a good thing."

PART 2 (30 MIN, FOR ADVANCED STUDENTS): ANALYSIS OF SCIENTIFIC DATA CONCERNING CLIMATE CHANGE

Divide the students into groups and ask them to analyse the documents in **WORKSHEETS B3.4, B3.5, B3.6** in order to answer the questions.

WRAP-UP 20 MIN

Write the students' answers to the previous questions on the whiteboard and discuss everyone's responsibility with respect to greenhouse gas emissions and climate change.

TEACHER TIP

If you wish (or the students), you can proceed to lesson E2 (page 132) or E3 (page 136) – Climate Justice, before continuing with Sequence C.

BACKGROUND FOR TEACHERS

HUMANS AND GREENHOUSE GASES

The use of **energy** has been part of human activity in various forms since its origins (fire, animal traction and mills for example). From the 1800s onwards, the industrial revolution has transformed the western world with the **steam engine**, hydroelectricity, **fossil fuels** and, lastly, nuclear, wind and solar energy sources. Electricity is an extraordinarily convenient way to carry and use energy, although it is very difficult to store (except in small or expensive batteries). Overall energy consumption has constantly grown worldwide, doubling in the last four decades, but its use remains extremely uneven. Most developing countries consider access to it to be critical for their future.

The **industrial revolution** brought with it unprecedented scientific, technological, economic and political changes affecting all sectors of human societies, from agriculture to medicine, and leading to new living standards (starting with Europe and North America). These changes occurred together with a considerable growth in the human population. The increasing use of fossil fuels as an energy source, together with a quickly growing population, led to today's vast exploitation of natural resources (such as fossil fuels) and the associated emission of **greenhouse gases**.

In 2019, **combustion** (wood and fossil fuels like oil, gas or coal) represented 85% of the world's energy consumption. Whatever the fuel, it produces carbon dioxide (CO_2), which disperses in the Earth's atmosphere. Other greenhouse gases are produced by human activities, such as methane (CH_4) or nitrous oxide (N_2O). For further details on greenhouse gas emissions, page 14 of the Scientific Overview. For the main sources of greenhouse gas emissions, see the worksheet for this lesson.

GLOBAL WARMING POTENTIAL OF GREENHOUSE GASES

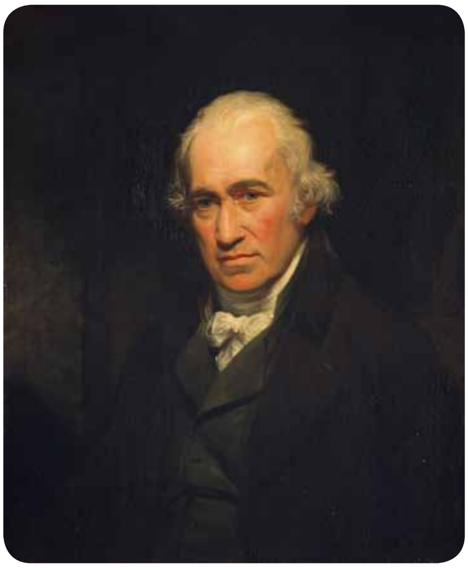
The different greenhouse gases have a different **Global Warming Potential** (GWP). The GWP depends mainly on two key characteristics of each greenhouse gas: its ability to **absorb radiation** (known as "radiative efficiency") and **the time it stays in the atmosphere** after being emitted (known as "lifetime").

The GWP of a gas (other than CO_2) is useful to calculate the amount of radiation that the emissions of that gas will absorb over a given period of time, in comparison to how much radiation 1 ton of CO_2 would be able to absorb (in the same period of time, usually considered over 100 years). The GWP of CO_2 is therefore 1; CH_4 has a GWP of 28-36, and N_2O of 265-298, while CFCs, HCFSs, PFCs and SF_6 can have GWPs in the thousands or tens of thousands. The overall contribution of a given greenhouse gas to global warming depends on both its GWP and the total amount emitted.

WORKSHEET B3.1

Is James Watt responsible for Ali missing school?

In order to answer the question, cut out and organize the cards provided in **WORKSHEET B3.2**.



James Watt (1736-1819).

Power loom weaving in a cotton mill in England around 1835.

Ali (in the blue shirt), Punjab, Pakistan.

Punjab, Pakistan.

WORKSHEET B3.2

As the Earth gets hotter due to climate change, Pakistan is likely to have more serious droughts and floods.

In the 1770s and 80s James Watt, a Scottish engineer, improved the steam engine. It could now power machines in factories. James Watt's steam engine is seen as an important part of the industrial revolution.

On average, people in Pakistan burn a lot less fossil fuel and give off less carbon dioxide than people in Europe or North America, for example.

The steam engine worked by burning wood or coal. Coal was used more and more during the industrial revolution.

The industrial revolution describes the period between approximately 1760 and 1830. It began in Great Britain, then spreading to Western Europe and to North America.

Last year, Ali's village was flooded. The rain fell heavily, and the river rose very high. The floods destroyed the only road to Ali's village, so he could not get to school, hospital or the market.

As the Earth gets hotter due to climate change, some of the ice caps on the mountains in Pakistan are melting and flowing down into Pakistan's rivers.

Since the industrial revolution, the amount of carbon dioxide in the Earth's atmosphere has gone up and up.

Today, the principle of the steam engine is still used in coal power plants. Burning the coal produces heat, which is used to produce water vapour at high pressure. The vapour is then used to turn a turbine and generate electricity.

Greenhouse gases in the Earth's atmosphere act like a "blanket", trapping heat from Earth's surface. Greenhouse gas emissions make this "blanket" thicker. Scientists have found that this makes the Earth warmer.

Burning coal, oil and gas releases carbon dioxide into the atmosphere.

Ali lives in a village in Pakistan. His village has many green fields and a big ground where he used to play cricket. Ali goes to school in a nearby town with his cousins.

Ali lives with his grandmother, his three siblings and his mother. They grow wheat and vegetables. They also have a cow and some hens which give them milk and eggs.

When Ali's village flooded, their crops were destroyed, their house was swept away, and they had to stay in a safe camp high up a hill for three weeks.

During the industrial revolution many people moved from the countryside, where they farmed the land, to work in city factories.

Eventually, people in Ali's village worked together to rebuild the road after it was destroyed by the floods.

Pakistan has a monsoon season when there is a lot of rain, and a dry season when there is much less rain.

The use of the steam engine meant that cotton could be spun much more quickly than before.

Before Watt's steam engine, factories were powered by flowing water. This meant factories had to be beside a river. The steam engine meant factories could be set up anywhere, and they often moved into cities.

Before the industrial revolution, things were often made in homes using hand tools. The industrial revolution saw things made in factories using special machinery.

Agree

Disagree

WORKSHEET B3.4

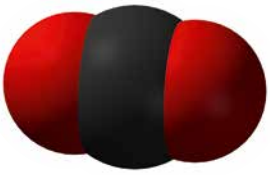
Look at the following identity cards of different gases and answer the following questions:

- **What are the main greenhouse gases in the atmosphere that are emitted by human activities?**
- **Which human activities are responsible for greenhouse gas emissions?**

WATER VAPOUR – H_2O

→ Is the most abundant greenhouse gas in the atmosphere.
→ **Human activities have only a minor direct influence on the amount of atmospheric water vapour.**
→ Humans have the potential to substantially influence the amount of water vapour in the atmosphere by changing the climate.

CARBON DIOXIDE – CO_2



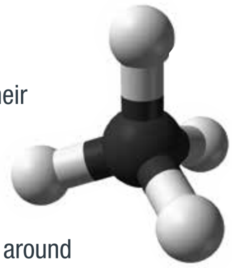
Emitted by:
→ **Burning fossil fuels** like coal, oil and gas
→ **Cement production**
→ **Deforestation**

The CO_2 in the atmosphere is partially absorbed by the ocean, land vegetation and the soil.

Concentration in the Earth's atmosphere has increased from ~ 280 ppm (parts per million) in pre-industrial times to over 400 ppm today.

Contributes to:
→ Anthropogenic greenhouse effect and global warming (major contributor)
→ Acidification of the oceans

METHANE – CH_4

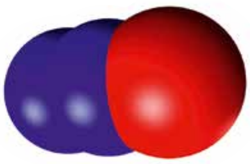


Emitted by:
→ **Cow and sheep** burps and defecation (it is produced in their stomach!)
→ **Fossil fuel** extraction and use
→ **Paddy rice production** when fields are under water
→ **Landfills and waste**

Concentration in the Earth's atmosphere has increased from around 750 ppb (parts per billion) in pre-industrial times to over 1850 ppb in 2017.

Contributes to:
→ Anthropogenic greenhouse effect (has high warming potential: it can trap around 30 times more heat than carbon dioxide)

NITROUS OXIDE – N_2O



Emitted by:
→ **Agriculture** (spreading artificial and natural fertilizers in fields and growing fodder crops)
→ **Fossil fuel** combustion
→ **Fuel vehicles**

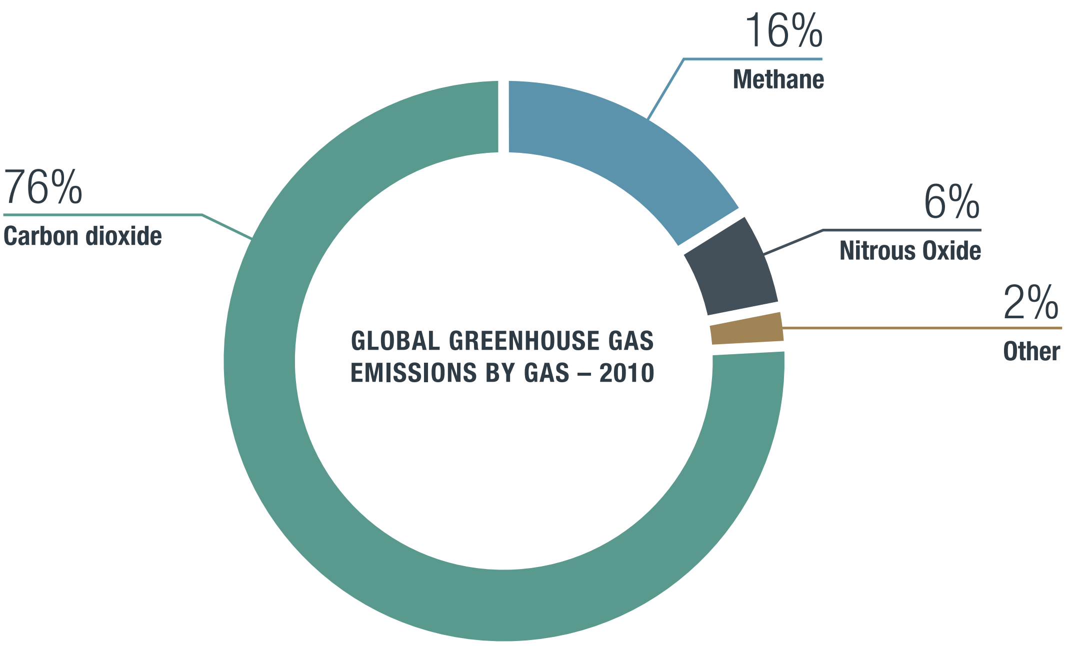
The concentration of nitrous oxide in the Earth's atmosphere has increased from 280 ppb in pre-industrial times, to more than 330 ppb in 2017.

Contributes to:
→ Anthropogenic greenhouse effect (even higher global warming potential than methane: it can trap almost 10 times more heat than methane)

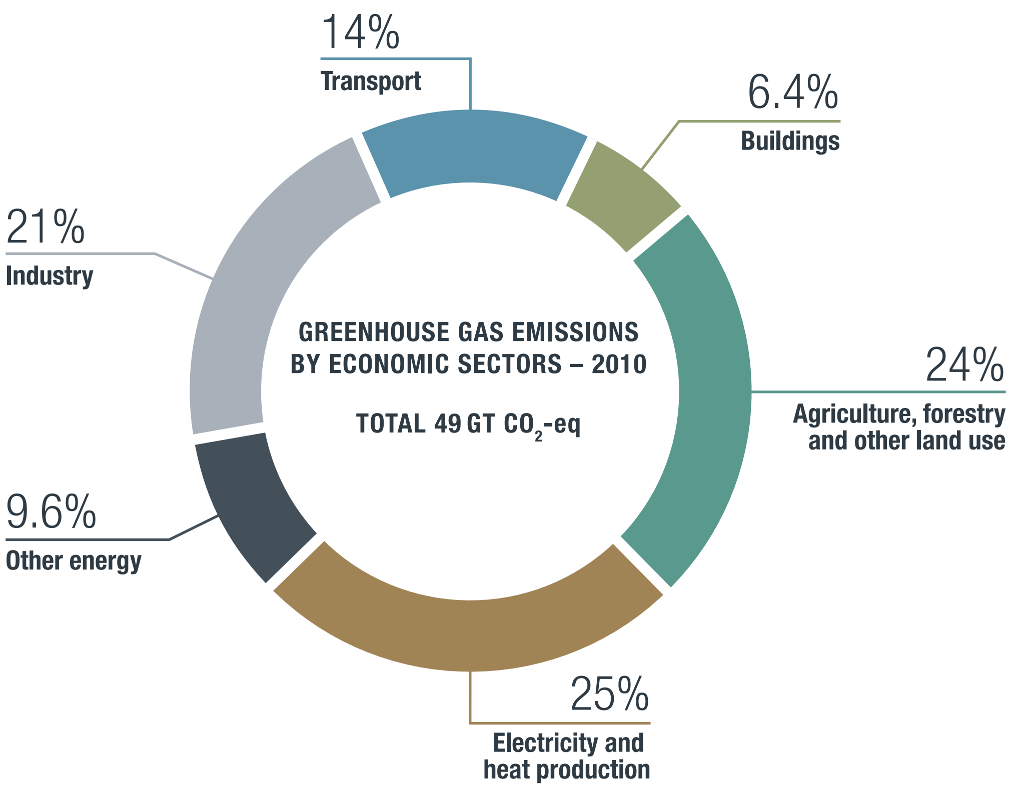
WORKSHEET B3.5

Look at the figures below and answer the following questions:

- Which gas contributes most to global anthropogenic greenhouse gas emissions?
- Which economic sectors (sectors of human activity) contribute the most to greenhouse gas emissions?



Source: adapted from https://www.epa.gov/ghgemissions/global-greenhouse-gas-emissions-data (data from IPCC – 2014 – details about the sources included in these estimates can be found in the Contribution of WG III to the AR5 of the IPCC).



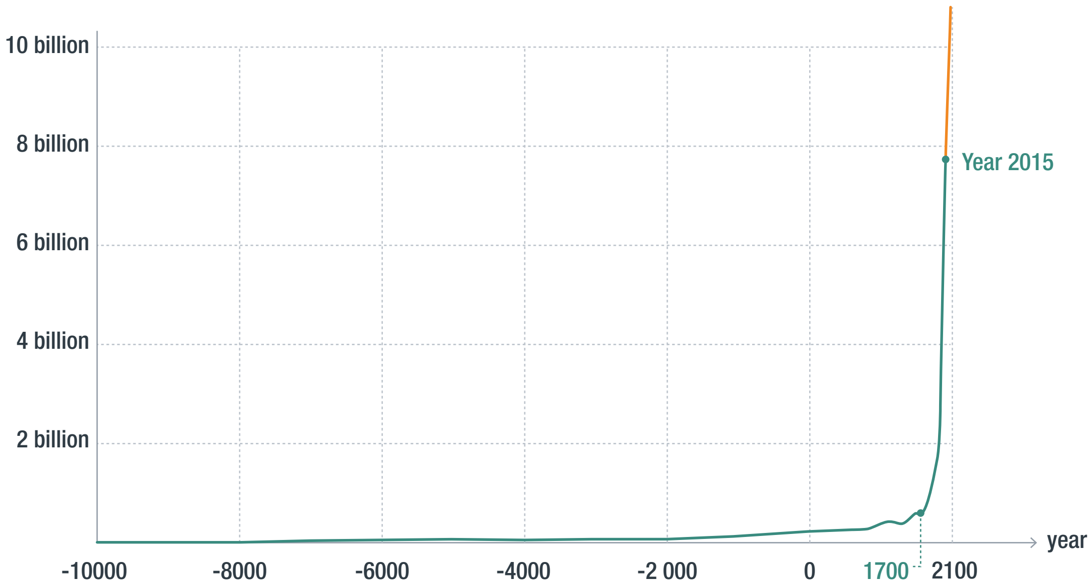
Source: adapted from IPCC AR5 WG3.

WORKSHEET B3.6

Technical progress since the industrial revolution is not only related to the steam engine, but also to unprecedented scientific, technological, economic and political changes affecting all sectors of human societies. All these developments have contributed to an unprecedented increase in the human population. More people and greater energy consumption have contributed to increased greenhouse gas emissions. Observe the two figures below and answer the following questions:

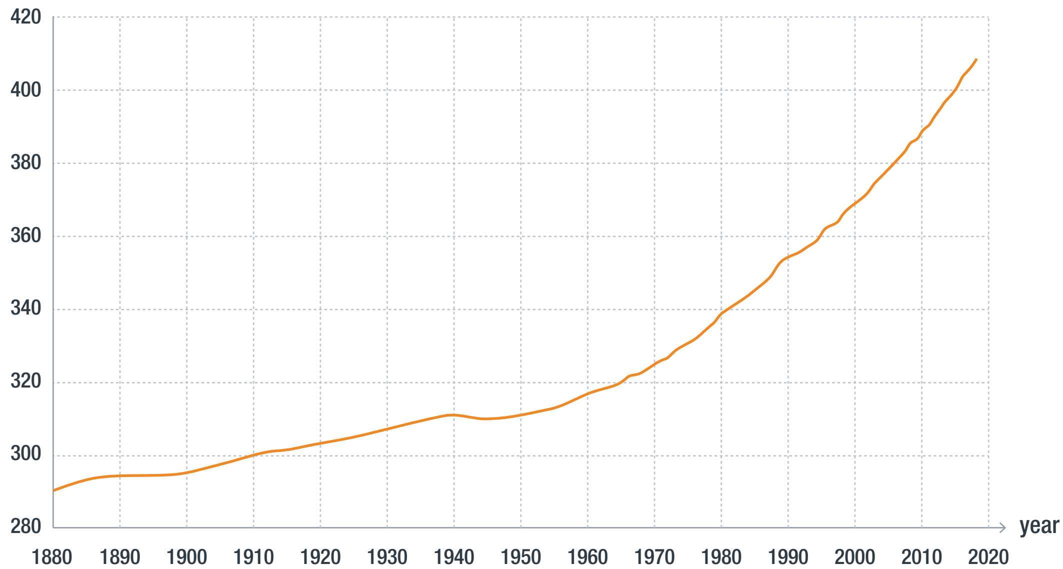
- How has CO_2 concentration in the atmosphere evolved since the industrial revolution?
- Name two factors that can explain this evolution.

WORLD POPULATION OVER THE LAST 12,000 YEARS AND UNITED NATIONS PROJECTION UNTIL 2100



Note: the years are represented according to the Gregorian calendar (years before 0 are years BCE – Before the Common Era – or BC – Before Christ).
Source: https://ourworldindata.org/world-population-growth#population-growth

GLOBAL AVERAGED CARBON DIOXIDE CONCENTRATION IN PPM



Source: NOAA – Earth System Research Laboratory – Global Monitoring Division (ftp://aftp.cmdl.noaa.gov/products/trends/co2/co2_annmean_mlo.txt)

SEQUENCE C

WHAT ARE THE CONSEQUENCES OF CLIMATE CHANGE ON THE OCEAN AND CRYOSPHERE?

The Earth is a complex system where everything is interconnected and in equilibrium. Therefore, climate change necessarily affects the whole system and its repercussions are very diverse.
In this sequence, six lessons are proposed to help students learn about and experiment on some of the most important consequences of climate change for the world's oceans and cryosphere. While directly affecting these systems, the impacts of climate change are also observed on key ecosystems and human communities and the issues involved are thus explored in these lessons. At the end of this sequence, the students will be able to understand causes and consequences of phenomena as diverse as sea level rise, cryosphere melting, ocean acidification, ocean heat uptake and marine currents.

LESSON LIST

◉ Core lesson ○ Optional lesson

LESSON C1
MELTING CRYOSPHERE AND SEA LEVEL RISE

MAIN SUBJECTS
Natural sciences

DURATION
~ Preparation: 5 + 10 min
~ Activity: 1 h 30

SUMMARY
The students carry out an experiment to determine that the melting of sea ice does not cause sea level rise, whereas the melting of ice on land does. Through a documentary analysis, students learn about the impacts of melting ice on freshwater supply.

KEY IDEAS
~ The cryosphere encompasses all areas of the Earth comprising frozen water.
~ An increase in the temperature of the atmosphere and the ocean leads to melting of the cryosphere.
~ 98% of the world's ice is contained in the polar ice sheets, formed by compacted snow.
~ Sea ice can be found in the Arctic as well as in the Antarctic. It is made of frozen water.
~ Permafrost is ground that has been frozen continuously for at least two years.
~ The melting of ice on land contributes to sea level rise, whereas the melting of sea ice does not.
~ The cryosphere is an important freshwater source for rivers in mid- and low-latitude mountains.

KEYWORDS
Cryosphere, sea ice, continental ice, ice sheets, glaciers, permafrost, melting, freshwater, sea level rise

INQUIRY METHOD
Experimentation

PREPARATION 5 + 10 MIN

MATERIALS

- **WORKSHEET C1.1** (one for the whole class);
- **WORKSHEET C1.2** (one for the whole class);
- **WORKSHEET C1.3** (one for the whole class);
- **WORKSHEET C1.4** (one for each group);
- **WORKSHEET C1.5** – for advanced students (one for each group);
- Ice cubes (3-4 cubes for each group);
- Large container: one for each group;
- Water;
- Heavy "waterproof" objects (pebbles, cobblestones): a few for each group working on continental ice (half of the groups).
- **Multimedia resources**: videos (sea level rise; glaciers) and multimedia activities (sea level rise). See page 182.

LESSON PREPARATION

1. **Prepare ice cubes the day before.**
2. Print **WORKSHEETS C1.1**, **C1.2** and **C1.3** (one for the whole class) and **WORKSHEET C1.4** (one for each group). The **WORKSHEET C1.5** can be used as an additional exercise by advanced students.
3. Download the videos from the OCE's website. See page 182.

TEACHER TIP
It is best to start this lesson before the lunch break, in order to leave enough time for the ice to melt during the break. If this is not possible, try to do the experiments described below in a warm place (or in the sun) in order to accelerate the melting.

INTRODUCTION 20 MIN

Start by asking the students: *Can you name some consequences of global warming?* Write the students' answers on the whiteboard. In general, students spontaneously mention sea level rise. We will focus on sea level rise in this lesson, and will come back to the other issues later.

PROCEDURE 40 MIN + BREAK + 20 MIN

PART 1 (40 MIN): CONTINENTAL VERSUS SEA ICE MELTING AND SEA LEVEL RISE

1. Ask the students: *Why do you think the sea level is rising?* Most students will think of the melting ice, but they do not distinguish between the melting of sea ice and the melting of continental ice. Show them **WORKSHEET C1.1** so they can see the difference.

2. Ask the students: *Where can we find large quantities of ice on Earth?* Show **WORKSHEET C1.2** to the class and discuss the different cryosphere reservoirs that exist on Earth. Write a definition of the word "cryosphere" on the whiteboard: **"The cryosphere encompasses all of the frozen water on Earth."** Glacier ice and ice sheets (in the Antarctic and Greenland) are formed on land from compacted snow, whereas sea ice (Arctic and Antarctic) is formed in the ocean. After looking at **WORKSHEET C1.3**, the students can also understand that icebergs and sea ice are different. Icebergs are made of freshwater and form on land, whereas sea ice is made of seawater and forms directly at the ocean's surface.

> **TEACHER TIP**
> One of the difficulties for students (and for most adults) is understanding the difference between sea ice (which is formed from frozen **seawater**) and icebergs (which are large pieces of **freshwater** ice that have broken off a continental glacier or ice shelf and float in the ocean).

3. Show **WORKSHEET C1.2** once more and ask the students: *What do you think: will the melting of all these different reservoirs contribute to sea level rise?* Answers will probably be very diverse. Ask: *Can you think of an experiment that will help us answer this question?* Help the students formulate the following question: *Do the melting of sea ice and the melting of ice on land both cause sea level rise?*

4. In groups, let the students think of an experiment that allows them to answer this question.

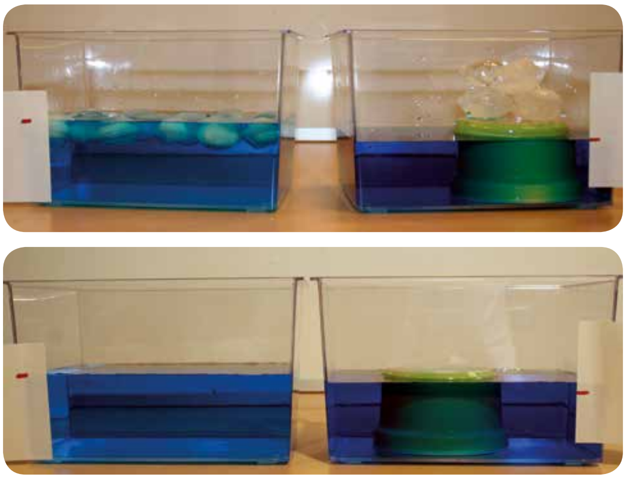
5. Once the protocol of the experiment has been discussed and approved by the whole class, the groups set up the experiment:

- They partially fill the container with water at room temperature. This water represents the ocean:
  - **Half of the groups** gently place the ice cubes in the water. The ice cubes represent sea ice.
  - **The other half** put a heavy object – representing a continent – at the bottom of the container, and then place the ice cubes on top of it. The ice cubes represent continental ice. The object should stick out of the water.

> **TEACHER TIP**
> Ask the students *How will you know whether the water level has risen or not?* Possible answers include: drawing a line on the container and attaching a ruler or a sheet of paper to the container.

- The water level must be marked after the ice cubes have been added.
- For the group working on sea ice: ensure there is enough water in the container, so that the ice cubes are not in contact with the bottom of the container (the sea ice should float).

The ice cubes placed in the water melt very quickly (within a few minutes), whereas those placed on the "continent" melt much more slowly (within a few hours).
This first observation helps to underline the vulnerability of sea ice: It melts faster than continental ice because it is in contact with seawater (which has a higher thermal conductivity than air). This is also the reason why you cool off faster in water than in air (for example, when you bathe in the sea).



Top: before ice melting. Bottom: after ice melting.

6. While the students are waiting for the ice to melt, they can take time to draw the experimental set-up and write down their observations.

7. When the ice cubes have melted, ask the students to compare their results. They will conclude that the melting of sea ice does not contribute to sea level rise, whereas the melting of continental ice does.

PART 2 (20 MIN): THE CONSEQUENCES OF CONTINENTAL ICE MELTING FOR FRESHWATER SUPPLY

8. Distribute **WORKSHEET C1.4** to each group and let them analyse it. With advanced students, you can work on the satellite image of **WORKSHEET C1.5**.

WRAP-UP 10 MIN

Hold a class discussion on the consequences of continental ice melting on the growth of plants and local resources (animals to hunt, agriculture, etc.), especially freshwater supply.
You can discuss other important uses of freshwater runoff from continental glaciers, such as hydropower production.

BACKGROUND FOR TEACHERS

Detailed information about the **cryosphere** and its different reservoirs is provided in pages 10-11 of the Scientific Overview. The services that the cryosphere (snow, ice and frozen ground) provides to humans are detailed on pages 12-13 of the Scientific Overview, and the changes observed in the cryosphere due to climate change are explained in pages 15-17 of the same section of this book. Hence, only three concepts that are key to this lesson are detailed below.

CONTINENTAL ICE AND SEA ICE ARE DIFFERENT

Continental ice is the ice on land, which comprises glaciers (in polar and mountain regions) and the Greenland and Antarctica ice sheets (where ice sits on land). It is formed by the slow accumulation of snow on land which is progressively compressed until it becomes ice. When the flow of a glacier reaches the ocean, large pieces of it may break off, becoming icebergs floating in the ocean. Continental ice is made out of **freshwater**.

Sea ice floats on the ocean and exists only in the Arctic and in the Southern Ocean, around Antarctica. Unlike continental ice, it is formed from frozen **seawater**. When seawater freezes, the salt cannot remain in the solid structure of the water (the ice) and is expelled into the surrounding seawater. This process contributes to a local increase in seawater salinity.

MELTING OF CONTINENTAL ICE CONTRIBUTES TO SEA LEVEL RISE, MELTING OF SEA ICE DOES NOT

By definition, continental ice sits on land. Hence, the resulting meltwater flows into the ocean, contributing to sea level rise.

Sea ice is already in the ocean. Part of it is above water (around 10% of its total volume), but most of it is submerged (around 90% of its total volume). The distribution of the emerged and submerged sea ice portions is due to the fact that the density of ice is about 90% the density of liquid water. This is one of water's unique properties, because solids are usually denser than the corresponding liquids. When the emerged portion of sea ice melts, it helps raise the sea level because it was initially out of the water. When the submerged portion of sea ice melts, it helps lower the sea level, because ice occupies a larger volume than liquid water (for the same amount of water, that is, for the same mass). Therefore, the two phenomena roughly compensate each other, which is why the sea level remains the same.

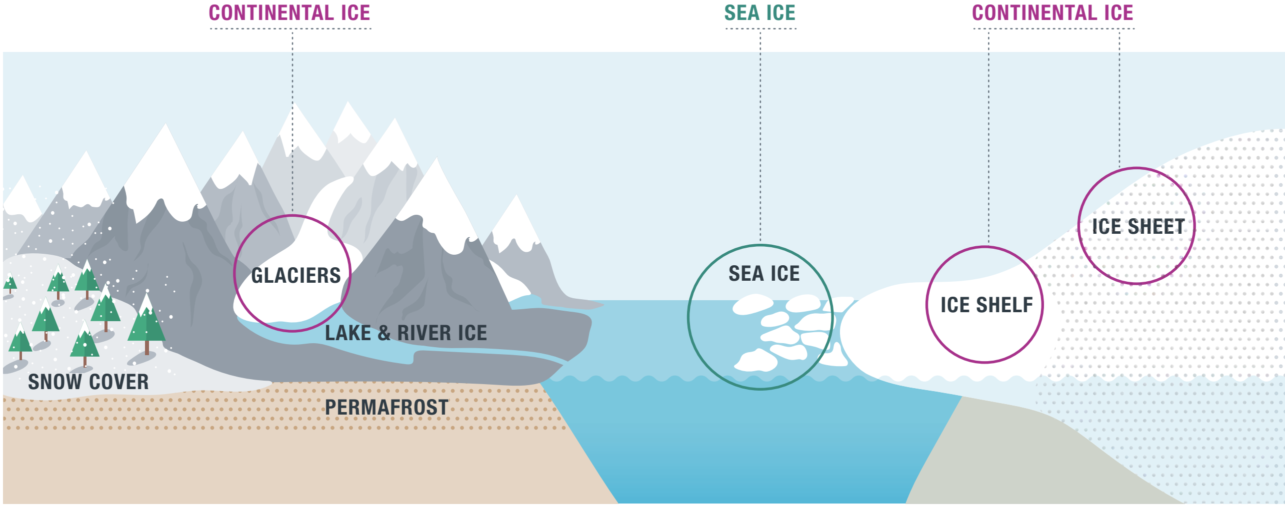
It can be mathematically demonstrated that the submerged volume of an ice cube (the portion of the ice cube below water level) corresponds to the total volume of water resulting from the melting of the ice cube. Therefore, the water level does not change with the melting of the ice cube. This simple demonstration, which can be done using four or five lines of calculation, is the result of two basic principles: mass conservation (the mass of the ice cube is equal to the mass of the volume of water produced by melting the ice cube) and buoyancy (in equilibrium, the weight of the ice cube is identical, in absolute terms, to the buoyant force, that is, to the weight of the volume of displaced water). Such an exercise can be given to high school students and was first demonstrated by Archimedes of Syracuse, in 250 BCE.

SEA ICE MELTS FASTER THAN CONTINENTAL ICE

Ice on water melts faster than ice on land, which has most of its surface in contact with air (rather than water). This is because heat transfer is much more efficient in water than in air, mainly due to the greater density of water. This greater density means that a higher number of molecules (of water) interact with the surface of the ice cube, improving the heat exchange process.

Another reason why Earth's sea ice is melting faster than continental glaciers is because it is just a few metres thick, while Greenland and Antarctica ice sheets are several kilometres thick.

WORKSHEET C1.1



Adapted from Fig. 4.25 of the IPCC Working Group I report (2013).

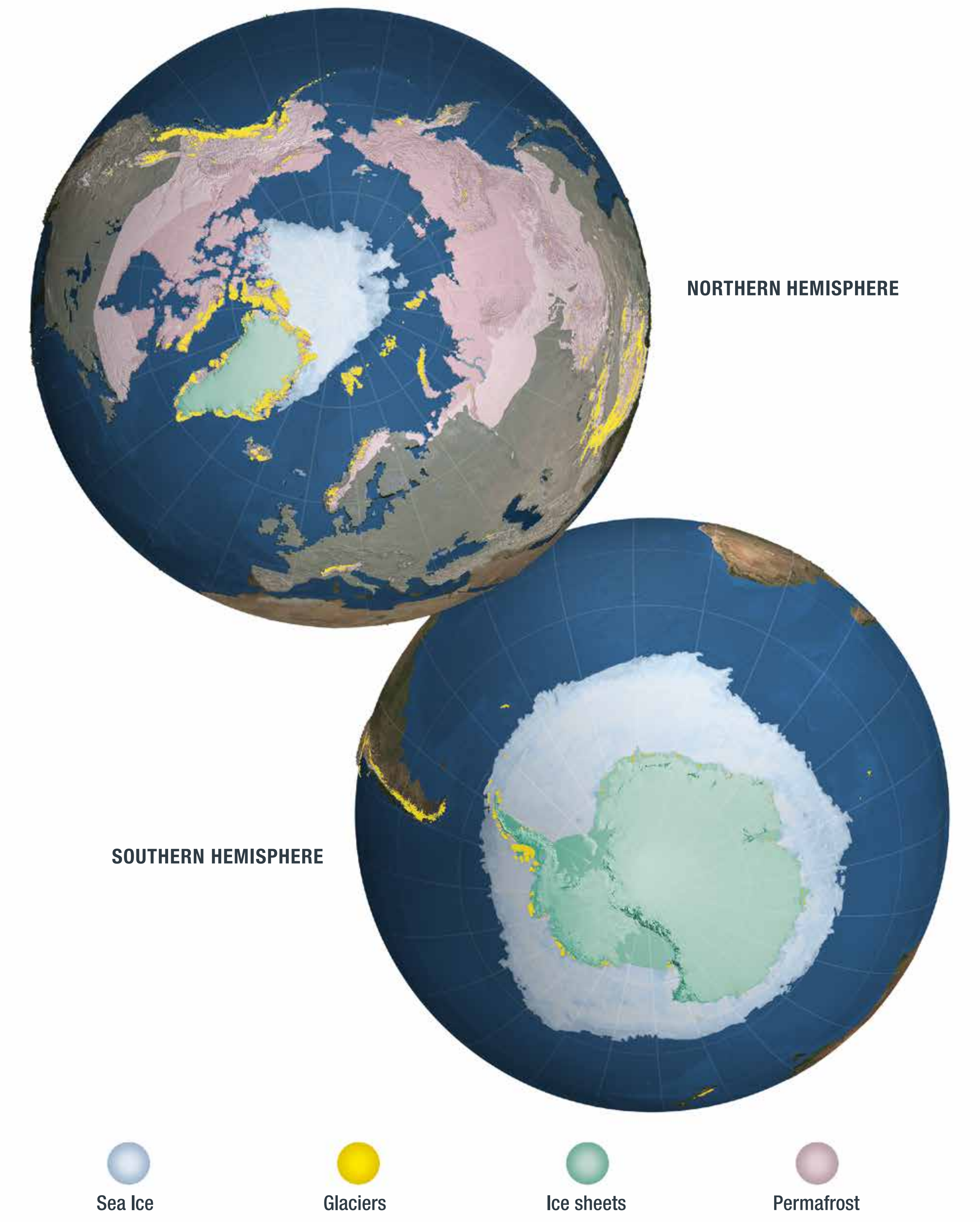
The Southern Patagonian Ice field is the largest expansion of continental ice in the southern hemisphere other than Antarctica and feeds multiple glaciers.

Antarctica ice sheet, near Adélie Land. Antarctica ice sheet is the largest expansion of continental ice on Earth.

Sea ice floating on the ocean north of Spitzbergen.

WORKSHEET C1.2

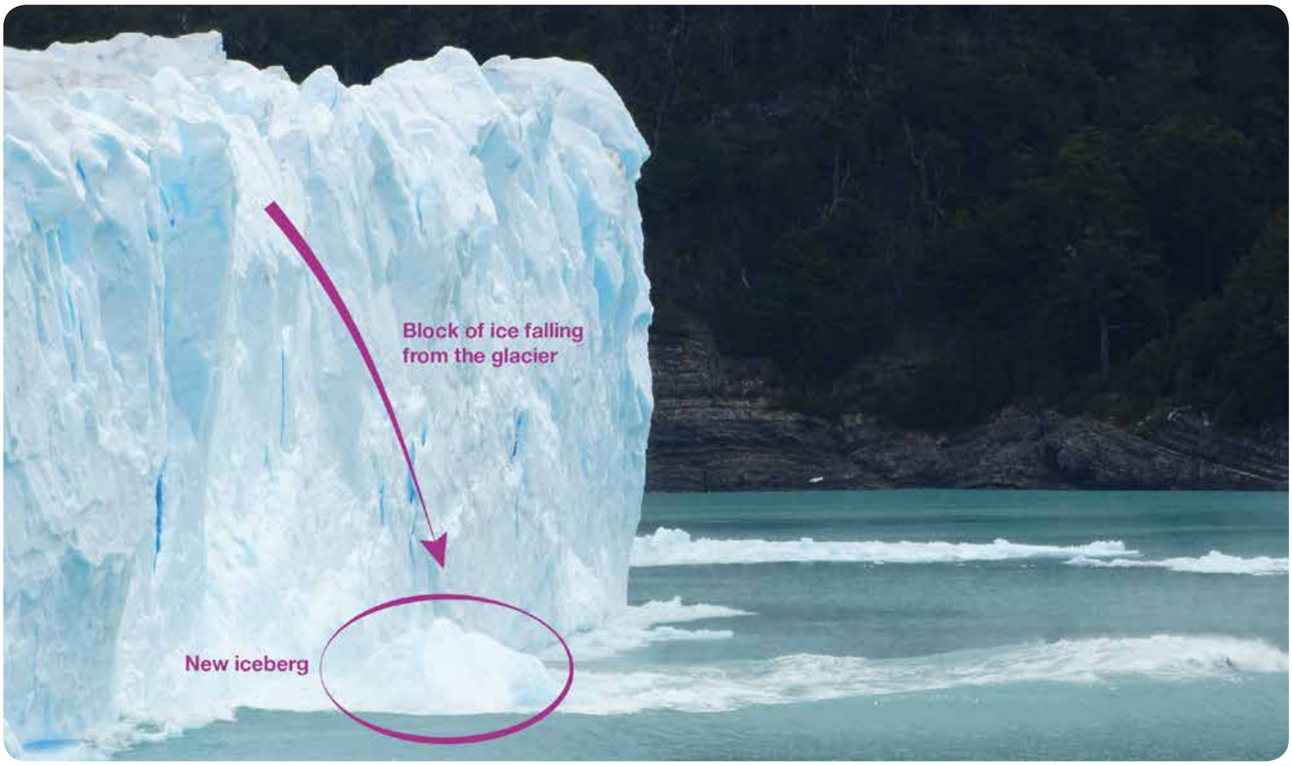
The cryosphere is all the frozen water on Earth. In the world, there are different reservoirs of “frozen water”. The following satellite images show these different cryosphere reservoirs.



Source: adapted from “NASA / Goddard Space Flight Center Scientific Visualization Studio”. https://svs.gsfc.nasa.gov/3885

WORKSHEET C1.3

Sea ice – the ice is formed from frozen seawater, directly at the ocean's surface.



Iceberg – block of a continental glacier (which sits on land) that falls into the ocean.

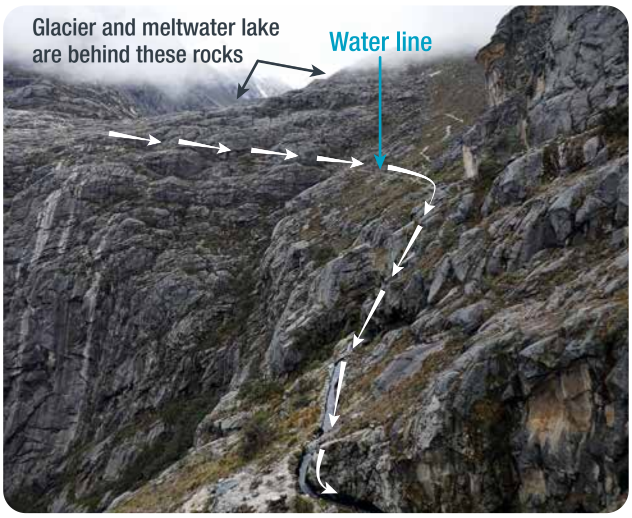
WORKSHEET C1.4

The figure below shows an example of a glacier in Argentinian Patagonia. The white arrows point to the water flowing from the glacier.

➔ Where do you think it is flowing to?

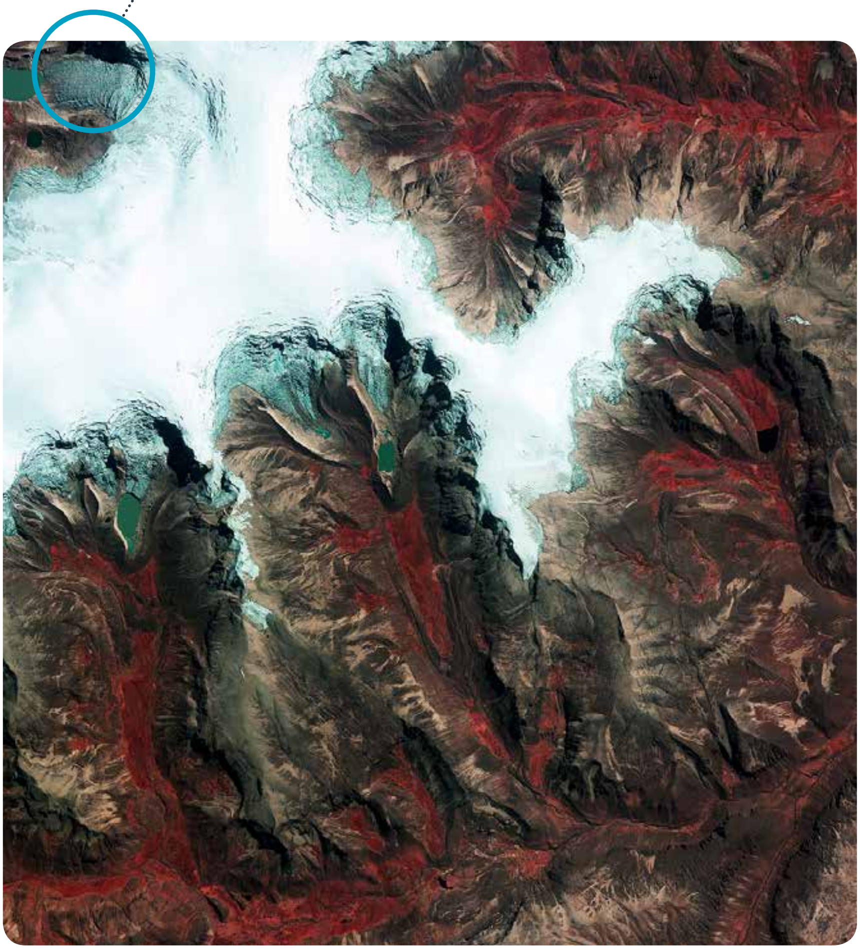
The figure on the left below shows the valley downstream of the glacier that was represented in the figure above. Sometimes, villagers even build channels to redirect the water directly from the meltwater lakes, as you can see in the figure on the right below. Notice that the water is milky and flows along a green valley, while the mountains on both sides of the valley are dry.

➔ Why do you think the valley is so green?



WORKSHEET C1.5

The following figure shows a satellite image of the largest ice cap in the tropics: the Quelccaya ice cap in the Peruvian Andes. The image was captured on 29 June 2009 by the Korean Kompsat-2 satellite. The colours are false: vegetation appears in red.



- Since the 1970s, the Quelccaya ice cap has been shrinking due to rising temperatures. It has already lost over 20% of its area. In this dry region, the communities living in the valleys downstream rely on the Quelccaya ice cap as a source of drinking water and electricity.
- As seen above, the vegetation (in red) grows mainly in the valleys and along water runoffs.
- This map shows the "glacier shape" of the valleys, carved by ancient glaciers before their retreat.
- According to some estimates, the ice cap could vanish within a few decades, depleting water supplies for millions of people as well as for local ecosystems.
- In the upper-left corner of the image, is the Qori Kalis Glacier, the ice cap's main outlet. This glacier is retreating – and this retreat has accelerated in recent years. It has already lost about 50% of its total length since the 1960s. Glacier melting led to the formation of a lake in the late 1980s. The lake has grown over the years, and further smaller lakes have formed around the ice cap.

LESSON C2
THERMAL EXPANSION OF THE OCEAN AND SEA LEVEL RISE

MAIN SUBJECTS
Natural sciences

DURATION
~ Preparation: 15 min
~ Activity: 1 h – 1 h 30

SUMMARY
The students carry out an experiment to ascertain how the thermal expansion of seawater contributes to sea level rise. A documentary analysis allows them to discuss the different impacts of sea level rise (on ecosystems and human communities).

KEY IDEAS
~ As the temperature of the atmosphere rises, so does the temperature of the ocean.
~ The global mean sea level has already risen around 15 cm since 1900. According to different scenarios, it will rise further – by between 25 cm and over 1 m by 2100.
~ Water, like all liquids, expands in volume when heated. This is called thermal expansion, and is one cause of sea level rise.
~ Due to sea level rise, coastal regions will increasingly be flooded, leading to coastal erosion.
~ In 2010, about 30% of the global population lived less than 100 km from the ocean.
~ Coastal ecosystems are at risk of being altered or destroyed.
~ Saltwater may seep into groundwater.

KEYWORDS
Thermal expansion, seawater, sea level rise, flooding, coastal erosion, coastal ecosystems, coastal communities

INQUIRY METHOD
Experimentation and documentary analysis

PREPARATION 15 MIN

MATERIALS
WORKSHEETS C2.1, C2.2 and **C2.3** (per group for advanced students).
For each group:
- A bottle or laboratory flask;
- A straw or pipette;
- A stopper;
- Coloured water (previously cooled in the refrigerator).

BACKGROUND FOR TEACHERS

Matter, whether in solid or liquid state (with the exception of water in certain temperature ranges), increases its volume when heated (**thermal expansion** or dilatation). As explained in detail on pages 14 and 16 of the Scientific Overview, the ocean has already absorbed more than 90% of the extra **heat** generated by global warming. The volume of the ocean is therefore increasing due to thermal expansion, which leads to **sea level rise. Around half of the sea level rise observed since the 1990s is due to the thermal expansion of seawater** (the other half is due to continental ice melting, as seen in lesson C1).
Sea level rise has multiple consequences for both **human settlements** and **coastal ecosystems.** Page 18 of the Scientific Overview provides detailed information on the challenges that human populations living by the coast are already facing and will continue to face due to sea level rise (in 2010, about 30% of the global population lived less than 100 km from the ocean).
Coastal ecosystems are driven to retreat inland when possible, or disappear when retreating is impossible: in coastal zones that have been artificialised due to human settlements, coastal ecosystems are "squeezed" between the rising sea level and human infrastructures and can ultimately disappear. This lesson's worksheet provides an insight into three important types of coastal ecosystems (**mangroves, salt marshes** and **seagrass meadows**), which provide us with numerous **ecosystem services** and are among the first at risk due to sea level rise.

Multimedia resources: multimedia activity (sea-level rise). See page 182.

LESSON PREPARATION

1. Print one copy of **WORKSHEETS C2.1** and **C2.2** for each group, and one copy of **WORKSHEET C2.3** for each student.
2. Refrigerate the coloured water ahead of time.

INTRODUCTION 20 MIN

Go over the conclusions of lesson C1: The atmosphere and the oceans are warming up, and the melting of continental ice leads to sea level rise.

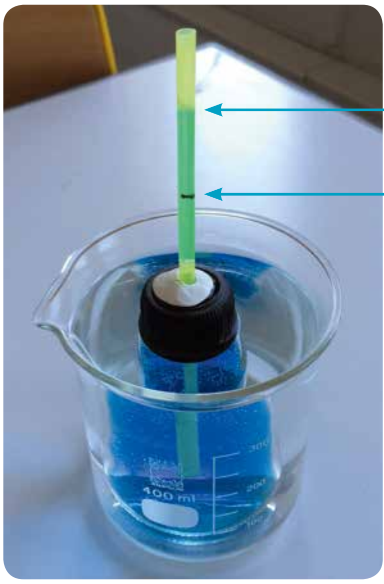
Explain to the students that the melting of continental ice only accounts for half of the sea level rise observed since the 1990s. Ask the class: *What else could cause sea level rise?* It is not very likely that the students will mention the expansion of water. You might want to show the students an analogue thermometer and ask them to explain how it works (heat causes the liquid in the small tube to expand, and so the level of the column of liquid rises).

PROCEDURE 1 H

PART 1 (30 MIN): THERMAL EXPANSION OF SEAWATER

1. Show the students the available material and ask them to imagine how they could test whether warming seawater causes the sea level to rise. Depending on the age of the students, you may wish to prepare the bottle + stopper + straw set in advance.

2. The students perform the experiment that they have proposed.



Example of a bottle of water being heated using a bain-marie. Watch the water column in the straw.

TEACHER TIP

- If the bottle is made of plastic, the water will also rise up in the straw if the bottle is squeezed (not only if the water is heated). It is therefore best to use a glass bottle. Moreover, glass conducts heat better than plastic, which is very useful here.
- The bottle needs to be filled up to the rim (a little bit of the coloured water should rise into the straw when it is inserted through the stopper into the water). The seal between the straw and the stopper needs to be watertight. You can use modelling clay or chewing gum.
- There are several possible ways of warming the water contained in the bottle, like holding it in your hand, placing it on a heater or in the sun. The most effective method is to put it into a container filled with hot water (the water does not need to be boiling – a temperature of 40°C is more than enough). Warming the container with the hands is an interesting option, because it shows the students that even a slight temperature variation has a visible effect.
- The colder the water in the bottle at the beginning of the experiment, the more apparent its expansion will be. It is therefore a good idea to fill the bottle with chilled water, rather than with water freshly taken from the tap.
- With this setup, even a small change in the water's volume can be made visible.

PART 2 (30 MIN, FOR ADVANCED STUDENTS): THE CONSEQUENCES OF SEA LEVEL RISE

3. Give the students **WORKSHEET C2.1, C2.2** and **C2.3** to analyse and answer the questions. When they are done, discuss the different consequences of sea level rise (coastal erosion, destruction of coastal ecosystems, impacts on coastal communities' livelihoods and on tourism). Some populations will have to leave their homes and migrate.

WRAP-UP 10 MIN

Discuss the conclusions of the activities:

- Seawater expands when heated. It is important to contextualize the experiment to ensure that the students have understood that the water level in the straw represents the sea level in the oceans.
- Sea level rise is mainly due to the melting of continental ice (see lesson C1, page 67) and to the thermal expansion of the oceans. Both phenomena are consequences of climate change.

For advanced students:

- Sea level rise will cause problems in coastal ecosystems and communities.
- Sea level rise is not constant and different locations will experience different rates of sea level rise.

WORKSHEET C2.1

Bangladesh is a country in South Asia. The Ganges and Brahmaputra rivers, and their delta, encompass a large part of the country. The delta is a very fertile region. Most of the country has an altitude of less than 12 m above sea level. Bangladesh has one of the highest population densities in the world, with over 160 million people living there today.

Altitude

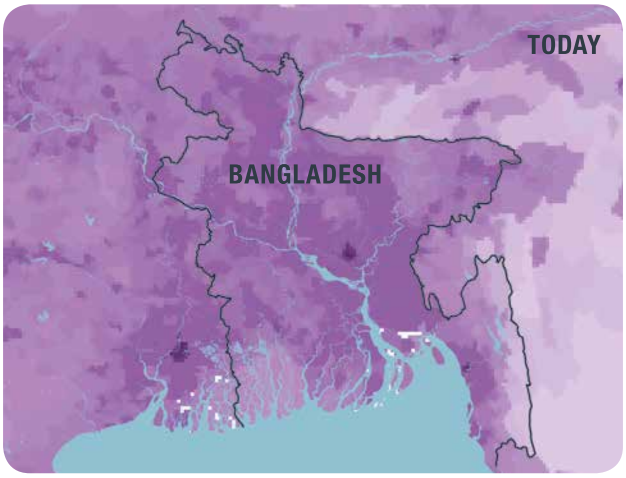
Deep waters · Shallow waters · < 0m · 0-3 m · 3-10 m · 10-70 m · > 70 m

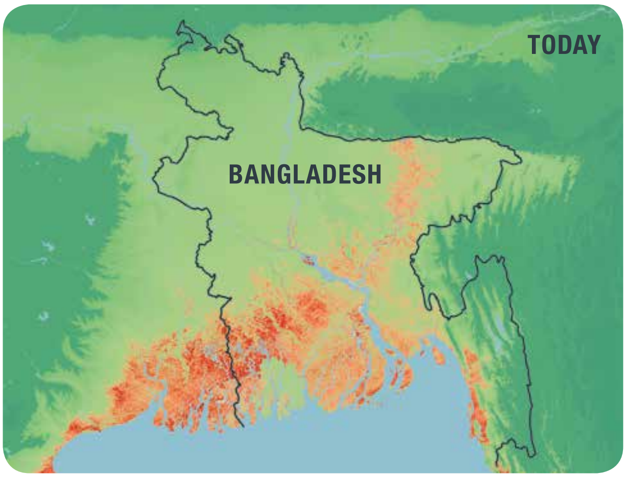
Look at the image on the right:

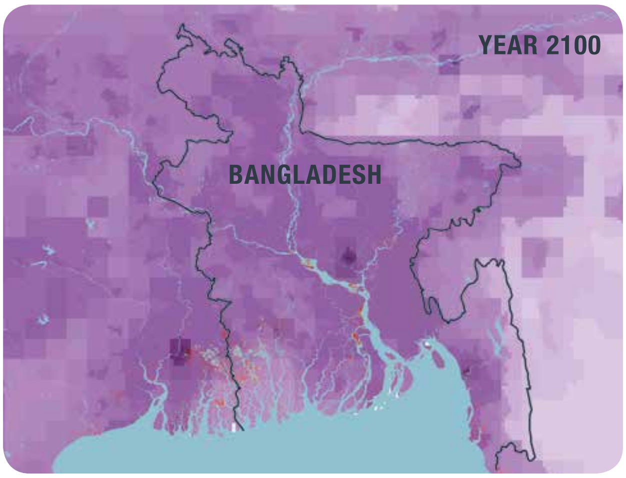
➔ **Which region of Bangladesh has the lowest altitude?**

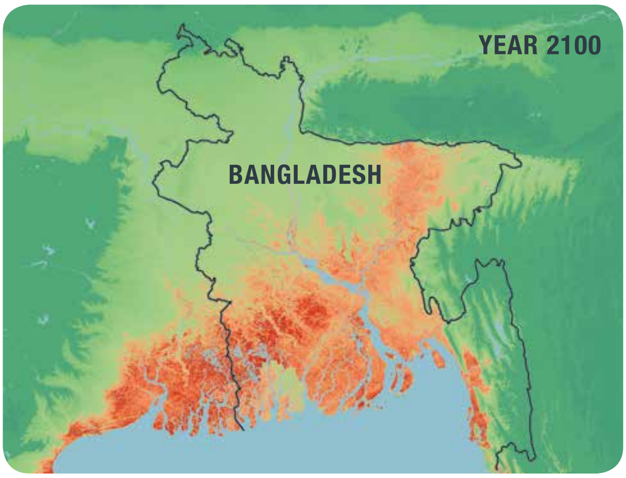
Look at the pictures below:

➔ **Which region of Bangladesh has the most inhabitants?**
➔ **What is the difference between the current population and the population expected in 2100?**
➔ **Which consequences of climate change will affect people living in Bangladesh the most?**
➔ **How will the risk of flooding change between today and 2100?**









Population density (hab/km²)

0-10 · 10-100 · 100-1M · 1M-10M · >10M

... in flooded areas (hab/km²)

0-10 · 10-100 · 100-1M · 1M-10M · >10M

Flood risk

High risk · Moderate risk · Safe · At altitude

Note: “Today” corresponds to a year between 2000 and 2015, depending on the available data.

WORKSHEET C2.2

Read the cards describing the different coastal ecosystems.

Why are these ecosystems so important? What is their importance for local communities? List the reasons.

MANGROVES

Mangroves are trees and shrubs that live in the coastal intertidal zone. These trees thrive in salty or brackish water, in areas with low-oxygen soil. Mangrove forests only grow along tropical and subtropical coasts.

Mangrove forests protect the coastline by buffering wave action and reducing coastal erosion. Their intricate root system also makes mangrove forests attractive to fish and other organisms seeking food and shelter from predators. Mangroves have a high capacity for absorbing carbon dioxide from the atmosphere, which they can store in the soil beneath them.

SALTMARSHES

Saltmarshes occur in temperate and arctic regions. Their grasses, herbs and shrubs grow in the intertidal zone, frequently near estuaries, in salty or brackish water. Saltmarshes are coastal wetlands that are regularly flooded at high tide. The soil therefore tends to be muddy and with very little oxygen. Saltmarshes protect the coastline by buffering wave action and trapping sediments. They reduce flooding by slowing and absorbing rainwater. They function like filters and clean chemical pollutants from the water. They are an important habitat, providing shelter, food and nesting grounds to birds. Saltmarshes also sequester and store CO_2 from the atmosphere.

SEAGRASS MEADOWS

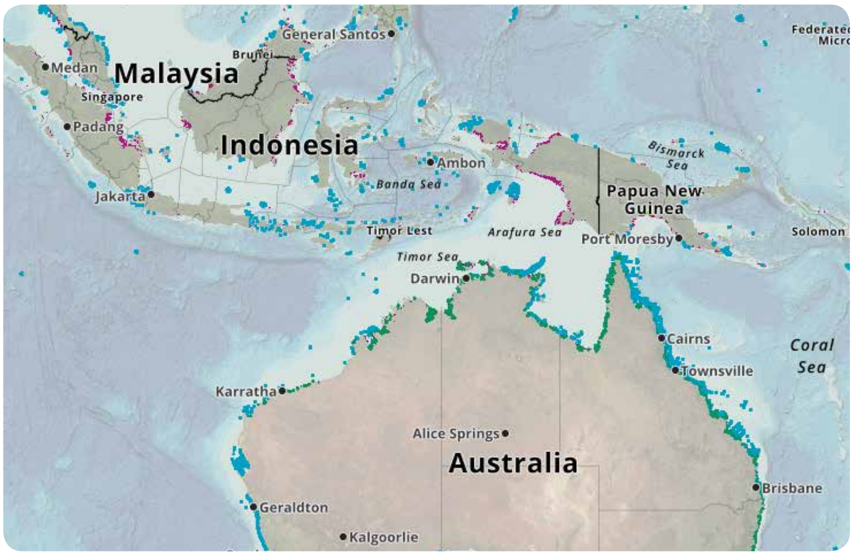
Seagrasses, often confused with seaweed, are actually plants with roots and leaves that can even produce flowers and seeds. They can settle in muddy, rocky or sandy soils. They are found in shallow salty or brackish waters, from the tropics to the Arctic. They can form dense underwater meadows, sometimes so large that they can be seen from space. Seagrass meadows provide protection against coastal erosion. They can store CO_2 in their roots and soil and are good filtering systems. They are home and provide food to a great community of animals.

Note:
Intertidal zone is a zone that is submerged during high tide and emerged during low tide.
Brackish water is a mix of seawater and freshwater that is saltier than freshwater, but less salty than seawater.

WORKSHEET C2.3

Observe the following maps showing the north coast of Australia, as well as the coasts of Papua New Guinea's and Indonesia.

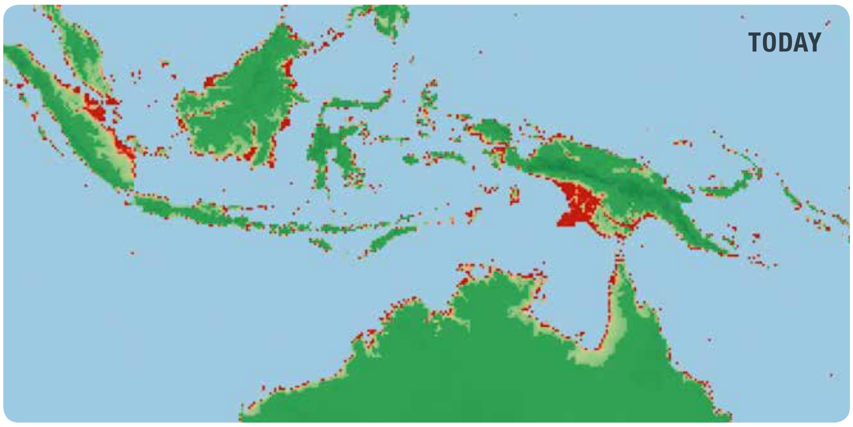
- What do you notice about the distribution of mangroves, saltmarshes and seagrass meadows along theses coastlines?



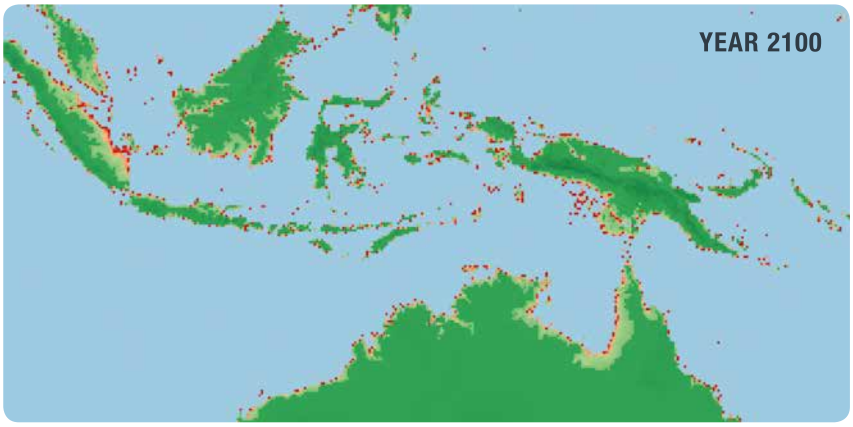
Distribution of ● Mangroves ● Saltmarshes ● Seagrass meadows
Source: Adapted from UNEP Ocean Data Viewer – http://data.unep-wcmc.org/datasets

Now, look at the risk of flooding along the same coastlines today and at the risk associated with future sea level rise by the year 2100.

- Are there more or less flooded regions along coastlines?
- In flooded regions, are there zones with important coastal ecosystems (mangroves, saltmarshes or seagrass meadows)?
- What do you think will happen to these coastal ecosystems?
- How do you think this may affect local communities which depend on these ecosystems?



Flood-risk map for the year 2000.



Flood-risk map for the year 2100 based on one possible future greenhouse gas emissions scenario.

● High risk ● Moderate risk ● Safe ● At altitude

Note: "Today" corresponds to a year between 2000 and 2015, depending on the available data.

LESSON C3
THE “WHITE” CRYOSPHERE AND ITS ALBEDO

MAIN SUBJECTS
Natural sciences

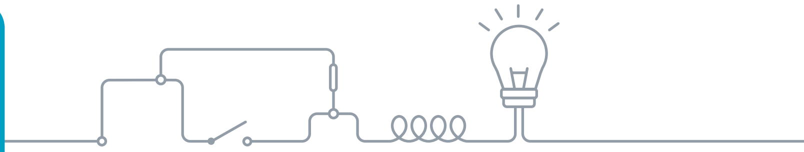
DURATION
- Preparation: 20 min
- Activity: 1 h 30

SUMMARY
The students debate the role played by sea ice in the Earth’s climate and carry out an experiment to understand the importance of the cryosphere as a surface with a high albedo. This lesson also provides an opportunity to discuss climate system feedbacks.

KEY IDEAS
- Due to its white colour, the cryosphere reflects most incoming solar radiation. It therefore regulates the amount of energy absorbed by the Earth.
- The capacity of a surface to reflect solar radiation is called albedo.
- Without the cryosphere, the temperature of the Earth's surface would be higher.
- As the cryosphere melts, the Earth’s overall albedo is decreasing, which leads to additional warming. The surface covered by ice is shrinking faster every year. This initiates a dangerous cycle, called a positive feedback.
- In the climate-ocean-cryosphere system there are many feedback loops (both positive and negative) that are very hard to stop once set in motion.

KEYWORDS
Cryosphere, reflection, albedo, additional warming, feedback loop

INQUIRY METHOD
Experimentation and documentary analysis



PREPARATION 20 MIN

MATERIALS
For each group:
- **WORKSHEET C3.1**;
- 1 white container or a container with white-coloured ink;
- 1 blue container or a container with dark-blue-coloured ink;
- 1 light bulb (at least 60 W, if possible, 100 W; no energy-saving lamps, use incandescent or halogen light bulbs), mounted on a support that can be fixed and tilted towards the table. Note: if the weather is sunny, the light bulbs may not be necessary – the experiments can be carried out in the sun.
- Thermometer.

Multimedia resources: video (sea ice and albedo). See page 182.

LESSON PREPARATION
1. Print or project **WORKSHEET C3.1**.
2. Download video from OCE’s website. See page 182.

INTRODUCTION 20 MIN

Start this session by showing the satellite image of the Arctic Ocean in **WORKSHEET C3.1**. The difference between the sea ice extent in 1979 and 2015 is noticeable. Ask the students: *What does the image show? What are the differences between the two maps?* They will observe that the white surface of the sea ice is retreating and being replaced by ocean, which has a much darker colour.

Recall lesson C1 on the melting cryosphere. We have learned that sea ice does not contribute to sea level rise.
Now, ask the students: *Why do we care about sea ice retreat if it does not contribute to sea level rise?* Students generally come up with the polar bear being threatened because its hunting habitat is shrinking. Polar bears are endangered due to the retreat of sea ice. The students will have identified the areas covered by ice because of their white colour, whereas the surrounding ocean is dark. Ask the students: *Why is the colour of the ice important? Do you think that the difference in colour between the ice and the ocean is important? Why? Does the ice or the ocean take up more heat?*

PROCEDURE 50 MIN

1. After the students have shared their hypotheses, ask them how they could check them. Encourage them to carry out an experiment. Two examples of experiments are suggested:

- Place the same quantity of water in two identical containers (with lids preferably) – one painted white (like the ice), the other one painted dark blue (like the ocean). Another possibility is to colour the water directly by mixing it with white or dark blue ink. Place the containers in the sunlight or under a light bulb. Measure the water temperature in the two containers.

- Carry out a similar experiment using two fabrics with different colours. You can, for example, measure the temperature under a white and a black T-shirt placed in the sun or under a lamp.

(A) Experiment using two containers with coloured water.

(B) Experiment using two fabrics of different colours.

2. The students read and write down the temperature values – for example, every 5 minutes, for approximately 20 minutes. Ask the students: *Can you predict what will happen as time goes by?*

3. During the 20 minutes, ask the students to draw two plots (one for the dark blue container and one for the white container) showing the change in temperature. By comparing the two plots, they will see that the temperature of the dark blue container increases faster than that of the white container. In the end of the experiment, the final temperature is higher for the dark container.

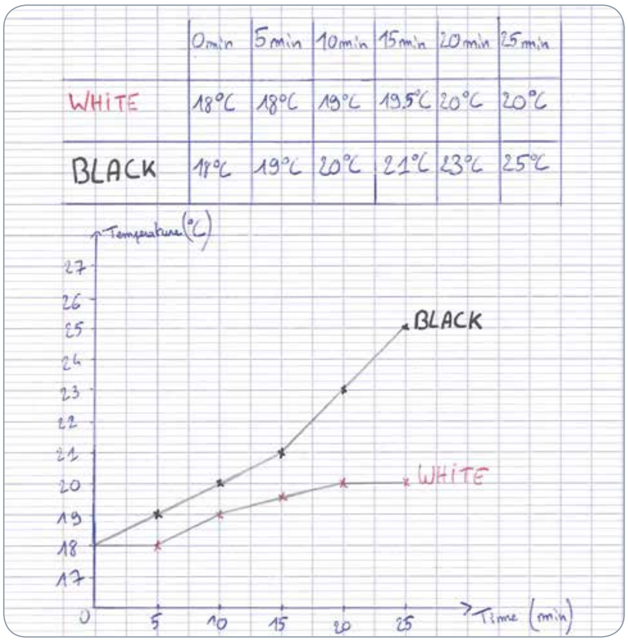
4. Discuss the results with the students. Ask them: *Would you prefer to wear a white or a black T-shirt on a hot and sunny day?* The students will find more connections between the findings of the experiment and their everyday experience. For example: *What happens if a car is parked in the sun in summer? Does the colour of the car or the seats make a difference?*

BACKGROUND FOR TEACHERS

As discussed in pages 8-11 of the Scientific Overview, the equilibrium temperature at the Earth's surface is highly dependent on the solar energy that reaches our planet. In lessons B1 and B2, we saw that the incoming radiation absorbed by the surface of our planet is partially emitted back as infrared radiation. However, not all incoming radiation is absorbed by the Earth's surface; part of it is directly reflected back to space.

The colour of the Earth's surface is not uniform; just think of oceans, snowy mountain tops, forests and sandy beaches. The whiter the surface, the more solar radiation it reflects back to space. **This whiteness is measured by a quantity named albedo.** Ice and fresh snow have a high albedo (from 40% to 80%), while the darker Arctic Ocean water has a low albedo (< 10%). When whitish ice permanently melts on large sea surfaces, the darker surface of the new open ocean absorbs more energy. The ocean warms more, which leads to more melting, hence more open ocean, etc. This amplification effect is called a **positive feedback**, the phenomenon being self-accelerating.

The climate system has multiple feedbacks, both positive (acceleration of change) and negative (slowing of change). Through these feedbacks, small changes to a few components of the climate system can have a major impact and destabilize the current equilibrium of the entire system.



Plots showing the change in temperature in the two containers used in experiment (A) on the previous page.

WRAP-UP 20 MIN

Write the word “albedo” on the whiteboard and tell the students that ice has a greater albedo than seawater. Ask them to try to define the word “albedo” given what they have observed. The students could come up with phrases like: Something has a high albedo when it reflects sunlight well.

Sum up the results of lesson C1: large ice surfaces (ice sheets, sea ice and glaciers) are melting because of climate change. Ask the students: *Given what we have just seen with light and dark containers, what might be the consequences of ice melting? What is so special about ice?* At this stage, the students will understand that the total or partial retreat of sea ice leads to oceans becoming warmer.

The discussion must underline the existence of a **positive feedback loop**: the warmer the temperature of the atmosphere, the warmer the temperature of the ocean, the more ice melts and the more the albedo is reduced. This in turn leads to an increase in temperature in the atmosphere, and so on and so forth. You can have the students draw this loop on the whiteboard and discuss that there are many different feedbacks in the climate-ocean-cryosphere system which strongly influence the Earth's climate.

In this lesson, the albedo effect was discussed for melting sea ice, but melting glaciers and ice sheets have a high albedo too: as ice/snow melts, the colour changes from white to the colour of the rock/soil beneath, warming the surrounding cryosphere and increasing melting. In the Andes and some parts of Europe, like Switzerland, communities cover some glaciers with white blankets to reduce melting during summer.

TEACHER TIP

The students may ask if global warming will result in more water evaporation, and hence more clouds (which are white when seen from space), which would lead to global cooling due to increased albedo. Indeed, this is what we call a negative feedback: a mechanism that counteracts the initial phenomenon (more evaporation → more clouds → greater albedo → lower temperature → less evaporation).
It is the balance between the climate system's positive and negative feedbacks – some of which may still be unknown – that will determine the evolution of the future climate. Climate models try to take into account all of these feedbacks.

OPTIONAL EXTENSION

Study the impact of the melting sea ice on polar ecosystems and indigenous populations.

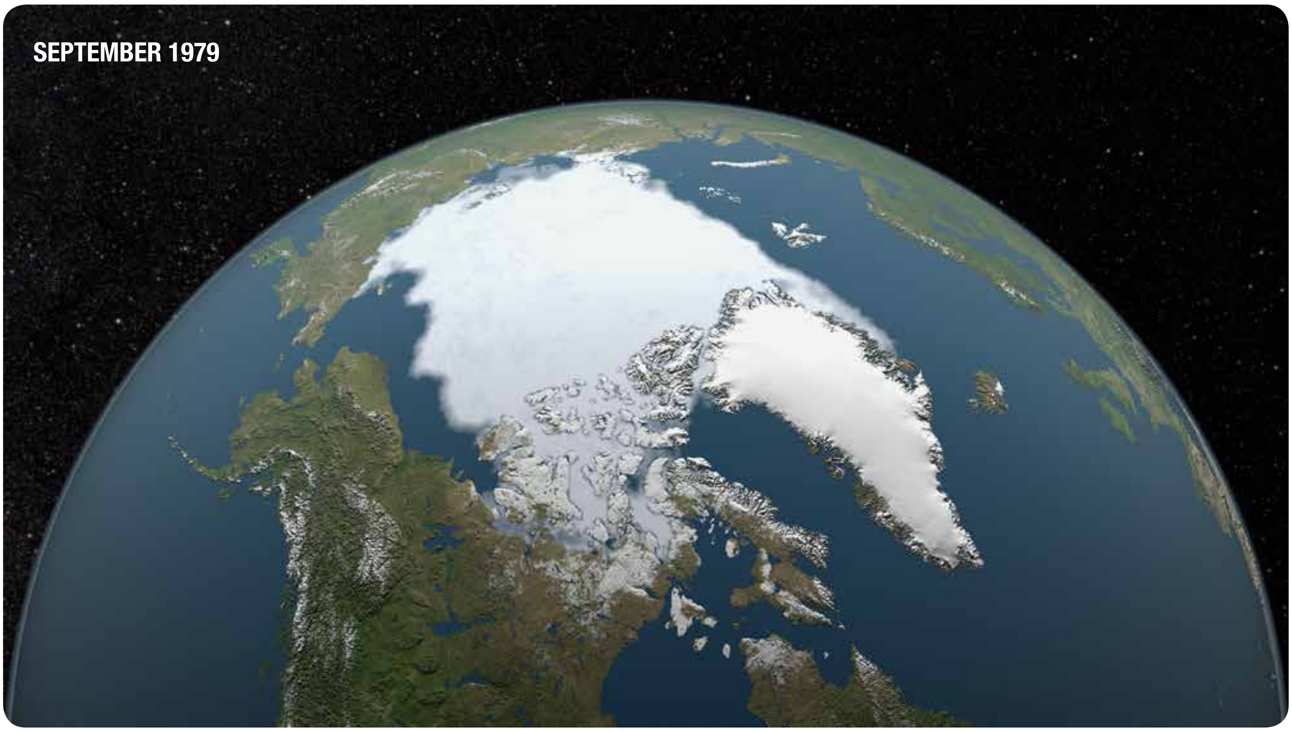
PROGRESSION TIP

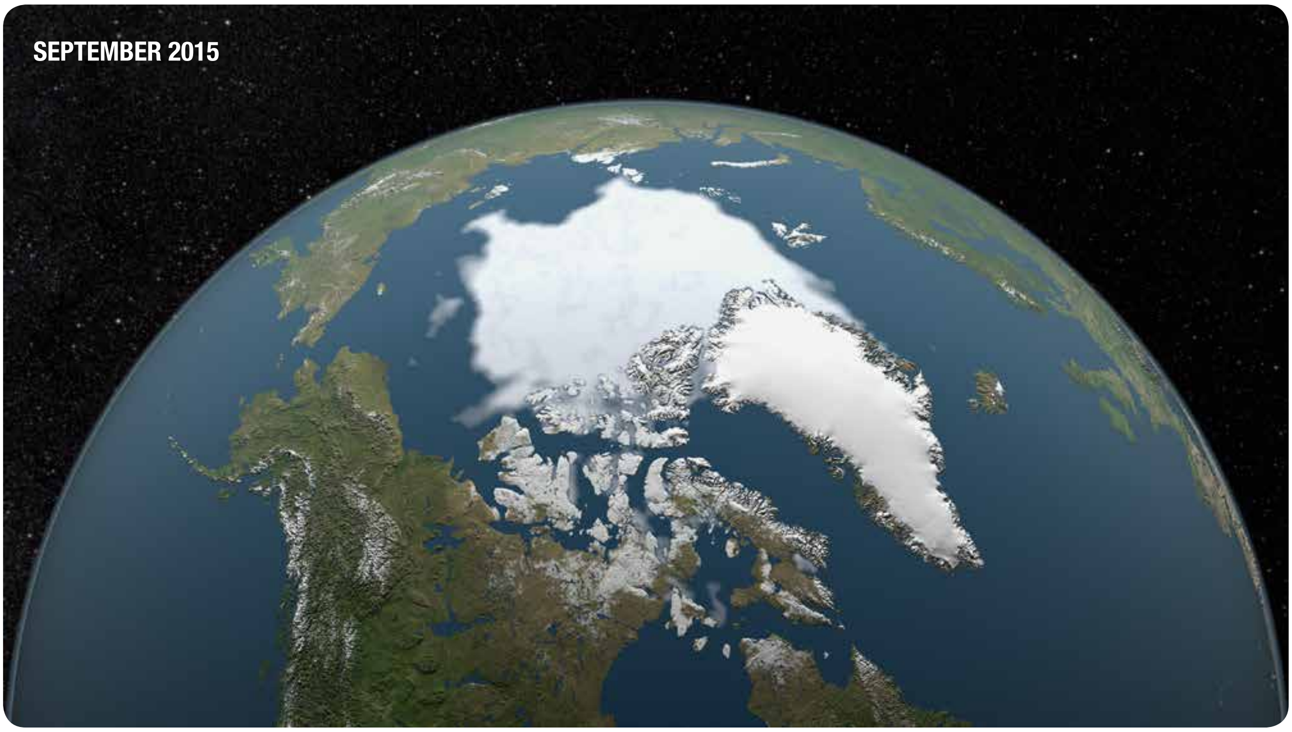
See lessons D2 (page 102) and D3 (page 123).

WORKSHEET C3.1

The two images show the Arctic sea ice extent during the month of September, in the year 1979 and in the year 2015.

➔ **What can you observe?**





Source: NASA – https://svs.gsfc.nasa.gov/4435

LESSON C4
OCEAN ACIDIFICATION

MAIN SUBJECTS
Natural sciences

DURATION
- Preparation: 10 min
- Activity: 1 h 30

SUMMARY
The students perform an experiment to understand the link between acidity and pH, and also between CO_2 concentration in the atmosphere and ocean acidification. They discuss the effects of ocean acidification on marine organisms.

KEY IDEAS
- The oceans' CO_2 uptake is increasing.
- The oceans are an important CO_2 sink. They have absorbed almost 30% of anthropogenic CO_2 in the past 200 years.
- Once dissolved in the ocean, CO_2 reacts with water to form carbonic acid, and contributes to an increase in ocean acidity.
- The seashells of marine organisms dissolve in very acidic water.
- Building new shells becomes increasingly difficult as ocean acidity increases.
- Shellfish, corals, plankton, sea urchins and starfish are some of the marine organisms that are affected.

KEYWORDS
Ocean acidification, CO_2 uptake, carbonic acid, pH

INQUIRY METHOD
Experimentation

PREPARATION 10 MIN

MATERIALS
- 1 straw and 1 container (for each group);
- 3 different seashells and 3 containers;
- Liquids to test acidity: water, vinegar, soft drinks, lemon juice, etc.
- pH meter or pH testing kit for swimming pools or red-cabbage juice (for each group);

Multimedia resources: video (ocean acidification). See page 182.

LESSON PREPARATION
Download the video on the OCE's website. See page 182.

TEACHER TIP
If you do not have a pH meter or a swimming pool pH testing kit, you can make "homemade" red-cabbage juice as follows:
→ Cut the red cabbage into small pieces, place them in a container and put the container in the freezer for a few hours. This will break up the cell walls of the red cabbage and give an even more intense colour to the juice.
→ Pour boiling water onto the red cabbage pieces. The water turns dark purple. Pour the red cabbage juice through a strainer, and there you are: your red cabbage juice is ready.
→ To test the red cabbage juice, blow through a straw into a glass of red cabbage juice, and check whether the colour changes from a dark violet to a more pinkish violet. If you add vinegar, the solution should turn a bright magenta colour, whereas adding sodium bicarbonate (baking soda) changes the solution greenish blue.

You should test the red cabbage juice in advance to make sure it works. It works best if you do not store it for too long before using it (one day). If you store it in the freezer, it can be kept for months.

INTRODUCTION 20 MIN

Ask the students: *What do you think happens to all the CO_2 in the atmosphere? Does it stay there? Where else can it go?* Some students will probably mention that plants absorb CO_2, but they will probably not be aware that a lot of CO_2 is absorbed by the oceans.

Ask the students what they think happens when CO_2 dissolves in the oceans. They may have some suggestions, such as possible effects on marine animals and water pollution. Discuss the fact that the ocean actually becomes more acidic as the CO_2 concentration in the water increases.

Ask the students for some examples of acidic liquids (vinegar, lemon juice, etc.), and then introduce the pH meter. Alternatively, you can use a pH testing kit for swimming pools or red cabbage juice.

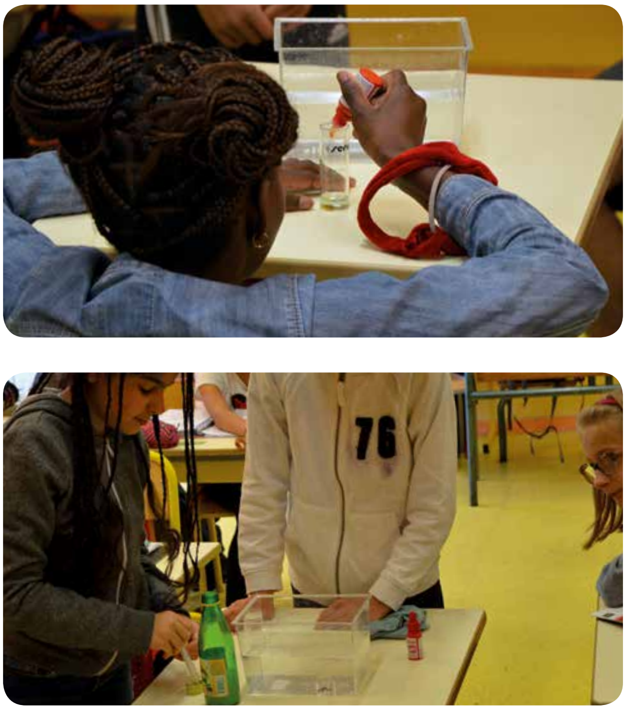
TEACHER TIP

If the class has done lesson B1, B2 or B3, the students already know that increased CO_2 emissions into the atmosphere are contributing to global warming. If not, consider doing a brief documentary research to introduce this idea (for example, analysing the correlation between global temperatures and changing CO_2 levels since the industrial revolution). In the previous lessons, some of the consequences of this global warming were studied. However, increasing atmospheric CO_2 concentration has other consequences besides global warming, namely ocean acidification.

PROCEDURE 1 H

PART 1 (30 MIN): OCEAN ACIDIFICATION

1. In groups, the students measure the pH of different liquids (water, vinegar, soft drinks, lemon juice, etc.). This allows them to understand the relationship between pH and acidity. Once this relationship is understood, they can proceed to the following step.



Students performing pH tests.

2. Ask the students: *Do you have an idea of how we could test whether our hypothesis that CO_2 increases the acidity of seawater is correct?*
Blowing through a straw in a glass of water over several minutes is enough to demonstrate that this hypothesis is true. The students can add salt to the water to make it more like seawater. This also increases the initial pH of the water (around 8 for seawater). Additionally, it makes it easier to see a colour difference before and after blowing into the straw when using red cabbage juice as a pH indicator.

3. Tell the students about the capacity of seawater to take up CO_2 and how this leads to ocean acidification. In the last 200 years, the oceans have already absorbed around 30% of the anthropogenic CO_2.

By blowing through a straw, students add CO_2 to the water.

PART 2 (30 MIN): CONSEQUENCES OF OCEAN ACIDIFICATION FOR MARINE ORGANISMS

4. Ask the students: *What do you think will happen to marine organisms living in the oceans?* Common answers include that marine organisms are poisoned or asphyxiated by CO_2, or they show deformations, do not reproduce or reproduce less, etc.

5. Ask the students to think of an experiment which could show whether acids can harm marine organisms. The solution is to use remains or dead bodies of animals (corals, shells, etc.). Before carrying out the experiment, ask the students to predict the result. A few possible hypotheses raised by the students:

- In vinegar, the shell will break into several pieces.
- In vinegar, holes will appear in the shell.
- The shell will be discoloured in vinegar.
- The shell will disappear in vinegar.
- There will be no visible difference between water and vinegar.

6. The experiment could be similar to the following:

- Place three shells (or the like) in three different solutions: in water (control experiment), in water mixed with vinegar, and in pure vinegar. After a few minutes, the shells begin to dissolve – bubbles appear and the water becomes opaque. Ask the students *What do you think the bubbles are made of?* They are made of carbon dioxide, which is produced when an acid (vinegar) reacts with the calcium carbonate of the shells. If left overnight, the shell placed in vinegar may dissolve completely.

→ The students should be aware that this experiment is an exaggeration: Vinegar is much more acidic than seawater (vinegar has a pH of 2-3, whereas seawater, in 2013, had a pH of around 8.05).

TEACHER TIP

Different shells have a different chemical compositions; depending on the amount of calcium carbonate in the shell, the reaction to vinegar may vary (more or less bubbles will appear).

Shells dissolving in vinegar.

Students observing the effect of vinegar on shells.

WRAP-UP 10MIN

To conclude, show the video explaining how ocean acidification affects the shells of plankton and corals. The class should then come up with a group conclusion on the effects of ocean acidification on marine organisms: not only can the shells of marine organisms be damaged, the formation of new shell material can be hindered as well. Ocean acidification affects all animals that have a shell or an exoskeleton[1] made of calcium carbonate.

PROGRESSION TIP

You may directly proceed to lesson D2 (page 102) if the students would like to understand the potential impacts of ocean acidification on ecosystems (impacts on the food web).

1 An exoskeleton is an external skeleton – it is found outside rather than inside the body. Humans, for example, have an internal skeleton, whereas a crab has an exoskeleton.

BACKGROUND FOR TEACHERS

We have seen how CO_2 contributes to global warming. However, there is another very important consequence of the increasing atmospheric CO_2 concentration: the increasing ocean uptake of CO_2, which leads to **ocean acidification**.

ACIDITY AND PH

An **acid** is a substance that, when dissolved in water, increases the amount of H^+ ions. These highly reactive ions are involved in many chemical reactions (for example, an acidic solution not a very convincing example).

pH is a unit that measures the concentration of H^+ ions. It is a logarithmic scale: a pH=6 solution is ten times more acidic than a pH=7 solution, itself ten times more acidic than a pH=8 solution, and so on. A solution is considered acidic if its pH is lower than 7, neutral when its pH equals 7, and basic, or alkaline, if its pH is higher.

OCEAN ACIDIFICATION

As detailed on page 17 of the Scientific Overview, around one quarter of the 40 billion tons of CO_2 emitted each year by human activity is absorbed by the ocean. Part of it is taken from the water by phytoplankton, part of it is sequestered by plants and sediments in vegetated coastal ecosystems (see lesson C2, page 75), and part of it dissolves in the ocean. Once dissolved in seawater, CO_2 reacts with water molecules (H_2O) to form **carbonic acid** H_2CO_3.

This is a reversible reaction, but if the amount of CO_2 is too high, the production of carbonic acid is predominant. The reaction that follows naturally is the dissociation of carbonic acid into H^+ ions and bicarbonate ions HCO_3^-. Gradually, this reaction contributes to ocean acidification (due to the increase of H^+ ion concentration and the resulting pH decrease).

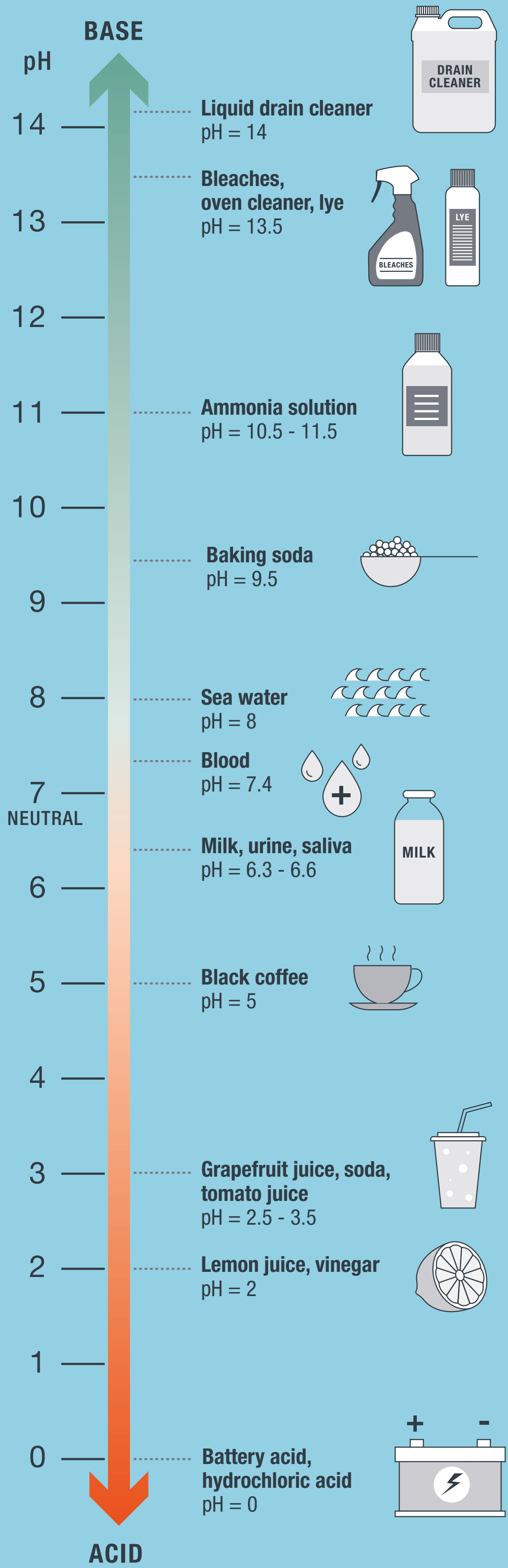
Marine organisms with **exoskeletons or shells use calcium carbonate** ($CaCO_3$) to produce them. Calcium carbonate is formed in the reaction of calcium and carbonate ions.

[...]

[...] If there is an excess of H^+ ions (as is the case in an acidic ocean), the CO_3^{2-} ions will tend to associate preferentially with H^+ ions rather than with Ca^{2+} ions, preventing the previous reaction from taking place and thus making it very difficult for some marine organisms (marine calcifiers) to build shells or calcium carbonate skeletons. Moreover, if the concentration of H^+ ions is so high that they can no longer find other ions to bind to, they may even cause the separation of $CaCO_3$ molecules that already exist in the shells and exoskeletons of those organisms, thus contributing to their progressive degradation. When this happens, we say that the shells "dissolve" in the acid solution. Hence, CO_2 absorption by the oceans has **a double impact on marine organisms**: it makes **forming new shells and exoskeletons more difficult** and can **deteriorate those that already exist.**

Global mean pH has dropped by around 0.1 units since the industrial revolution to around 8.05 in 2013. A small increase in ocean acidity (even if seawater pH remains above 7) is enough to affect marine calcifiers at their different development stages. The experiment performed in this lesson, with seashells and vinegar, shows the effect of ocean acidification on marine calcifiers, exaggerated for educational purposes (the pH of vinegar is much lower than the real pH of seawater).

The pH of seawater is expected to further decrease by between 0.3 to 0.4 units by 2100, depending on future emissions. As a result, many species (including corals) are threatened, with a direct impact on marine biodiversity, but also on the economy and human food security.



pH scale and examples of different solutions.

LESSON C5
MARINE CURRENTS AND CLIMATE REGULATION (ADVANCED STUDENTS)

MAIN SUBJECTS
Natural sciences

DURATION
~ Preparation: 15 min
~ Activity: 1 h 30

SUMMARY
The students carry out two experiments to determine how differences in the density of seawater (which depend on salinity and temperature differences) can drive ocean currents. The analysis of a thermohaline circulation map helps them understand how marine currents influence climate worldwide.

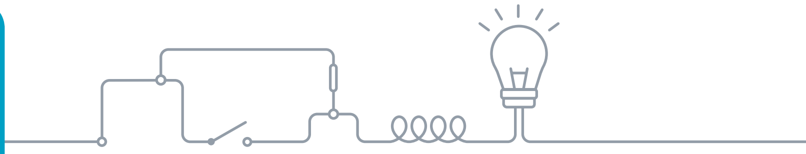
KEY IDEAS
~ Freshwater is less dense than saltwater. Warm water is less dense than cold water. Water that is less dense rises; water that is more dense sinks.
~ The oceans, land and atmosphere exchange heat and moisture. The sun is the main motor of oceanic and atmospheric circulation.
~ Density differences drive thermohaline circulation, which acts as a global conveyor belt transporting ocean water within and throughout all ocean basins.
~ Marine currents play a key role in regulating global and regional climate.
~ Changes in ocean circulation have a major impact on regional climates and affect the Earth's ecosystems.

KEYWORDS
Density, salinity, thermohaline circulation, marine currents

INQUIRY METHOD
Experimentation and documentary analysis

PREPARATION 15 MIN

MATERIALS
- **WORKSHEET C5.1**;
- Tanks filled with water at room temperature and a sponge (one for each group);
- Three small containers (bottle, teacup, other);
- A kettle;
- Cold water;
- Food colouring;
- Salt;



Multimedia resources: videos (marine currents and El Niño).

LESSON PREPARATION
1. Print out **WORKSHEET C5.1** (one for each group).
2. Put water in the fridge the day before.
3. Download video from the OCE's website. See page 182.

INTRODUCTION 20 MIN

Hand out a map of the thermohaline circulation (**WORKSHEET C5.1**) to each group and ask the students about the meaning of the red and blue colours (warm and cold water) and the direction of the arrows (sinking and rising water). *What is shown on the map?* The map shows the movement of water in the oceans: the ocean currents. *What happens to the warm water when it reaches the poles?*

PROCEDURE 50 MIN

PART 1 (30 MIN): THERMAL CURRENTS

1. Ask the students to design an experiment that allows them to test what happens when a region of the ocean is either cooled or warmed. Once a protocol is agreed on, ask the students to predict the result.

2. The students, divided into small groups, can carry out an experiment like this:

→ Fill a tank with water at room temperature. It represents the ocean.
→ Fill a small container with warm water, coloured red (red is usually associated with “warm”). You may use a kettle, but the water does not need to boil.
→ It helps to place a sponge floating at the water surface and to pour the hot water onto it. The hot water is absorbed by the sponge before it starts diffusing. The hot water remains at the surface.

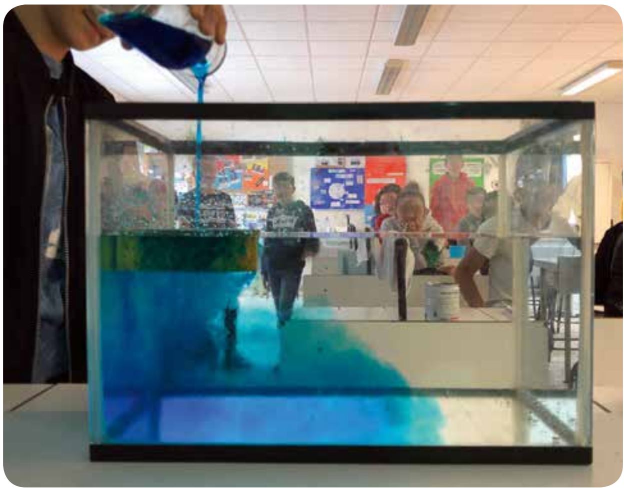
BACKGROUND FOR TEACHERS

Ocean circulation and currents play a central role in regulating the climate and supporting marine life by transporting heat, carbon, oxygen, and nutrients throughout the ocean. The global ocean circulation can be divided into two major components: 1) the fast, wind-driven, upper ocean currents, and 2) the slow, deep ocean circulation. These two components act simultaneously to drive the "meridional overturning circulation", the movement of seawater across basins and depths.

In this lesson, we focus only on slow, deep ocean circulation. This component is sometimes referred to as "**thermohaline**" circulation, due to its dependence on changes in temperature (from the greek word "thermos" meaning "warm") and salinity (from the greek word "halinos" meaning "salty"), both of which modify the density of seawater. **When a parcel of seawater cools or gets saltier, its density increases and it "sinks"** by way of a process called vertical mixing. This "sinking" occurs primarily in high latitudes, where heat loss to the atmosphere and sea ice formation lead to significant changes in temperature and salinity. Marine surface currents have a considerable effect on coastal temperatures and living conditions, as shown by the Gulf Stream, which, together with westerly winds, is responsible for the mild European climate.

The role of ocean currents on the climate system and the effects of climate change on the overturning circulation are further in pages 10 and 18 of the Scientific Overview, respectively.

- → Fill another small container with cold water, coloured blue (usually associated with "cold").
- → Pour the cold water over the sponge in the tank and observe what happens. The blue water sinks to the bottom of the tank.



The cold-water sinks to the bottom of the tank.

3. Ask the students: *Do warm and cold water behave similarly in the ocean?*

TEACHER TIP

Cold water is denser than warm water, hence it can be thought of as being "heavier". The word density will be introduced at the end of the lesson.

PART 2 (20 MIN): SALINE CURRENTS

4. The students can do a similar experiment by replacing the hot and cold water with saltwater:
A small container is filled with water in which a large amount of salt has been dissolved (i.e. 5 tablespoons of salt for one cup of water).

5. The students pour the saltwater onto the sponge and observe what happens. Saltwater is denser than freshwater and thus it sinks.

While the above experiments may appear to be very simple, they usually create astonishment: The students see water "rising" or "sinking"! This is because cold water is denser than warm water, and saltwater is denser than freshwater. If the students have already dealt with buoyancy, they can apply their previous knowledge to these experiments.

TEACHER TIP

At equal mass, denser water has a lower volume. This is why it sinks. The density is defined as:

$$\text{Density} = \frac{\text{Mass}}{\text{Volume}}$$

This can be checked using an accurate scale: weigh an equal volume of hot and cold water. You will see that hot water has a smaller mass because it is less dense.

WRAP-UP 20 MIN

Look at the thermohaline circulation map again. In colder regions like the poles, the currents flow into deep water. Ask the students: *Why do the currents "sink" into deep water at the poles?*

> **TEACHER TIP**
> In reality, the answer to this question is very complicated – see the background for teachers. In this lesson, we have explored only two of the most important driving forces of ocean currents.

The students will probably answer that it is because the water is colder, which is partially true.

Ask the students: *Besides being colder, there is another reason for it to sink. What could it be?* Since they have seen that saltwater sinks in freshwater, they might answer that it is because the water is saltier as well – although it is counterintuitive.

The question that arises next is: *Why would the water at the poles be saltier? Wouldn't you think that with all the freshwater that is produced from melting sea ice, it would be less salty?* They will most probably be confused, not understanding where the salt comes from.

Ask them: *How does sea ice form?* They will answer: from freezing seawater. At this point, you have to give them the information that sea ice is not salty – except for some brine[1] confined in brine pockets in the ice. (Brine is a solution of water and a high concentration of salt.)

Ask them: *Seawater is salty whereas sea ice is not. So, when sea ice forms, where does the salt go to?* It actually goes into the surrounding water. *And what happens when water becomes saltier?* It gets denser and sinks. Therefore, there are two reasons for the water to sink at the poles: it sinks because it is colder and it sinks because it is saltier.

Introduce the students to the key role marine currents play for the world's climate: for example, they transport heat from the equator to the poles. Discuss the impacts of climate change on marine currents and the resulting consequences for the climate in different regions. Climate change impacts the marine currents because it affects both water temperature and salinity (through the melting of sea ice, for example).

The contribution of the ocean to climate regulation will be discussed again in lesson C6 (page 92).

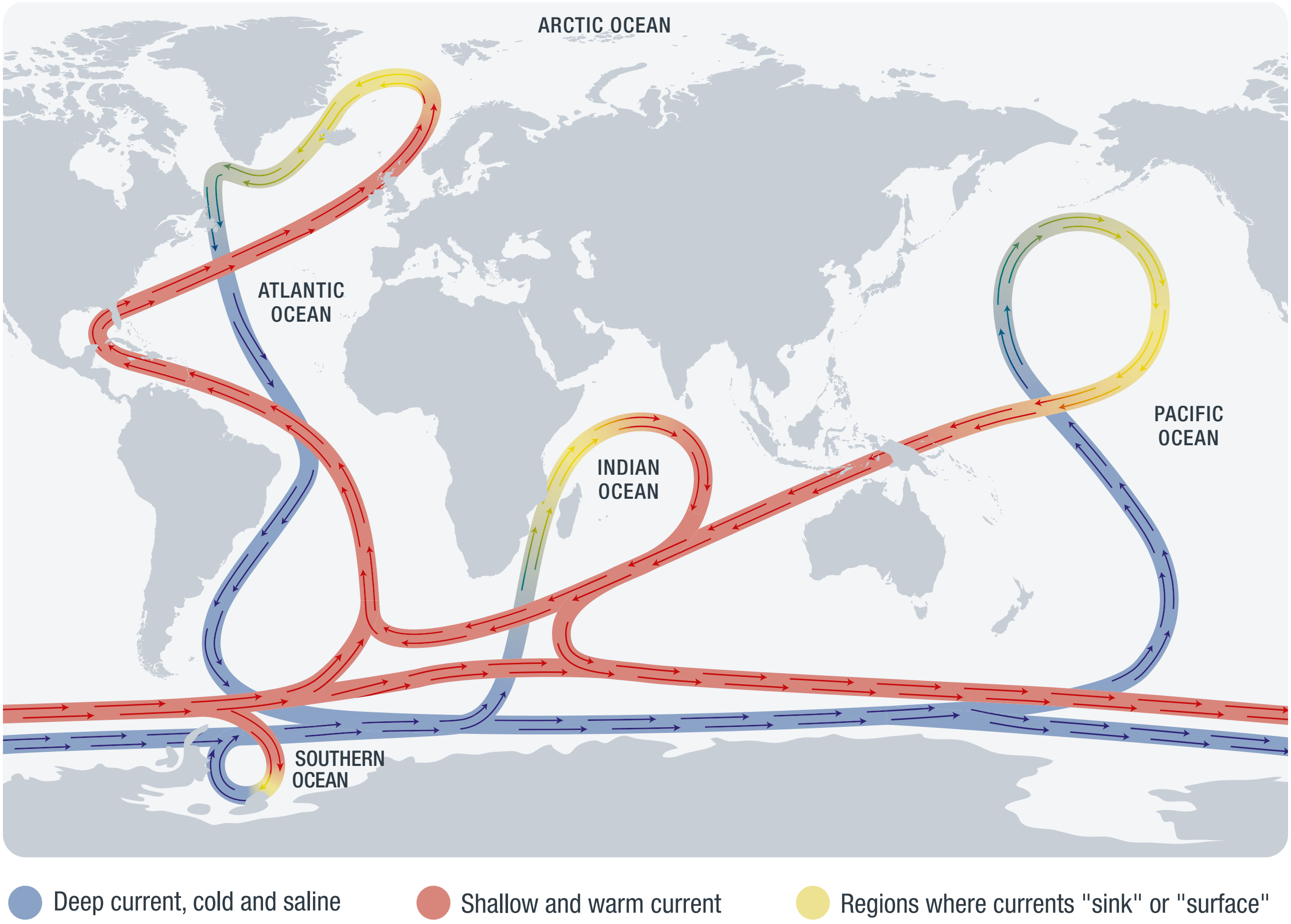
OPTIONAL EXTENSION

High school students may study the El Niño phenomenon, as an example of the important role played by marine currents in the world's climate.
A video on El Niño is available on the OCE's website. See page 182.

1 Brine is a solution of water and a high concentration of salt.

WORKSHEET C5.1

The figure below shows the thermohaline circulation map: deep currents, cold and saline, are shown in blue; whereas warm surface currents are shown in red and regions of "sinking" or "surfacing" currents are shown in yellow.



The global ocean conveyor belt is a constantly moving system of ocean circulation driven by differences in seawater density. It is also called the thermohaline circulation.

The Gulf Stream, and its extension, the North Atlantic current, is a warm ocean surface current. This current flows from Florida to the northeast, first along the east coast of North America, and then across the Atlantic towards Europe. On its way north, the current warms the air above the ocean and its water cools down. Furthermore, because part of the water in this surface current evaporates, the salt content of the water – the salinity – increases.

In two places – north-east of Iceland and south-west of Greenland – part of the water of the North Atlantic current sinks into the depths of the ocean. The temperature difference is only one of the reasons for it to sink. The other reason is that the salinity of this current is higher than the salinity of the surrounding water at both locations.

LESSON C6
OCEAN'S THERMAL INERTIA AND CLIMATE REGULATION (ADVANCED STUDENTS)

MAIN SUBJECTS
Natural sciences

DURATION
- Preparation: 15 min
- Activity: 1 h

SUMMARY
Through a documentary analysis and an experiment, the students learn about the role of the ocean's thermal inertia (compared to the land) in climate regulation.

KEY IDEAS
- The oceans absorb most of the solar radiation reaching the Earth (approximately 70% of the Earth is covered by oceans).
- The oceans are an important heat sink and have already absorbed 90% of the heat from global warming.
- The oceans' capacity to absorb heat and their large thermal inertia contribute to regional and global climate regulation.
- The large thermal inertia of the oceans means that they cool down slowly when cooled and warm up slowly when heated.
- The oceans contribute to a mild climate – warmer winters and cooler summers – along the coastlines.

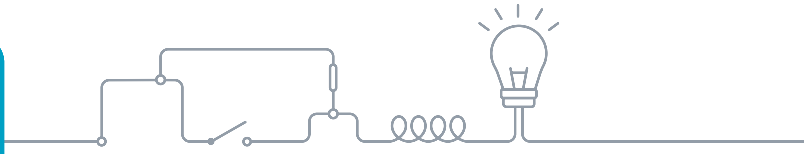
KEYWORDS
Thermal inertia, heat sink, climate regulation

INQUIRY METHOD
Experimentation; documentary analysis

PREPARATION 15 MIN

MATERIALS
For each group:
- **WORKSHEET C6.1;**
- 1 kg of water;
- 1 kg of sand, soil and / or semolina;
- 2 containers.

LESSON PREPARATION
Print copies of **WORKSHEET C6.1** (one for each group).



INTRODUCTION 10 MIN

Start by asking the students: *How can oceans influence climate? We sometimes hear the expression "oceanic climate". What does that mean? How can oceans have an influence on a region's climate? Is the climate of an inland region very different from the climate of a coastal region?* A documentary analysis will help answer these questions.

PROCEDURE 40 MIN

PART 1 (10 MIN): THE OCEAN'S INFLUENCE ON REGIONAL CLIMATES

1. Divide the students into groups and hand out a copy of **WORKSHEET C6.1** to each group. Each group should focus on a single graph.

2. Ask: *What are the similarities and differences between the temperature curves of the two cities?* The students will probably first observe that, for all temperature curves, the temperature is higher in summer and colder in winter.

3. Guide them so they notice that the temperature range between maximum (solid lines) and minimum (dotted lines) temperatures (and also between summer and winter) is narrower for blue curves than for red curves. If you have a map, ask the students to locate each city on the map. *What do red curve regions have in common? And blue curve regions?* Blue regions are located near the coast, while red regions are located in continental interiors. In other words, "oceanic" climates have milder winters and cooler summers when compared to "continental" climates. The continental climate is also drier (not shown).

PART 2 (30 MIN): THE THERMAL INERTIA OF WATER

4. Building on the previous discussion, ask the students: *If the air is really warm, which one do you think will warm first, the ocean or the land?* Ask them to design an experiment to test their hypotheses.

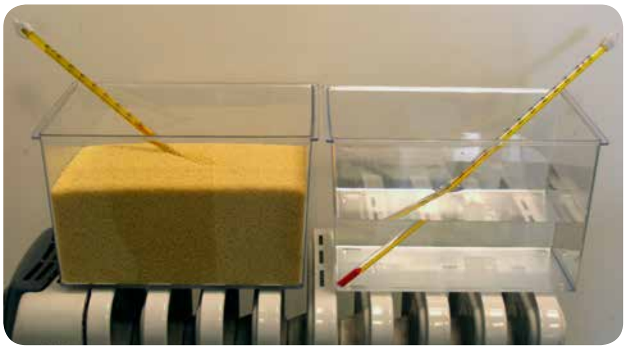
5. The groups perform an experiment, for example as follows:
- Place an identical mass of water and sand (or soil or semolina) in two similar containers.
- Place the containers on a radiator.
- Measure and note the temperature of both containers every 5 minutes for half an hour.

TEACHER TIP
A measuring example: the temperature of 1 kg of semolina rises by 17°C within about half an hour. At the same time, the temperature of the same mass of water (1 kg) only increases by 6°C. Instead of placing the containers on a radiator, you can place them in a refrigerator – preferably on the same shelf to ensure the temperature is the same. Measure the cooling time of the water and the other material: the water cools down more slowly.

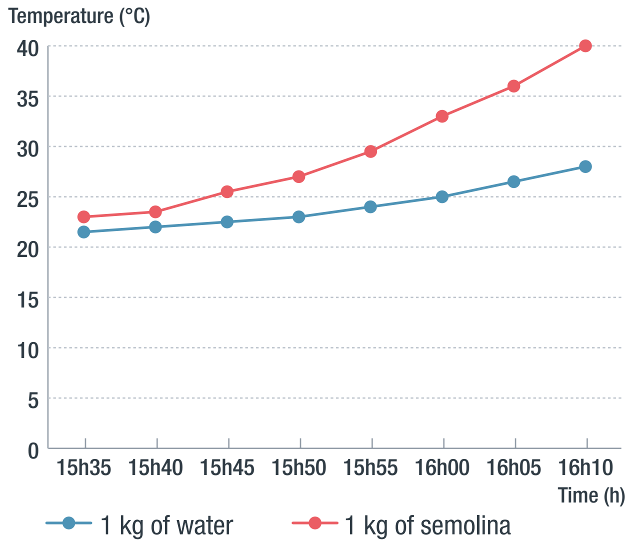
WRAP-UP 10 MIN

Discuss the different heating or cooling times observed for the two materials. The degree of slowness with which a material changes its temperature in response to the surrounding temperature is called **thermal inertia**. *How does this relate to cities near the coast heating and cooling less than cities inland?* The ocean temperature does not vary as much as the land temperature – it does not heat or cool as much. This influences the climate of coastal cities, which have a “temperate” climate. The students may conclude: “Oceans are less sensitive to temperature variations than land – they have a greater thermal inertia than land. As a consequence, regions near the coast have milder climates than continental regions.”

To further develop the topic, you can ask the students: *Which one of the two do you think is capable of absorbing more heat before reaching the same final temperature: the ocean or land?* The answer is: the ocean. Recall the first lesson on climate change and ask the students: *How do you think the ocean and land will react to a global temperature increase?* The atmospheric temperature has increased by 1°C since pre-industrial times, while the ocean temperature near the surface has increased by only 0.6°C. However, we know that 90% of the excess energy due to climate change has been stored in the ocean, and only 1% has been stored in the atmosphere.



Heating two containers: the left one is filled with semolina (red curve on the plot), the right one with water (blue curve on the plot).

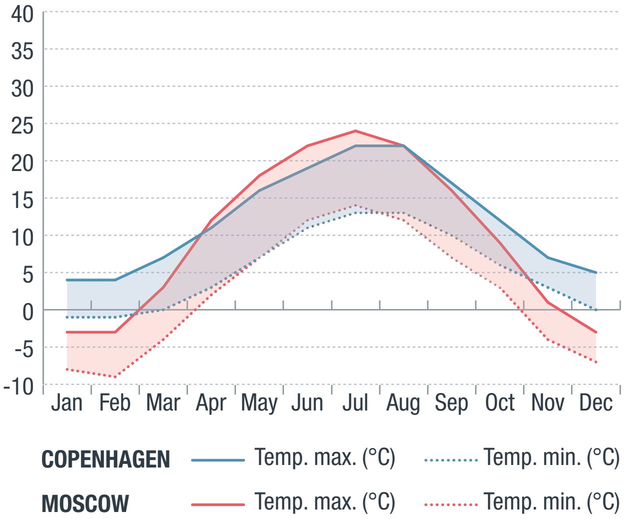


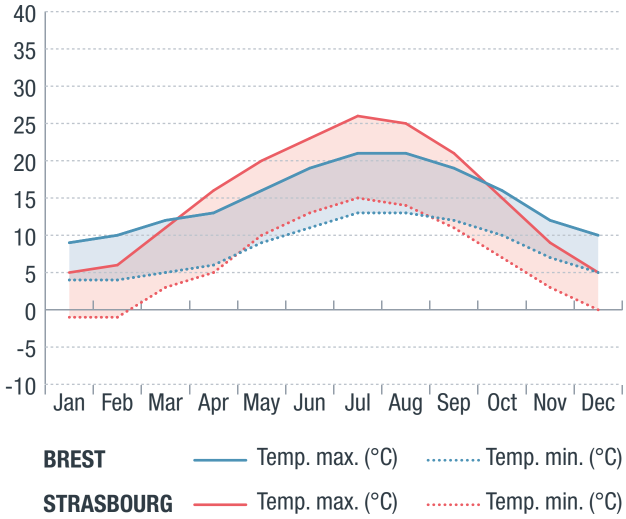
BACKGROUND FOR TEACHERS

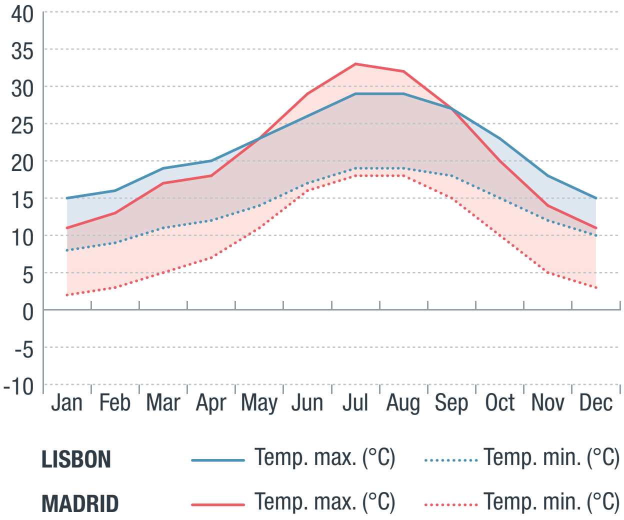
Inertia is the property of all physical substances to resist change. Liquid water has a large inertia with respect to **changes in temperature**: we say it has a large **thermal inertia**. This means that seawater can absorb a significant amount of energy before warming up and, inversely, it can release a significant amount of energy before cooling down. This helps reduce local climate variations, which are otherwise driven by the atmosphere and land surface, and explains the significant differences between **oceanic** (warmer winters and cooler summers) **and continental climates** (greater daily and interseasonal temperature variations). However, seawater’s large thermal inertia and the huge volume of the ocean also mean that, even if humans stop emitting greenhouse gases and the ocean heat uptake is therefore reduced, the ocean will take a very long time (possibly thousands of years) to cool down to its pre-industrial temperature.

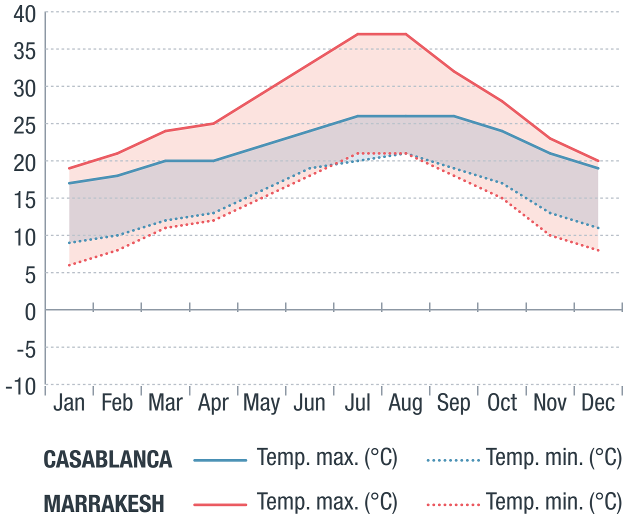
WORKSHEET C6.1

➔ What are the similarities and differences between the temperature curves of the two cities of each graph?
➔ What do you think are the reasons?









Source: Météofrance data

Look up the different cities in the map. Notice that each pair of cities in the same graph is located at a similar latitude.

➔ How far are they from the sea?

SEQUENCE D

WHY ARE THE OCEAN AND CRYOSPHERE IMPORTANT TO US?

Very often, in order for people to understand why we should take care of something, they need to understand why that something is important to us. As such, this sequence focuses on the importance of an equilibrium in the ocean and cryosphere systems, mainly from the point of view of human communities.

The first lesson reviews the consequences of climate change for ocean and cryosphere ecosystems, while also taking into account the ecosystem services they provide us with. A special focus on the food webs of different polar and marine ecosystems is drawn in the second lesson. The third lesson, which we highly recommend you adapt to your local context, is aimed at helping students realize that some of the services provided go beyond basic livelihood issues, and reach the realm of cultural, historical and spiritual heritages.

LESSON LIST

◉ Core lesson ○ Optional lesson

◉	D1	**Consequences of climate change on ecosystem services** Natural sciences The students create a conceptual framework showing the ecosystem services the ocean and cryosphere provide. They explore how climate change impacts those ecosystem services.	page 96
◉	D2	**Food webs and ecosystems** Natural sciences Through a role-playing game, the students explore polar and marine food webs. They learn that in ecosystems, all organisms interact with and depend on each other for their survival.	page 102
○	D3	**Humans, the ocean and the cryosphere** Social sciences / Visual or performing arts This session is to be adapted to local contexts. An example is provided. Through documentary research and or an artwork / artistic performance, the students learn about the cultural importance of ocean and cryosphere for human populations across history.	page 123

LESSON D1
CONSEQUENCES OF CLIMATE CHANGE ON ECOSYSTEM SERVICES

MAIN SUBJECTS
Natural sciences

DURATION
- Preparation: 25 min
- Activity: 1 h 30

SUMMARY
The students create a conceptual framework showing the ecosystem services the ocean and cryosphere provide. They explore how climate change impacts those ecosystem services.

KEY IDEAS
- Humans need various ecosystem services provided by the ocean and cryosphere: oxygen, food, freshwater, climate regulation, coastal protection, cultural services.
- The Earth system is a complex system in which everything is interconnected.
- Climate change resulting from human activities affects the ocean and cryosphere, as well as human livelihoods.

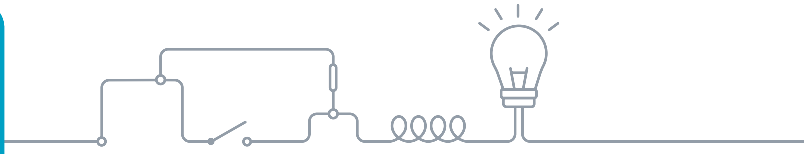
KEYWORDS
Ecosystem services, complex system, human activity, human livelihoods

INQUIRY METHOD
Documentary analysis

PREPARATION 25 MIN

MATERIALS
- **WORKSHEETS D1.1, D1.2, D1.3**;
- A large paper sheet to stick all the stickers;
- Glue.

LESSON PREPARATION
Print **WORKSHEETS D1.1** and **D1.2**, one copy for each group of 3 to 4 students. Print only one copy of the extra stickers on **WORKSHEET D1.3** (each group gets a different sticker).



TEACHER TIP
This lesson has two main objectives: 1) to review the links between climate change and the ocean and cryosphere ecosystems studied in the previous lessons, and 2) to understand how these links will have several consequences on the ecosystem services provided and on human livelihoods.

INTRODUCTION 20 MIN

Start by asking the students to think about the different impacts of climate change on the ocean and cryosphere that they learned about in the previous lessons and note each *concept* on the whiteboard. Some of the concepts suggested by the students should match the stickers provided in **WORKSHEET D1.1**.

TEACHER TIP
"Concept" refers to a simple statement that corresponds to an idea you want the students to take away (validated by the scientific community, and not an initial representation). **One concept = one sentence.** It is not a keyword, a question, or even a "notion" (which tends to involve intuitive knowledge). Example: "The concentration of CO_2 in the atmosphere is increasing."

Continue the discussion with the students: *Why do we care about these changes in the ocean and cryosphere? What do we need the ocean and cryosphere for in our lives?* Note the answers on the whiteboard, again in the form of concepts. Some of the concepts suggested by the students will certainly match the stickers provided in **WORKSHEET D1.2**.

PROCEDURE 40 MIN

1. Divide the class into groups and give each group the list of the concepts needed to build the first part of the conceptual framework ("Mechanisms" stickers, **WORKSHEET D1.1**). If some of the concepts suggested by the students are pertinent but not mentioned in the list provided, let the students add a new sticker for each concept suggested and validated by

the class. In order to save time (or to adapt to your own objectives), you could cut out the listed "concepts" stickers beforehand.

2. Ask the students to place the stickers in a logical order, indicating the connections between them with arrows. For example, an arrow could mean "leads to" or "is due to".

3. Once they have managed to put all the "Mechanisms" stickers into a logical order, give them the "Services" stickers, **WORKSHEET D1.2**.

> **TEACHER TIP**
> Depending on the level of your students, you could give them the "Mechanisms" stickers first and then the "Services" stickers, or give them all stickers at the same time.

Organising the different stickers to build a conceptual framework.

Presentation in front of the whole class.

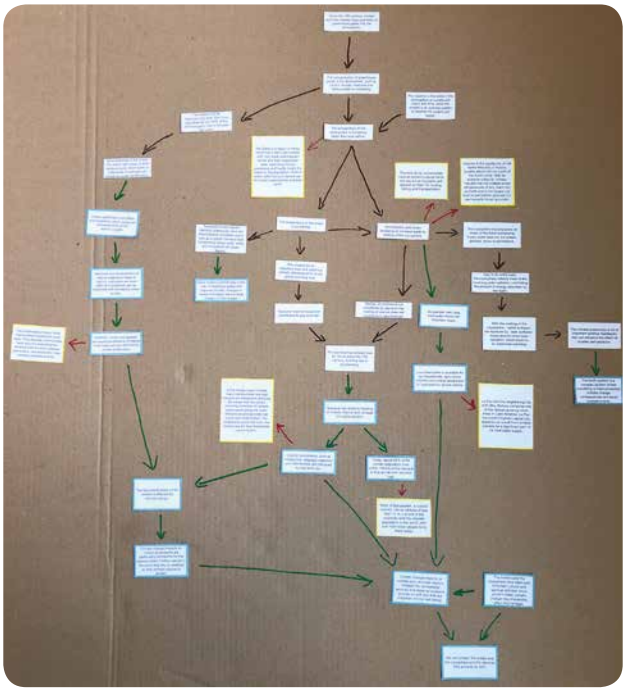
4. Once they have finished their conceptual framework, tell them that each group will also represent a population of one region of the world. Give each group an extra "Local community" stickers provided in **WORKSHEET D1.3**. Each group has to include this extra sticker in their framework logically. To do so properly, they have to think about how their community will be affected by climate change and which ecosystem services will no longer be available for them. Ask the students to list possible solutions for their community.

5. A representative of each group presents the conceptual framework and the solutions for his/her community.

WRAP-UP 30 MIN

Compare and discuss the different solutions with the class. Discuss on how many of the ecosystem services provided by the ocean and cryosphere are being affected by climate change. You can also take advantage of the discussion to go further into the social consequences of climate change. *(Some communities can adapt, others cannot: what does the ability to adapt depend on? Resources? Education? Other factors? Some will have to migrate, becoming climate refugees.)*

> **TEACHER TIP**
> This lesson also helps evaluate what the students have learned during the project. Mistakes or missing parts may lead to a deeper discussion to recall the logical sequence that may have been poorly retained or not completely understood. For this activity, there is not a single right answer, and the conceptual frameworks prepared by the students may all be different. What is important is their way of thinking and explaining their organization and links between the concepts.



Conceptual framework. One of the many possible framework solutions.

OPTIONAL EXTENSION

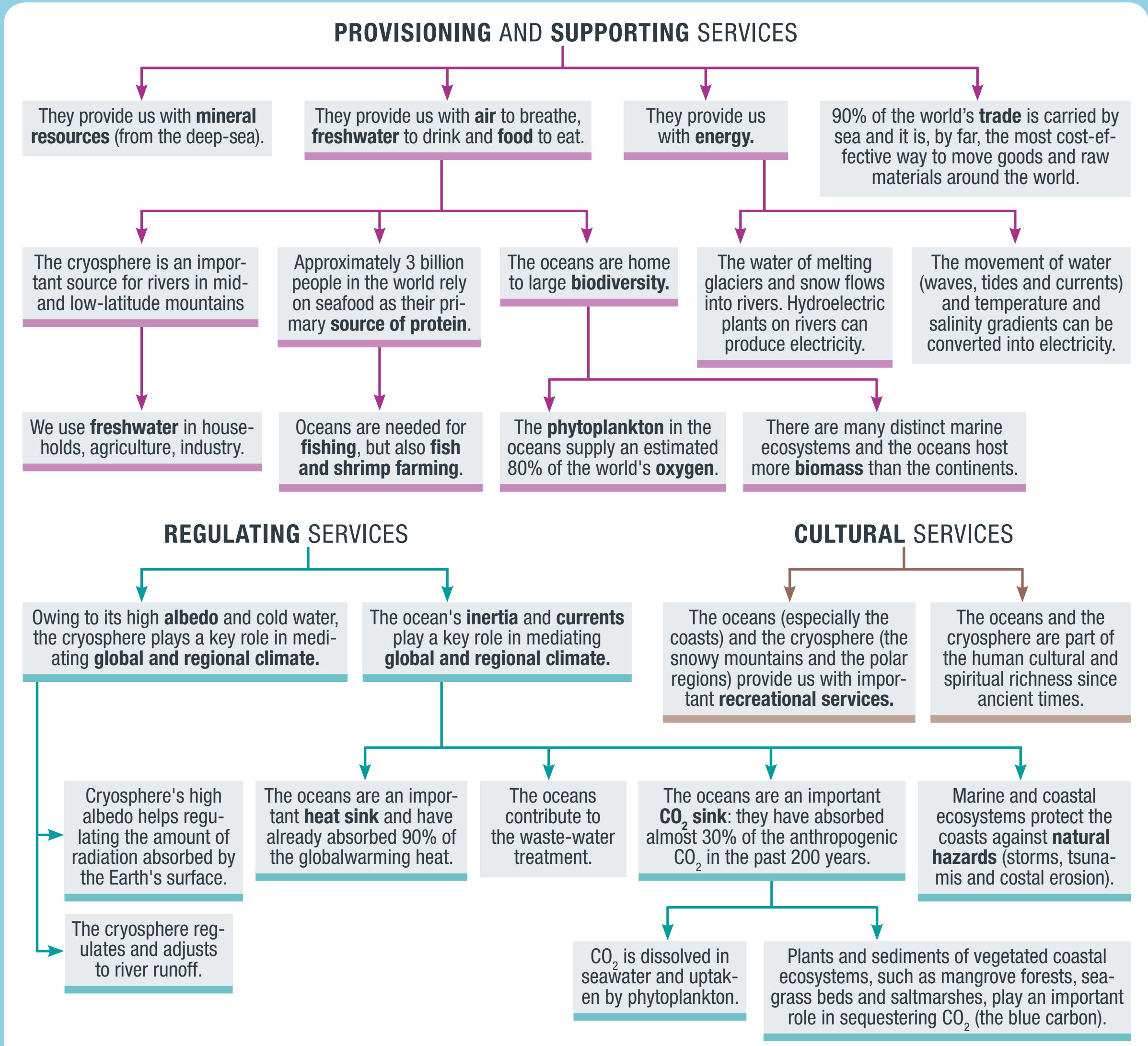
Work with a visual arts teacher to produce a mural painting about the services provided by the ocean and cryosphere and how these services are threatened by climate change.

BACKGROUND FOR TEACHERS

The term **ecosystem services** emerged in the 1970s to raise public awareness of biodiversity conservation. It is a concept which frames ecosystem functions as goods and services for the human population. The Convention on Biological Diversity (1992) defines ecosystems as *"a dynamic complex of plant, animal, and micro-organism communities and the non-living environment, interacting as a functional unit"*. Interactions within the ecosystem can produce various important services for human societies.

The ecosystem services approach aims to evaluate man-made pressures by incorporating ecology and economics. It identifies ecological functions and translates them into economic units. As an ecosystem functions using its natural resources, it produces goods and services that increase human wellbeing. The concept of ecosystem services examines how people depend on ecosystems, what benefits ecosystems provide in a utilitarian sense, and how to better manage and protect ecosystems for the benefit of both nature and people.

There have been several attempts to classify the different kinds of services ecosystems supply. One common typology is the Millennium Ecosystem Assessment. This framework divides ecosystem services into four groups: provisioning services, supporting services, regulating services and cultural services (see pages 12-13 of the Scientific Overview for further details). Below you can find a non-exhaustive description of the different provisioning, supporting, regulating and cultural services that the ocean and the cryosphere provide us with.



The services underlined are already, or are expected to be in the near term, adversely affected by climate change.

MECHANISMS

The temperature of the atmosphere is increasing faster than ever before.	The global mean sea level has rise by around 15 cm since 1900, and this rise is accelerating.	Atmospheric and ocean temperature increases lead to melting of the cryosphere.
Melting of continental ice contributes to sea level rise; melting of sea ice does not contribute to sea level rise.	The cryosphere encompasses all areas of the Earth comprising frozen water (sea ice, ice sheets, glaciers, snow or permafrost).	Seawater thermal expansion contributes to sea level rise.
The oceans are an important CO_2 sink: they have absorbed almost 30% of the anthropogenic CO_2 in the past 200 years.	The climate system has a lot of important positive feedbacks that can amplify the effect of smaller disruptions.	Because it is white, the cryosphere reflects most incoming solar radiation, controlling the amount of energy absorbed by the Earth.
Once dissolved in the ocean, CO_2 reacts with water to form carbonic acid, leading to a drop of seawater pH known as ocean acidification.	The weather is the state of the atmosphere at a particular place and time, while the climate is an average pattern of weather for a particular region.	The oceans are an important heat sink and have already absorbed 90% of the extra heat from global warming.
Since the 19^{th} century, human activities have released large quantities of greenhouse gases into the atmosphere.	The concentration of greenhouse gases in the atmosphere, such as carbon dioxide, methane and nitrous oxide, is increasing.	The temperature of the ocean is increasing.
With the melting of the cryosphere, “white surfaces” are replaced by “dark surfaces”: these absorb more solar radiation, which leads to additional warming.	Temperature and salinity (density) differences drive the thermohaline circulation, which acts as a global conveyor belt transporting ocean water within and across all ocean basins and depths.	

SERVICES

The oceans and cryosphere have been part of human cultural and spiritual wealth since ancient times: climate change may irreversibly affect this heritage.

Rising sea levels lead to flooding of coastal regions and increased coastal erosion.

Today, about 40% of the human population lives within 100 km of the sea and is thus at risk from rising sea levels.

As marine currents play a key role in mediating global and regional climate, changes in ocean circulation have a large impact on the climate.

Seashells and exoskeletons of marine organisms made of calcium carbonate are more difficult to build and can be dissolved with increasing ocean acidity.

Coastal ecosystems, such as mangroves, seagrass meadows and saltmarshes, are menaced by sea level rise.

Shellfish, corals and plankton are essential elements of marine food webs and are affected by ocean acidification.

The large biodiversity of the oceans is affected by climate change.

Less freshwater is available for households, agriculture, industry and energy production (in hydroelectric power plants).

The Earth system is a complex system where everything is interconnected: climate change consequences are never isolated.

We can protect the ocean and cryosphere and the services they provide us with.

Ocean acidification will affect phytoplankton, which supplies an estimated 80% of the world's oxygen.

Climate change impacts on coastal and mountain regions threaten the recreational services that these ecosystems provide and are important for our wellbeing.

Climate change impacts on marine ecosystems are particularly worrisome for the approximately 3 billion people worldwide who rely on seafood as their primary source of protein.

LOCAL COMMUNITIES

Most of Bangladesh, a coastal country, has an altitude of less than 12 m. Bangladesh has one of the highest population densities worldwide, with over 160 million people living there today.

La Paz, and the neighbouring city of El Alto, in Bolivia, comprise one of the fastest-growing urban areas in Latin America. La Paz, the world's highest capital city, depends on runoff from Andean glaciers for a significant part of its freshwater supply.

The Inuit Arctic communities have an ancient cultural link to sea ice ecosystems and depend on them for hunting, fishing and transport.

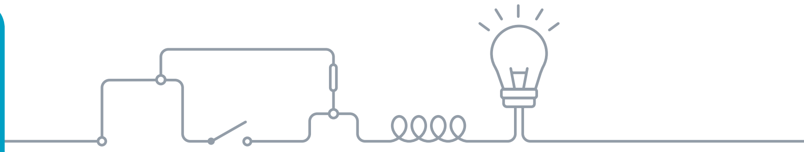
In the Kerala coast of India, many communities live near mangroves. Mangroves buffer wave action, providing protection for people and and infrastructures along the coast. Mangroves also provide fuel wood and small timber. The inhabitants catch fish from the nearby sea for their household consumption.

The Sahel is a region in Africa which has a semi-arid climate, with very weak and irregular rainfall and high evaporation rates. Agriculture is very precarious and hardly meets the needs of the population. When a water deficit occurs, famine can hit human communities and their cattle.

Yakutsk is the capital city of the Sakha Republic in Russia, located about 450 km south of the Arctic circle. With an extreme subarctic climate, Yakutsk has the coldest winter temperatures of any major city on Earth and is the largest city built on permafrost.

The livelihoods of many small island states depend on coral reefs. They provide communities with food security from fisheries, revenue from tourism, erosion prevention, and protection from extreme weather events.

LESSON D2
FOOD WEBS AND ECOSYSTEMS



MAIN SUBJECTS
Natural sciences

DURATION
- Preparation: 25 min
- Activity: 1 h – 1 h 30

SUMMARY
Through a role-playing game, the students explore polar and marine food webs. They learn that in ecosystems, all living organisms interact with and depend on each other to survive.

KEY IDEAS
- Changes in the ocean and the cryosphere systems affect living organisms.
- Ecosystems are fragile.
- The disappearance of a single element from an ecosystem can disrupt the entire food web, eventually affecting humans as well.

KEYWORDS
Ecosystem, fragile equilibrium, food web

INQUIRY METHOD
Role-playing game / multimedia activities + mural painting

PREPARATION 25 MIN

MATERIALS

- **WORKSHEETS D2.1, D2.2, D2.3, D2.4, D2.5, D2.6, D2.7, D2.8, D2.9, D2.10, D2.11, D2.12, D2.13;**
- Yarn (so that each species of the food web of the worksheets can be hung around the neck of each student);
- String (yarn will do as well) to extend between groups of students (long enough, at least 2 m, and more than one per student).

Multimedia resources: multimedia activities Food webs, videos (acidification and corals; mangroves). See page 182.

LESSON PREPARATION

→ **Option 1:** Choose one or several food webs to work on, and print the corresponding worksheets: Coral reef (**WORKSHEETS D2.1, D2.2, D2.3**), Kelp forest (**WORKSHEETS D2.4** and **D2.5**), Arctic Ocean (**WORKSHEETS D2.6** and **D2.7**), Mangrove (**WORKSHEETS D2.8** and **D2.9**), North Sea (**WORKSHEETS D2.10** and **D2.11**), Antarctica (**WORKSHEETS D2.12** and **D2.13**).
Make a necklace for each species in the food webs (the image of the species, glued on cardboard + yarn, for example). Each student will represent a species and hang the corresponding necklace around the neck, so that his / her hands are free to hold the strings that connect him / her to other species.

→ **Option 2:** Connect to the multimedia activities (see page 182). If the Internet connection is too weak or inexistent, the multimedia activities can be downloaded ahead of time. Refer to the instructions on the OCE's website.

TEACHER TIP
The goal of this lesson is to explore the consequences of climate change on food webs, but it does not focus on the study of the food webs in themselves. A preliminary lesson about the different species can be introduced to build the food webs beforehand.

INTRODUCTION 10 MIN

Recap the different consequences of climate change on the ocean and cryosphere. Ask the students: *What consequences could the various climate change phenomena (like cryosphere melting, rising sea level, ocean acidification, etc.) have for animals and plants in the ocean or cryosphere ecosystems?* Write the students' suggestions on the whiteboard.

PROCEDURE 35 – 70 MIN

OPTION 1 (35 MIN) – ROLE-PLAYING GAME

1. Inform the students that they will now play the ecosystem game. Give each student a card corresponding to a species that is part of a food web (provided in the **WORKSHEETS**) and several pieces of string. Different ecosystems are available with different levels of complexity depending on the grade you are teaching. The food webs can be chosen depending on the level of the students, their previous knowledge of the ecosystems, and their geographical area.

Assign each student one specie, following the ratio:

- **Example 1 – Coral reef food web**
  WORKSHEETS D2.1, D2.2, D2.3
  - 1 student for each of these species: shrimp, triggerfish, parrotfish, butterfly fish, Moorish idol, damselfish, octopus, turtle, grouper, blacktip shark;
  - 2 students for sponge and coral;
  - For the remaining students: ⅓ play phytoplankton, ⅓ play macroalgae, ⅓ play organic matter.

- **Example 2 – Kelp forest food web**
  WORKSHEETS D2.4 and D2.5
  - 1 student for each of these species: crab, starfish, kelp bass, sea otter, sea lion, orca;
  - 2 students play abalone, sea urchin, clam;
  - For the remaining students: ½ play phytoplankton, ½ play kelp.

- **Example 3 – Arctic food web**
  WORKSHEETS D2.6 and D2.7
  - 1 student for each of these species: seal, walrus, polar bear, bowhead whale, little auk;
  - 2 students for copepod, krill, Arctic cod, clam;
  - For the remaining students: ½ play phytoplankton, ½ play ice algae.

- **Example 4 – Mangrove food web**
  WORKSHEETS D2.8 and D2.9
  - 1 student for each of these species: mangrove snapper, brown pelican, red ibis, periophthalmus, crocodile;
  - 3 students play shrimp, crab, mangrove periwinkle, annelid;
  - The remaining students play mangrove trees.

- **Example 5 – North Sea food web**
  WORKSHEETS D2.10 and D2.11
  - 1 student for each of these species: herring, Atlantic mackerel, spiny dogfish, grey seal, herring gull, blue mussel, oystercatcher;
  - 2 students play shrimp, jellyfish;
  - 3 students for krill;
  - For the remaining students: ½ play phytoplankton, ½ play organic matter.

- **Example 6 – Antarctic food web**
  WORKSHEETS D2.12 and D2.13
  - 1 student for each of these species: toothfish, penguin, albatross, cuttlefish, Weddell seal, leopard seal, orca, humpback whale;
  - For the remaining students: ⅔ will play phytoplankton and ⅓ krill.

Make sure the students understand that phytoplankton, ice algae, macroalgae, mangrove and kelps are the most abundant organisms, at the base of the food web. Top predators are always less abundant, but they need a lot of individuals from the species they feed on to have enough food to eat.

2. Read the text of all species with the students.

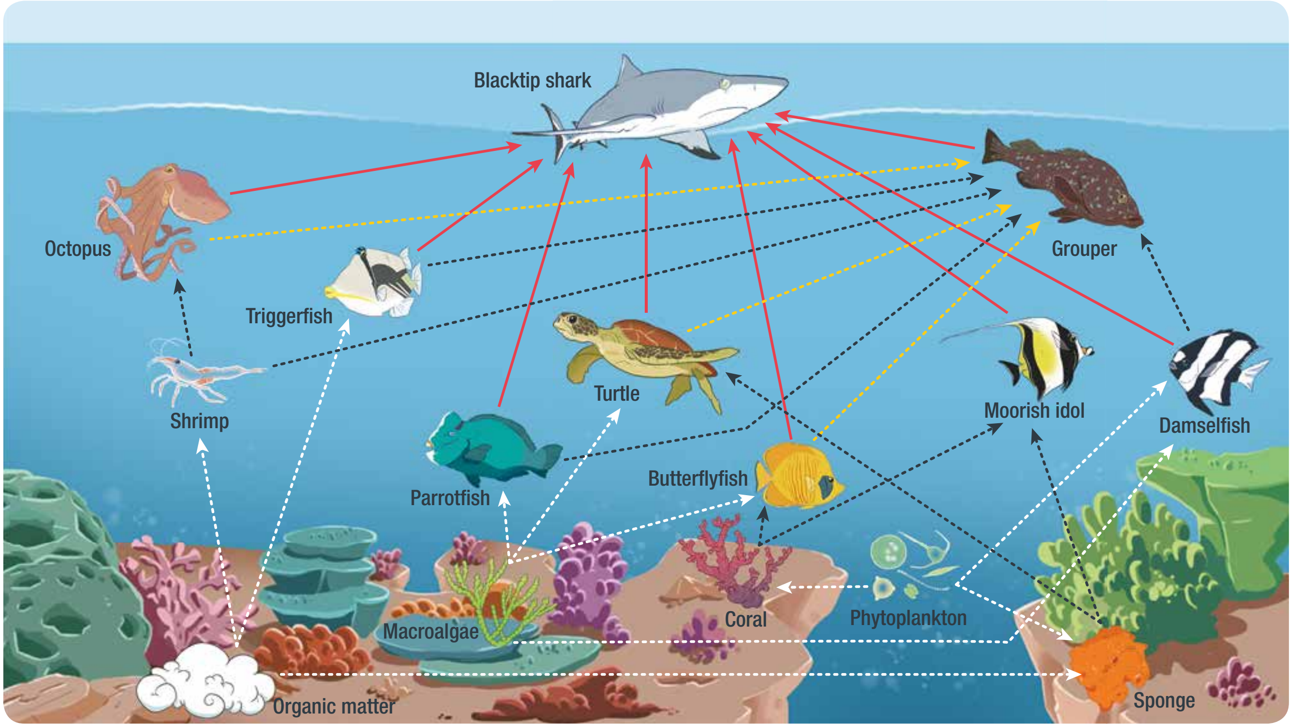
3. The students have to figure out on which species their species depends on for living (which species it can eat). Start from the beginning of the food web (phytoplankton, macroalgae, ice algae, mangrove or kelp), and continue up the food web to the predators. They will hold a string per species they depend on, which hold the other end of each string. Ask the students in turn to explain their choice of connections.

"Krill student" connecting to the rest of the food web.

Phytoplankton necklaces.

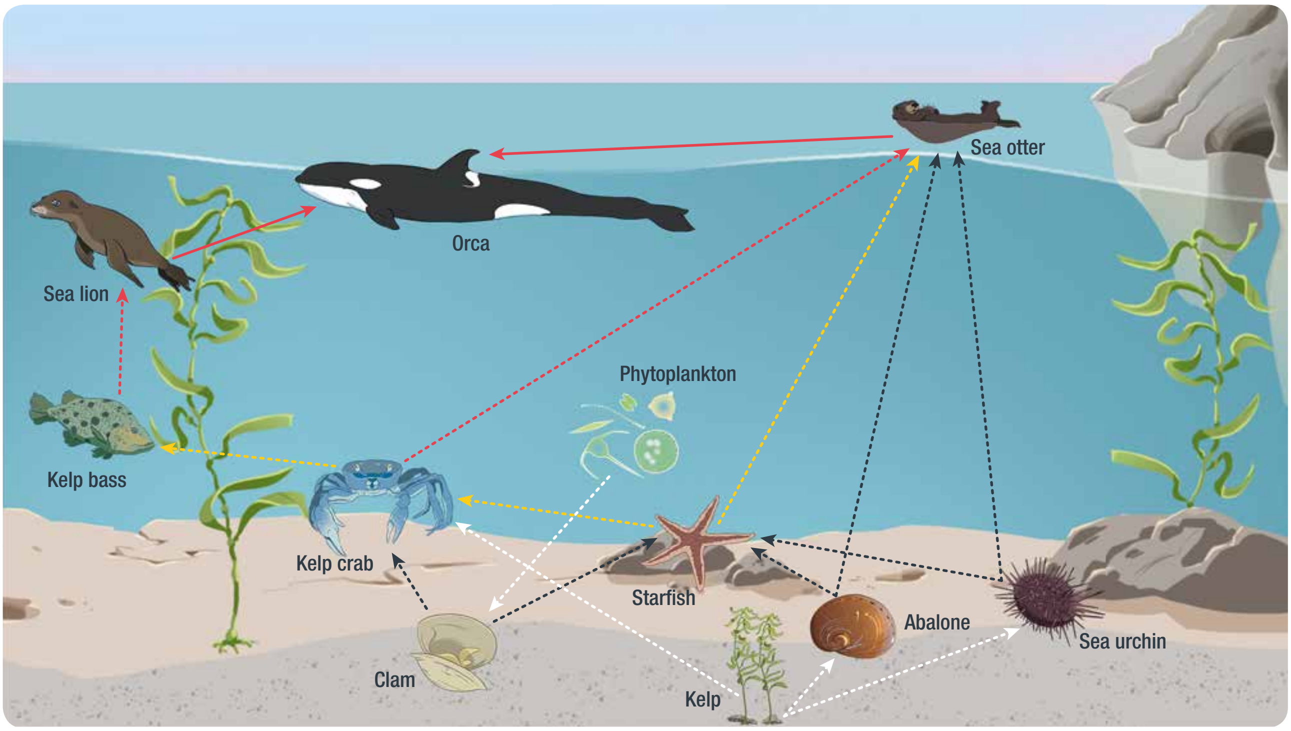
Solution for Worksheets D2.1, D2.2, D2.3

Example 1 – Coral reef food web



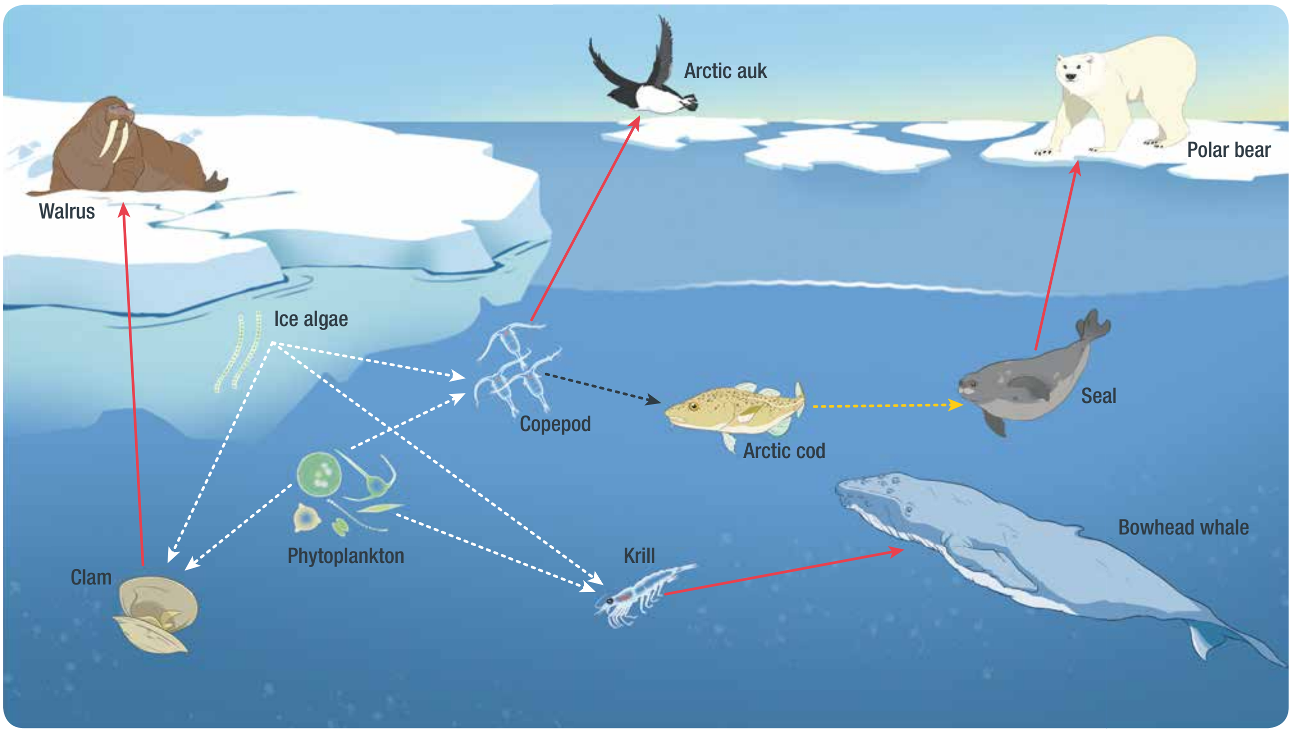
Solution for Worksheets D2.4 and D2.5

Example 2 – Kelp forest food web



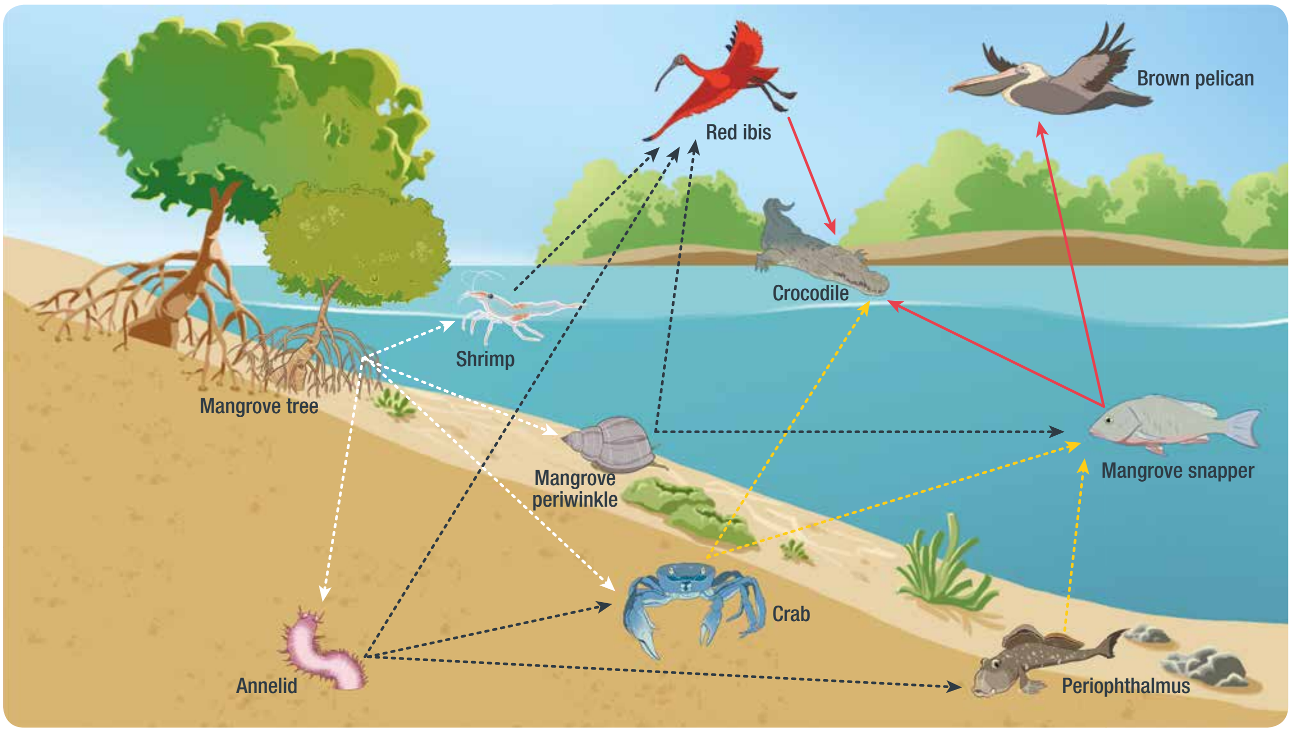
Solution for Worksheets D2.6 and D2.7

Example 3 – Arctic food web



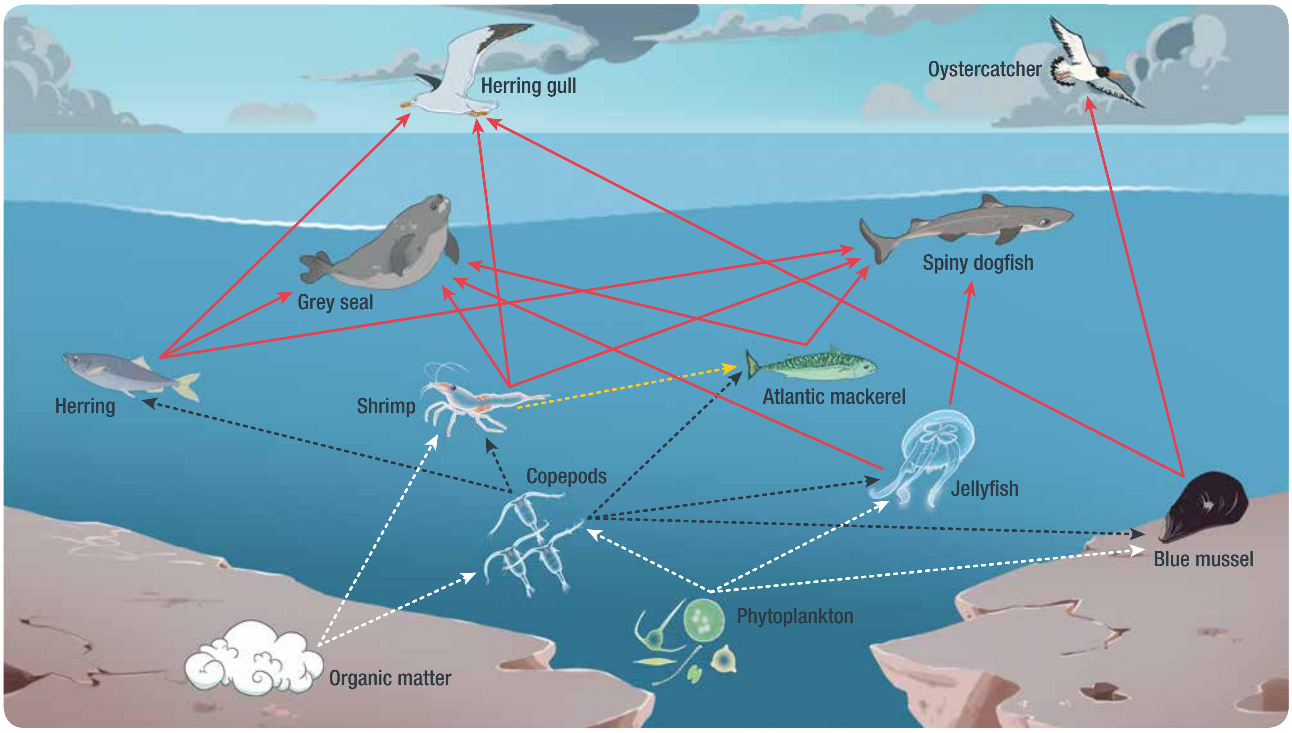
Solution for Worksheets D2.8 and D2.9

Example 4 – Mangrove food web



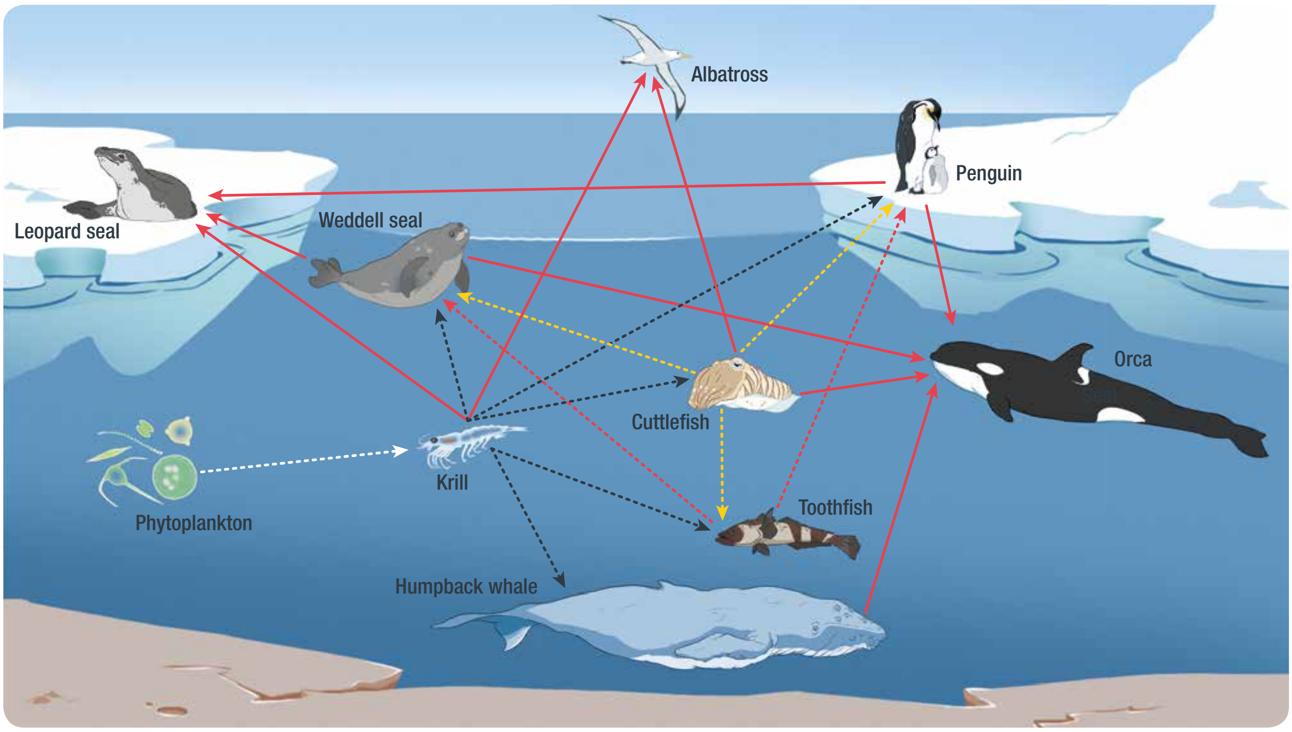
Solution for Worksheets D2.10 and D2.11

Example 5 – North Sea food web



Solution for Worksheets D2.12 and D2.13

Example 6 – Antarctic food web



4. Once the ecosystem is set (all species are connected and everyone agrees on all connections), you can suggest different disruptions to these ecosystems. You can review the student suggestions you wrote on the whiteboard, and add some of those suggested below for the corresponding food web. If one species dies due to a perturbation of its ecosystem, the student sits down on the floor, releasing the strings connecting it to all its predator and prey species. A species can also die when it no longer has food (all its prey species are sitting down on the floor).

Example 1: Coral reef food web

- When water temperatures are unusually high (e.g. during marine heatwaves), coral bleaching can occur. Corals bleach when the polyps expel the symbiotic algae that live inside their tissues. Bleaching leads to the destruction of coral reefs, which are home to approximately 25% of all marine species. Bleached corals continue to live for a while but will die of starvation if water temperatures do not fall again, allowing their symbiotic algae to return.
- Like many reef-forming organisms, corals are made of calcium carbonate and are very sensitive to changes in the pH of sea water. Due to the absorption of man-made CO_2 from the atmosphere, the pH of seawater is falling, leading to ocean acidification. This affects the corals, in particular, which struggle to form their hard skeletons, altering overall reef structures. Certain phytoplankton species are also affected by ocean acidification.
- Other aspects of climate change can also affect coral reef ecosystems, including rising sea levels, increasing occurrence of extreme weather events associated to tropical cyclones, increasing extreme wave heights and altered ocean circulation patterns.
- When combined, all of these impacts dramatically alter the ecosystem function of coral reefs, as well as the services they provide to people worldwide.

Example 2: Kelp forest food web

- Kelp does better at a temperature around 10 to 15°C. They do not survive at a water temperature higher than 20°C. Climate-induced increase in seawater temperature will most likely affect primary production (by kelps), having consequences in the whole food web.
- Some species of sea urchin prefer warmer water. With the increase in water temperature and the decrease in sea otter populations due to hunting, populations of sea urchin are therefore likely to increase drastically. Their grazing pressure could considerably reduce kelp populations and affect the whole ecosystem.

Example 3: Arctic food web

- As the water temperature rises, sea ice melts. Sea ice is the habitat of walruses and seals, the favourite food of polar bears. None of these animals can survive without ice.
- As well as being the habitat of large animals, sea ice also hosts a type of microalgae which only develop in the ice: ice algae. Despite being microscopic, ice algae form large colonies which can reach a few metres below the surface of the ice. In areas covered by ice, ice algae are the main food source for the rest of the Arctic food web. Climate-induced decreases in sea ice will lead to a decrease in ice algae, affecting the whole food web.
- Little auks feed on copepods species specific to cold waters. The warming of their water will alter their diet. The birds will then struggle to find food and their populations will decline.

Example 4: Mangrove food web

- Over the last 50 years, almost half of the world's mangroves have disappeared to make way for shrimp aquaculture and coastal development, or have been used as fuel. Global warming and coastal squeezing due to sea level rise further stress mangrove forests, eventually leading to their disappearance. Although mangroves represent only 1% of the world forests, they store a significant quantity of carbon. Their disappearance could lead to the release of an important amount of CO_2 into the atmosphere.
- Mangroves are the home of shrimp and juvenile fish. Their disappearance have a consequent impact on fisheries.

Example 5: North Sea food web

- Because of the warming of seawater, phytoplankton communities have already started to move northward. This may lead to a reduction in zooplankton (copepods) stocks. Following the northward shift of their food, fish will also move north. Without food, seabirds may struggle to find food causing their population to decline.

Example 6: Antarctic food web

- Krill feed on organisms that can be found under sea ice. Sea ice also protects them from predators. If global warming causes sea ice to retreat, krill will be affected.
- Ocean acidification affects existing shells and the formation of new shells made of calcium carbonate (a chemical compound particularly vulnerable to pH changes). As ocean acidity increases (pH drops), certain phytoplankton species are also affected.
- Ice is the habitat of penguins and seals. Climate-induced ice retreat puts their lives at risk.

Example of an Antarctic food web mural done by students (APECS-France).

5. You can play the same game with different food webs. The students should realize that all living beings are interconnected and that it is important to maintain a balanced ecosystem.

> **➔ TEACHER TIP**
> Primary producers, such as phytoplankton, are "fed" by the sun (via photosynthesis). This means that the students representing them never have to sit down, unless directly affected by climate change consequences.

6. After the game has been played with different ecosystems and climate change consequences, place all role-playing cards on the whiteboard. Ask the students to draw each of the links between species that were represented in the game, connecting all species with arrows, starting with those that are at the basis of the food webs.

OPTION 2 (35 MIN)– MULTIMEDIA ACTIVITIES

Instead of doing the role-playing game, you can use the multimedia activities provided ("Food webs" multimedia activities).

WRAP-UP 10 MIN

Discuss the interdependence of all organisms in ecosystems, how ecosystems have a fragile balance that must be maintained, and the consequences for humans if this balance is not preserved.

OPTIONAL EXTENSION (2 H) – ECOSYSTEM FOOD WEB MURAL

Each student draws a species from the chosen food web, alone or with its predator / prey, on a landscape A4 sheet of paper. Within your class, predator / prey ratios should be respected, in order to avoid having 30 orca per class and only 5 penguins, for example. With the help of your students' drawings, you can create a large mural depicting an ecosystem and its species.

BACKGROUND FOR TEACHERS

ECOSYSTEM

All living things from a given environment form a functional whole, within which the different elements, living things and abiotic factors (the "non-living" elements, such as climate-related factors, type of soil, chemical elements present, etc.) interact. The English botanist Arthur Tansley suggested the term "**ecosystem**" at the beginning of the 20th century to describe this whole, which is the basic ecological unit, in order to qualify an environment and the conditions that characterize it. Tansley also coined the term "biotope". The living things that populate a given biotope are referred to as the biocoenosis. So, we get:

ecosystem = biotope + biocoenosis.

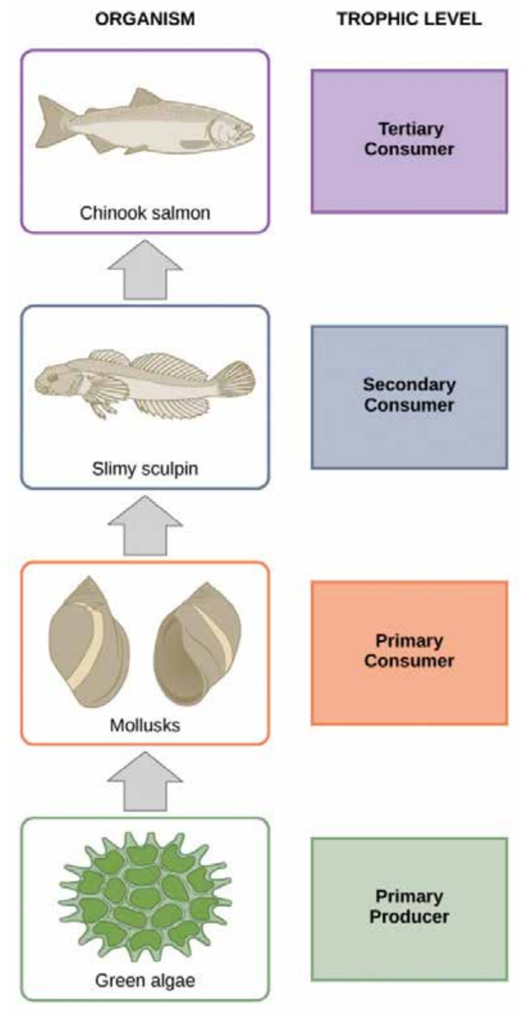
There are a multitude of marine and coastal ecosystems, including estuarine ecosystems, coral reefs, beaches, ocean floor ecosystems and mangrove forests. The cryosphere can also be part of marine ecosystems, which is the case in Arctic and Antarctic ecosystems. However, the cryosphere is also present in numerous terrestrial ecosystems such as Himalayan ecosystems and tundra ecosystems, for example. Each is characterised by a number of abiotic factors and living beings.

Aside from the variations caused by seasons, ecosystems can be affected by various regular or sporadic fluctuations (tidal level, storms, snowfall, etc.), which change the distribution of the different species. While ecosystems evolve over time to reach a state of equilibrium known as "climax", this equilibrium may be easily broken if the functioning of the ecosystem is disrupted, by human activities or climate change for example.

FOOD WEBS

Each ecosystem is structured by **trophic relations**, in which every organism represents a **prey** or a **predator** for another one. Those relations can be viewed as chains, symbolising "who is eaten by whom". However, the reality is more complex, because **food chains** are actually **food webs**, meaning that an organism may eat several species and a species may be eaten by multiple organisms.

Autotroph organisms are always the basis of every food web. These organisms, such as plants and phytoplankton, can produce their own food using light, water, carbon dioxide or other chemical compounds. They are also called **"primary producers"**. Autotrophs are then eaten by heterotrophs, which are not capable of producing their own food. **Heterotroph** organisms can be differentiated into several categories, such as **primary, secondary or tertiary consumers**, depending on their position in the food web (if they directly eat the autotrophs, or instead they eat heterotrophs that eat autotrophs, and so on). When drawing a food web, the arrows conventionally symbolize "is eaten by".



Example of a food chain.

As all species in an ecosystem are interconnected, even the slightest disruption in a species population, or the loss of a single species, can affect all others that depend on it. Considering that a species needs particular environmental conditions (including specific climatic conditions) to thrive, any disruption in these conditions may result in an imbalance of the entire food web with widespread consequences in the ecosystem.

WORKSHEET D2.1

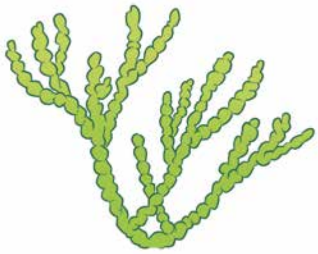
CORAL REEF FOOD WEB 1/3

PHYTOPLANKTON

Phytoplankton are microscopic organisms floating in the sun-lit upper layer of the ocean. Like plants, phytoplankton use sunlight, water, CO_2 and dissolved minerals for photosynthesis and to produce organic compounds. Phytoplankton are a primary producer, at the base of the food web.

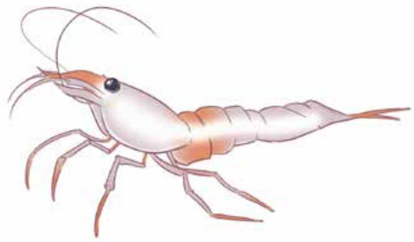
ORGANIC MATTER

Refers to a large pool of carbon-based compounds in seawater that comes from the remains of plants and animals, and their waste products. Descending clumps of organic carbon can resemble snowflakes and are known as “marine snow”. Shrimp and triggerfish feed on organic matter.



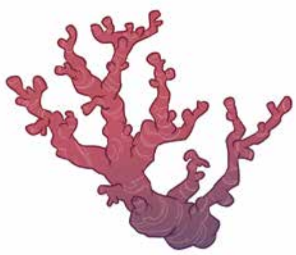
MACROALGAE

Macroalgae, like seagrasses, typically occur in shallow water where there is enough light for growth. They are primary producers, like phytoplankton. They serve as a food source and habitat for crustaceans and molluscs, but also for fish such as parrotfish, butterfly fish and damselfish (which farm macroalgae), as well as turtles.



SHRIMP

Shrimp inhabit the seabed and shallow waters near coasts and estuaries. Shrimp feed on organic matter they find on the seabed, and hide in the sand to escape predators such as octopus and groupers.



CORAL

Corals are animals. They have tiny tentacle-like arms that they use to capture food (phytoplankton) from the water and sweep it into their mouth. Most structures we call “coral” are in fact made up of hundreds or thousands of tiny coral creatures called polyps. Each soft-bodied polyp secretes a hard outer skeleton made of calcium carbonate. Most corals contain algae. Residing within the coral’s tissues, these algae take up the coral’s waste products. In turn, the corals draw on the oxygen and organic products supplied by the algae.

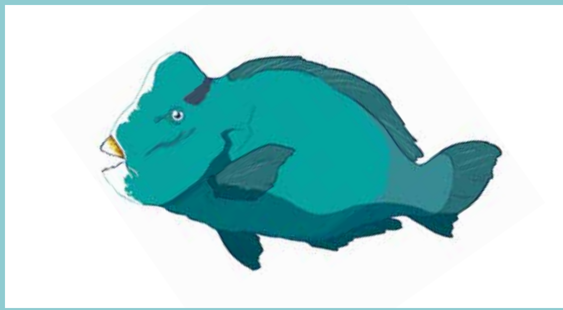
SPONGE

Sponges are found in a wide variety of shapes and colours and are often mistaken for plants. They are animals with bodies full of pores and channels allowing water to circulate through them. As water flows through a sponge’s porous exterior, the sponge gains some forward motion, receives food (phytoplankton) and oxygen, and dispels waste. They serve as food for Moorish idols and turtles.

CORAL REEF FOOD WEB 2/3

TRIGGERFISH

Triggerfish are brightly coloured fish that live in tropical shallow waters. They feed on organic matter and are eaten by sharks and grouper.

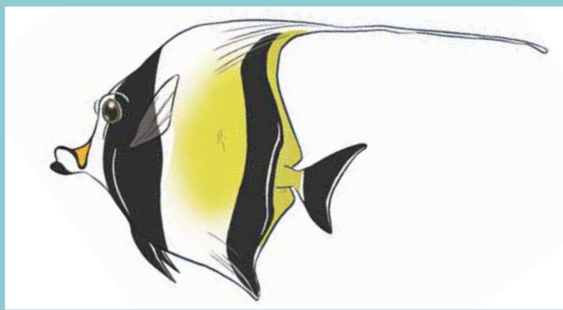


PARROTFISH

Parrotfish live in tropical and subtropical waters. With their parrot-like beak they scrape macroalgae from corals and rocky substrates. They are eaten by sharks and grouper.

BUTTERFLYFISH

Butterflyfish are small, brightly coloured bony fish. They need corals to hide in, and feed on corals and macroalgae. They are eaten by sharks and grouper.



MOORISH IDOL

With characteristic disk-like striped bodies, Moorish idols feed on sponges and corals. They are eaten by sharks.

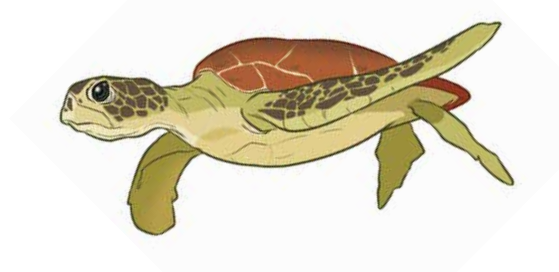
DAMSELFISH

Damselfish are small, brightly coloured fish that live in or near coral reefs. They feed on macroalgae, which they farm, and phytoplankton, and are eaten by grouper and sharks.

OCTOPUS

The octopus is a soft-bodied mollusc and has eight muscular arms, each equipped with two rows of suckers. It mainly eats shrimp and is eaten by sharks and grouper.

CORAL REEF FOOD WEB 3/3

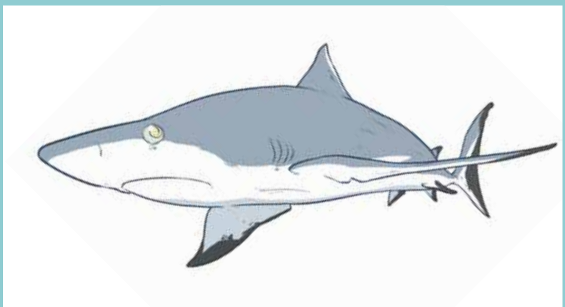


TURTLE

Turtles are reptiles with a bony or leathery shell and flippers, that live in the ocean but, every year, they go ashore on sandy beaches to lay their eggs in the sand. They eat macroalgae and sponges. Their predators are sharks, and young turtles can also be eaten by grouper.

GROUPER

Groupers are large fish with heavy bodies belonging to the sea bass family. They have a big head and a wide mouth. They usually eat fish such as damselfish and are eaten by sharks. They eat fish (such as damselffish, butterflyfish, parrotfish and triggerfish), crustaceans (such as shrimps), and octopus. Large grouper can even eat turtles.



BLACKTIP SHARK

The blacktip shark usually lives in coastal tropical and subtropical waters around the world, including brackish habitats. Blacktip sharks eat all types of fish, octopus and turtles.

KELP FOREST FOOD WEB 1/2

PHYTOPLANKTON

Phytoplankton are microscopic organisms floating in the sun-lit upper layer of the ocean. Like plants, phytoplankton use sunlight, water, CO_2 and dissolved minerals for photosynthesis and produce organic compounds. Phytoplankton are a primary producer, at the base of the food web.

KELP

Kelps are a type of brown macroalgae occurring in temperate and Arctic waters. Like other macroalgae, they typically occur in shallow water where there is suitable light for growth. They are primary producers, like phytoplankton. They serve as food source and habitat to sea urchins, abalones and crabs.

SEA URCHIN

Sea urchins are spiny marine animals living on the seabed. They are typically between 3 and 10 cm in diameter. Sea urchins move slowly and feed on macroalgae. They are the most important herbivores in kelp forests. Their predators include sea otters and starfish.

ABALONE

Abalone are marine snails. They live on the seabed and feed on kelp and other macroalgae. Abalone are eaten by sea otters and starfish.

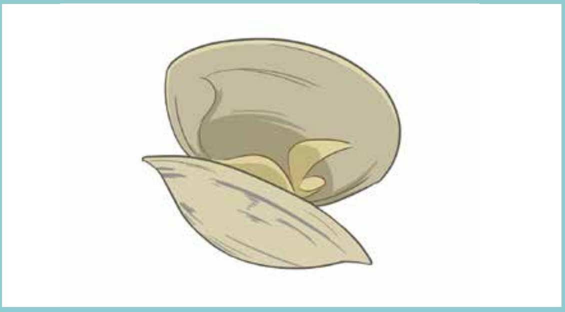
KELP CRAB

Kelp crabs live in the seabed amid kelp forests. In summer, kelp crabs eat kelp and macroalgae. In winter, when the macroalgae die, they turn to an animal diet and eat clams and starfish. Sea otters are major kelp crab predators, but they are also eaten by kelp bass.

STARFISH

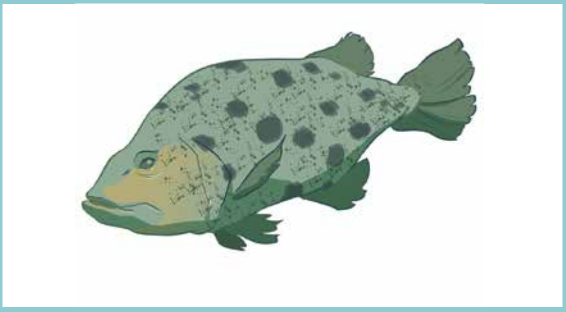
Starfish – or sea stars – live on the seabed. They have a central disc and five arms. They feed on sea urchins, abalone, clams and other shellfish. They serve as food for crabs and sea otters.

KELP FOREST FOOD WEB 2/2



CLAM

Clams are a type of shellfish (5 cm across). They feed on phytoplankton and are eaten by crabs and starfish.

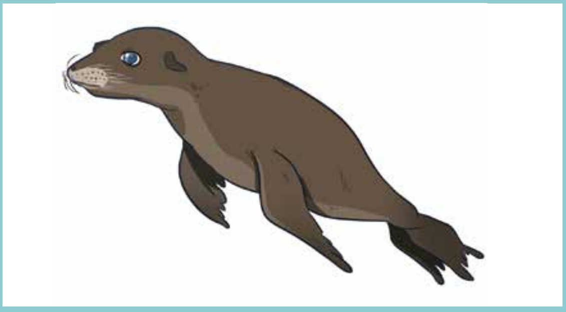


KELP BASS

The kelp bass is a species of marine fish living in kelp forests. It feeds on crustaceans such as crabs and is eaten by sea lions.

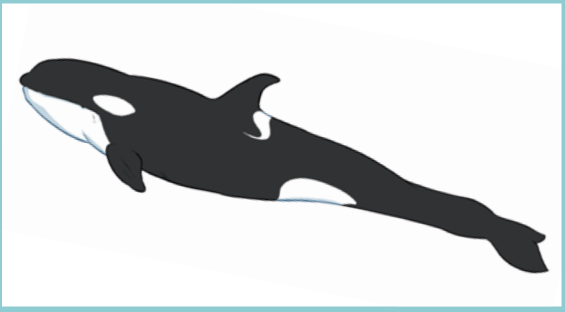
SEA OTTER

The sea otter is the smallest marine mammal. It typically weighs between 14 and 45 kg. Sea otters stay warm thanks to their exceptionally thick coat. They prey on sea urchins, starfish, abalone and crabs. They are hunted by orcas.



SEA LION

The sea lion is a marine mammal related to seals and walruses. A male sea lion weighs an average of 300 kg, while a female weighs around 100 kg. Sea lions feed on fish (kelp bass) and are eaten by orcas.



ORCA

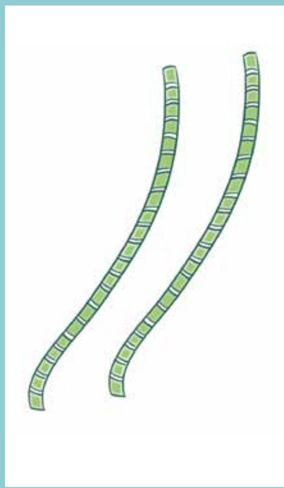
The orca is found in the Arctic and the Southern Oceans and can go as far as tropical seas. It is a highly social animal that lives in families. Its hunting techniques are highly developed and it feeds on large animals, such as sea otters and sea lions.

WORKSHEET D2.6

ARCTIC FOOD WEB 1/2

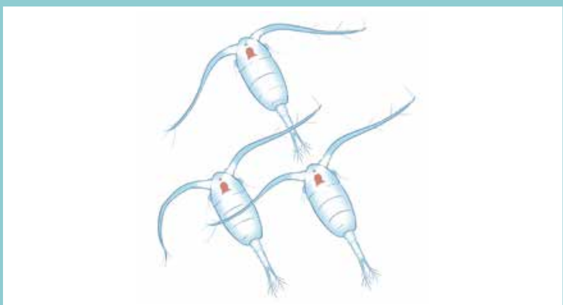
PHYTOPLANKTON

Phytoplankton are microscopic organisms floating in the sun-lit upper layer of the ocean. Like plants, phytoplankton use sunlight, water, CO_2 and dissolved minerals for photosynthesis and to produce organic compounds. Phytoplankton are a primary producer, at the base of the food web.



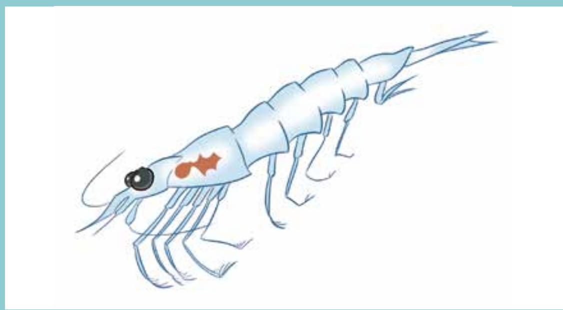
ICE ALGAE

Ice algae are primary producers which develop in the sea ice. They uses sunlight, CO_2 and water to produce organic matter. Despite their microscopic size, they can form chains of a few metres, and animals usually prefer them to phytoplankton due to their higher nutritional value. Hence, they are eaten by clams, copepods and krill.



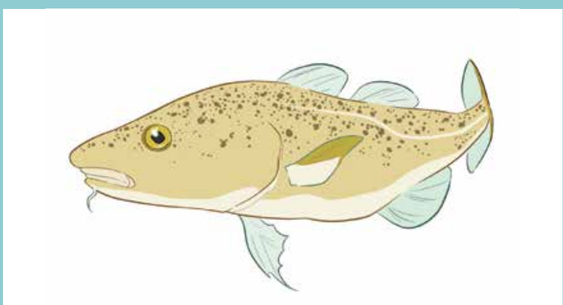
COPEPOD

Copepods are a type of zooplankton, tiny animals drifting with the ocean currents. They are 1 to 5 mm long. They feed on phytoplankton and ice algae and are eaten by fish like Arctic cods and by birds like little auks.



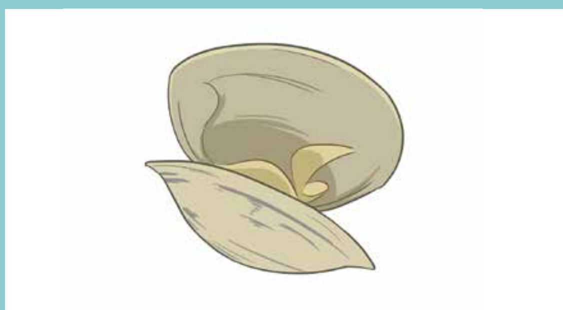
KRILL

Krill, as copepods, are part of the zooplankton. They can be a few centimetres long and weigh up to 2 g. Krill are filter feeders – they filter phytoplankton out of the water and also eat ice algae. They are eaten by whales.



ARCTIC COD

Arctic cods (about 30 cm long) live in the cold waters of the Arctic Ocean and around Greenland. They feed on copepods and are eaten by seals.



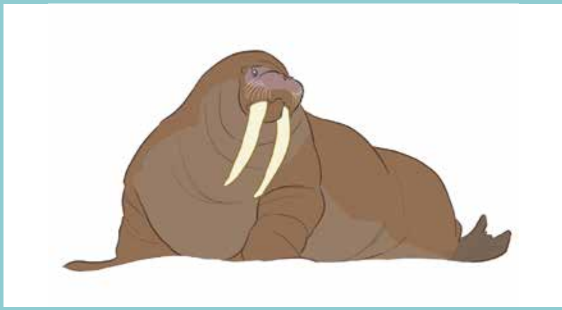
CLAM

Clams are a type of shellfish (5 cm across). They are related to other molluscs such as snails and octopus. They filter phytoplankton and ice algae that reach the seabed and are eaten by walruses.

ARCTIC FOOD WEB 2/2

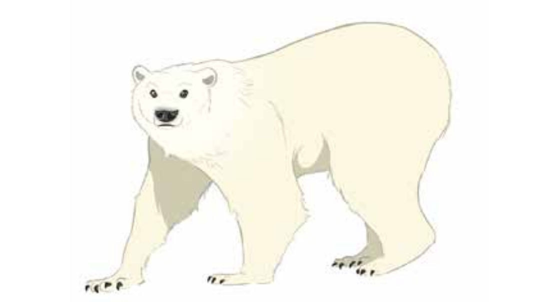
SEAL

The Arctic Ocean is home to several seal species (ribbon seals, bearded seals, ringed seals, spotted seals, hooded seals and harp seals). These large marine mammals mainly eat fish (Arctic cods) and are eaten by polar bears.



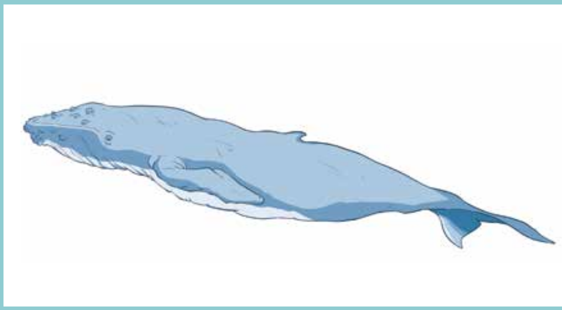
WALRUS

Walruses are large marine mammals (up to 1,700 kg) that inhabit Arctic waters. They are easily recognised by their tusks. Their blubber enables them to spend a lot of time diving in the cold Arctic waters to find their favourite food: clams.



POLAR BEAR

Polar bears are the largest land carnivores that can weigh more than 650 kg. They have a thick white fur to keep them warm. Polar bears spend most of their time on sea ice hunting for seals.



BOWHEAD WHALE

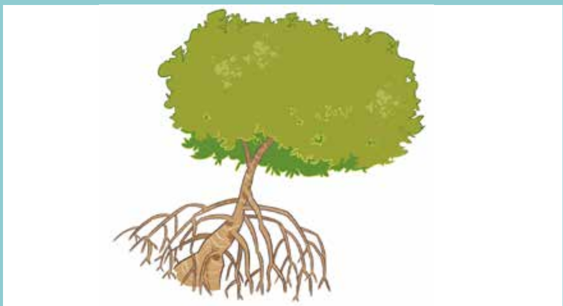
There are 17 different types of whales living in Arctic waters. The bowhead whale is the only baleen whale (toothless whales that filter food from seawater) living there all year round. They only eat krill.

LITTLE AUKS

Little auks are among the most common and smallest seabirds in the North Atlantic, weighting only 150 g. They prefer regions with cold currents and avoid more temperate waters. Little auks feed on copepods.

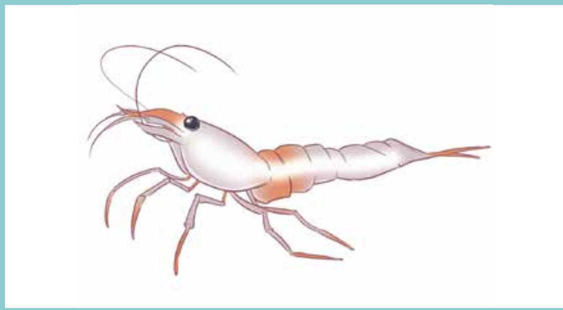
WORKSHEET D2.8

MANGROVE FOOD WEB 1/2



MANGROVE TREE

Mangrove trees grow in large colonies in tropical and sub-tropical coastal areas regularly flooded by tides. The large amount of detritus (leaves, twigs, barks, flowers and seeds) they create can be eaten by crabs, shrimp, sea snails and annelids.

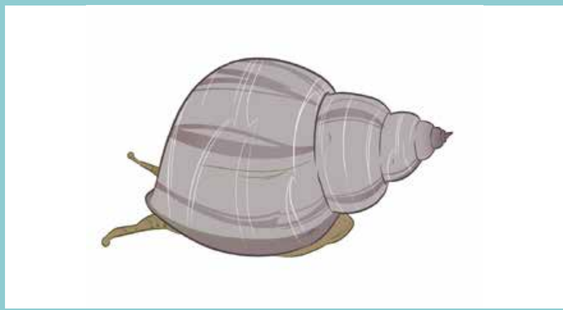


SHRIMP

Shrimp use the muddy bottoms as their homes. Shrimp feed on mangrove detritus they find on the seabed and hide in the sand to escape their predators, such as the red ibis.

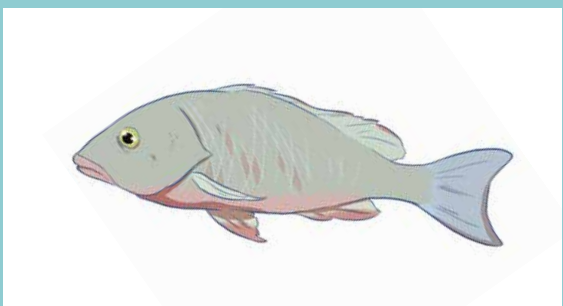
CRAB

Crabs are the most abundant animals in mangroves. Crabs come out of their burrows at low tide to feed on mangrove detritus and annelids. They are eaten by crocodiles and mangrove snappers.



MANGROVE PERIWINKLE

This species of sea snail lives mainly above sea level, on the branches and roots of mangrove trees. It feeds on mangrove detritus and is eaten by mangrove snappers and red ibis.



MANGROVE SNAPPER

The mangrove snapper is typically greyish red and up to 40 cm long. It feeds mostly on small fish such as the periophthalmus, sea snails (such as the mangrove periwinkle) and crabs. It can be eaten by brown pelicans and crocodiles.

BROWN PELICAN

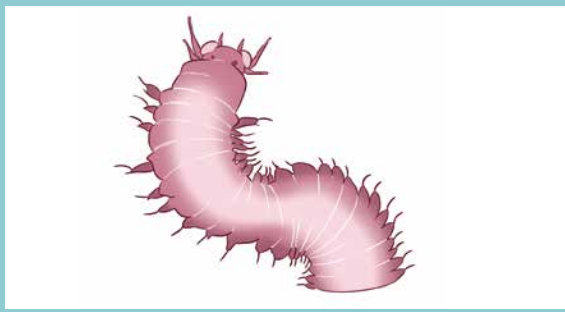
The brown pelican is the smallest of the pelican family. It brown pelican nests in secluded areas such as mangroves. It mainly feeds on fish like the mangrove snapper.

WORKSHEET D2.9

MANGROVE FOOD WEB 2/2

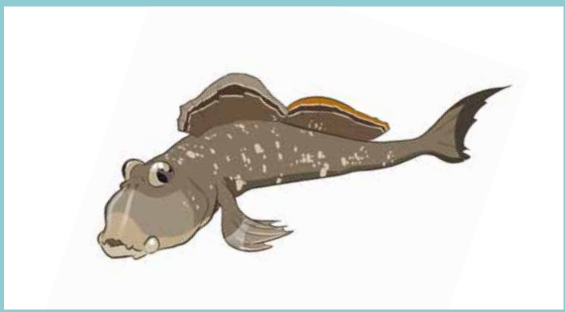
RED IBIS

The red ibis has special feet to move on mud. With its long and thin beak, it can feed within mud by eating shrimp, annelids and sea snails, such as the mangrove periwinkle. Crocodiles can catch red ibis while they are feeding.



ANNELID

Annelids are microscopic worms living in burrows within the mud. They feed on mangrove detritus deposited on the mud, and are eaten by periophthalmus, crabs and red ibis.



PERIOPHTHALMUS

The periophthalmusIt lives mostly in mud and sand bottoms, but can also be seen on mangrove branches, as it can live temporarily out of the water. It feeds on annelids and is eaten by mangrove snappers.

CROCODILE

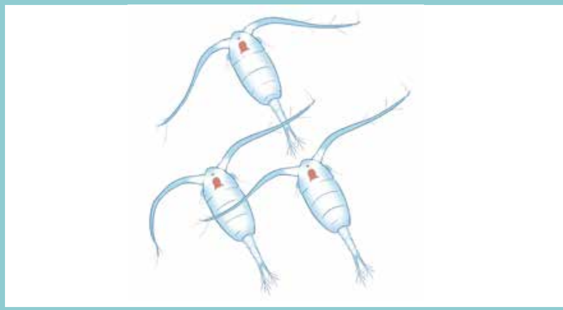
The crocodile is an opportunistic carnivorous predator. It usually hunts its prey by ambushing them, and then either dragging them underwater so they drown or swallowing them whole. It can eat a variety of prey, including fish (mangrove snapper), birds (red ibis) and crabs.

WORKSHEET D2.10

NORTH SEA FOOD WEB 1/2

PHYTOPLANKTON

Phytoplankton are microscopic organisms floating in the sun-lit upper layer of the ocean. Like plants, phytoplankton use sunlight, water, CO_2 and dissolved minerals for photosynthesis and produce organic compounds. Phytoplankton are a primary producer, at the base of the food web.

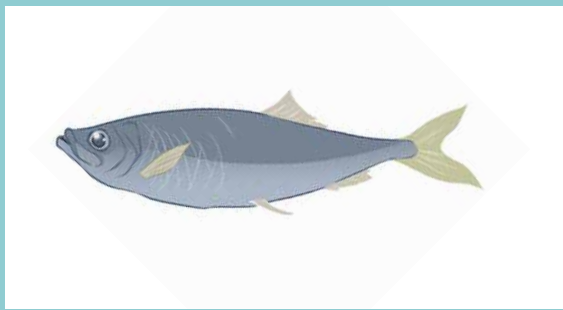


COPEPODS

Copepods are a type of zooplankton, tiny animals drifting with the ocean currents. They are 1 to 5 mm long. They feed on phytoplankton and are eaten by shrimp, herring, mackerel, jellyfish and blue mussels

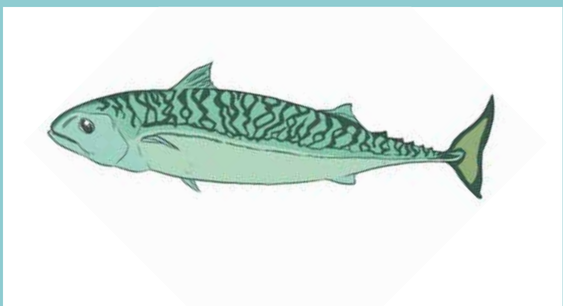
ORGANIC MATTER

The ocean holds a lot of organic matter that comes from dead animals and plants or from animals' faeces. This organic matter accumulates as sediment on the seabed. Descending clumps of organic carbon can resemble snowflakes and are known as "marine snow", serving as food for copepods and shrimp.



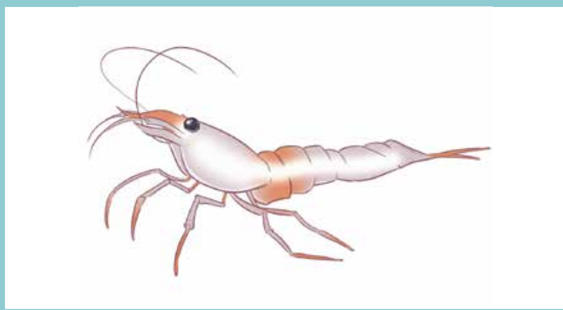
HERRING

Herring live in the open ocean close to the surface. They swim in huge schools and feed on krill. Herring serve as food for species as diverse as spiny dogfish, grey seals, and herring gulls.



ATLANTIC MACKEREL

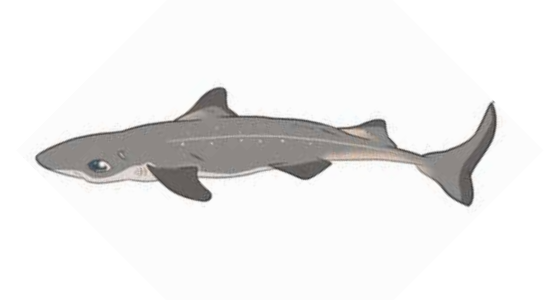
Atlantic mackerel inhabit the open ocean, between the surface and a depth of 200 m, as well as coastal waters. They are constantly in motion and form huge schools. Mackerel feed on copepods and shrimp and their predators include grey seals and spiny dogfish.



SHRIMP

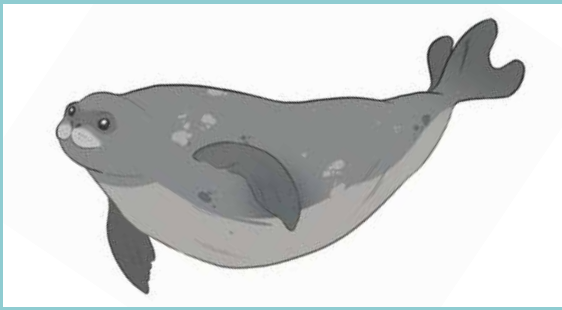
Shrimp inhabit the seabed and shallow waters near coasts and estuaries. They feed on copepods and organic matter. Shrimp hide in the sand to escape their predators: spiny dogfish, grey seals, Atlantic mackerel and herring gulls.

NORTH SEA FOOD WEB 2/2



SPINY DOGFISH

The spiny dogfish is a small shark (approximately 1 m long). It lives in the open ocean at depths between 50 and 200 m. Spiny dogfish hunt in large groups, feeding on other fish such as herring and Atlantic mackerel, and on jellyfish and shrimp or even oystercatchers.

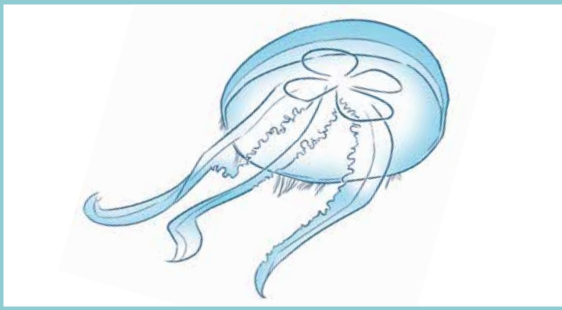


GREY SEAL

Grey seals live in huge colonies on sand or rocks along the coast. They are carnivores and very fast swimmers, diving for their prey at depths of up to 70 m. Grey seals eat almost everything: fish, such as herring and Atlantic mackerel, but also shrimp and jellyfish.

HERRING GULL

Herring gulls are the most common gulls on North Sea shores. They prefer to breed on steep cliffs to protect their eggs and hatchlings from predators on the ground. Herring gulls are omnivores and feed, among others, on herring, Atlantic mackerel, shrimp and blue mussels.



JELLYFISH

Jellyfish can swim but usually drift with the ocean currents and are thus classified as zooplankton. They catch their prey with their four tentacles. Jellyfish feed on phytoplankton and zooplankton like copepods. Spiny dogfish and grey seals are among their predators.

BLUE MUSSEL

Blue mussels are bivalve molluscs living in the intertidal zone. They attach to rocks or to one another, forming large mussel beds. They are filter feeders, feeding on phytoplankton and zooplankton (such as copepods). Their predators are birds like oystercatchers or seagulls, such as the herring gulls.

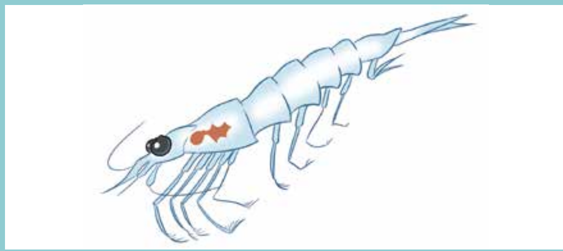
OYSTERCATCHER

Oystercatchers are widespread in the Wadden sea and other shallow intertidal zones. With their long orange beaks, these birds can open the shells of blue mussels to eat them.

ANTARCTIC FOOD WEB 1/2

PHYTOPLANKTON

Phytoplankton are microscopic organisms floating in the sun-lit upper layer of the ocean. Like plants, phytoplankton use sunlight, water, CO_2 and dissolved minerals for photosynthesis and produce organic compounds. Phytoplankton are a primary producer, at the base of the food web.



KRILL

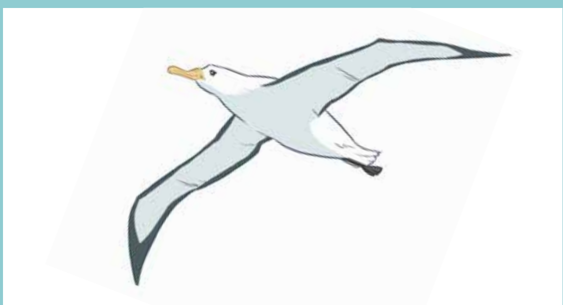
Krill are a type of zooplankton, tiny animals drifting with the ocean currents. They can be a few centimetres long and weigh up to 2 g. Antarctic krill are one of the most abundant multicellular species in the world (est. 500 million tons). Krill are filter feeders – they filter phytoplankton out of the water. They serve as food for all animals in the Antarctic food web except orca.

TOOTHFISH

This fish from the Antarctic is caught at a depth of 2000 m. Toothfish eat krill and cuttlefish, and are eaten by seals and penguins.

PENGUIN

Penguins breed on the pack ice (sea ice not land-fast) in Antarctica during the winter. Females lay a single egg that the adults keep warm on their legs, while taking turns to go fishing at sea. Its elongated shape and fin-like wings (penguins do not fly) allow them to swim underwater. They eat krill, cuttlefish and toothfish, and are eaten by leopard seals and orcas.



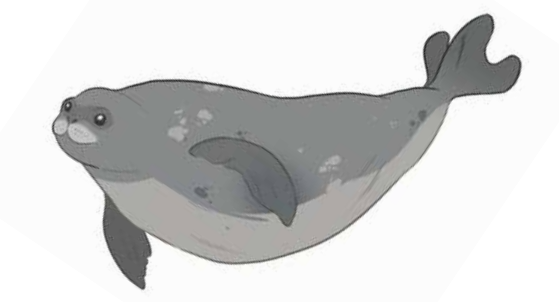
ALBATROSS

The albatross is a seabird. It has the record for the largest wingspan of all current bird species (which can reach more than 3 m). It nests in colonies on isolated islands. Albatross eat cuttlefish and krill.

CUTTELFISH

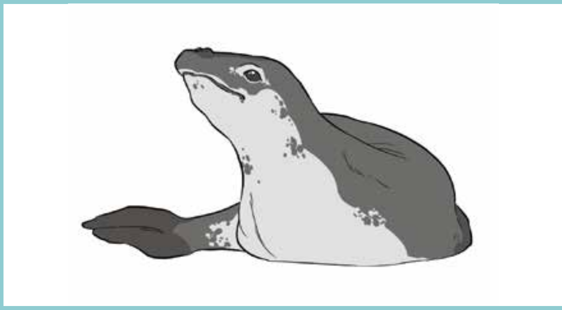
The cuttlefish is a fast-growing shellfish. It has eight arms and two longer tentacles that they use to catch their preys. Cuttlefish eat krill and serve as food for seals, orcas, albatross, penguins and large fish such as toothfish.

ANTARCTIC FOOD WEB 2/2



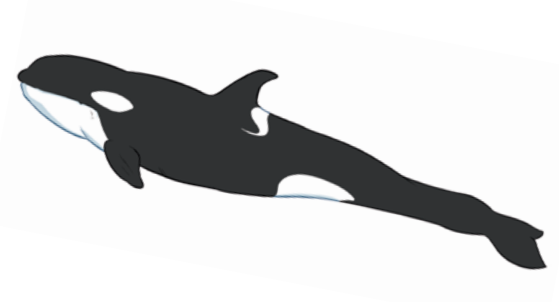
WEDDELL SEAL

The Weddell seal is between 2 and 3 m long and can live up to 20 years. It is an exceptional diver and can stay underwater for more than an hour in search of food (krill, cuttlefish and toothfish).



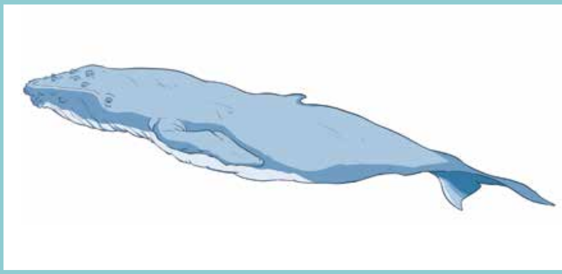
LEOPARD SEAL

The leopard seal is a powerful predator of up to 4 to 5 m long that weighs more than 500 kg. It is a solitary animal and can live for more than 20 years. Leopard seals eat penguins, krill and Weddell seals.



ORCA

The orca is found in both the Arctic and Southern Oceans, and can go as far as tropical seas. It is a highly social animal that lives in families. Its hunting techniques are highly developed and it feeds on large animals, such as seals, whales, cuttlefish and penguins.



HUMPBACK WHALE

The humpback whale is generally 14 to 15 m long and weighs about 25 tons. It lives in the world's oceans and breeds near the equator. It migrates either to the Arctic or Antarctic when summer arrives and the pack ice melts. Humpback whales feed on krill and are eaten by orcas.

LESSON D3
OCEAN AND CRYOSPHERE CULTURAL SERVICES

MAIN SUBJECTS
Social sciences / Visual or performing arts

DURATION
~ Preparation: 20 min
~ Activity: 2 h

SUMMARY
This session should be adapted to local contexts. An example is provided.
Through documentary research and / or an artwork / artistic performance, students learn about the cultural importance of the ocean and cryosphere for human populations across history.

KEY IDEAS
~ The oceans and cryosphere have influenced and influence our history, culture and economy.
~ Before the use of coal, gas and (petroleum) oil, whale oil was an important energy source.
~ There is a strong link between polar exploration and the whale industry: the discovery of Spitzbergen and of Antarctica opened new territories for whale hunters, contributing to an increase in whale hunting.
~ The number of whales has decreased dramatically since then, but today populations are starting to increase again.

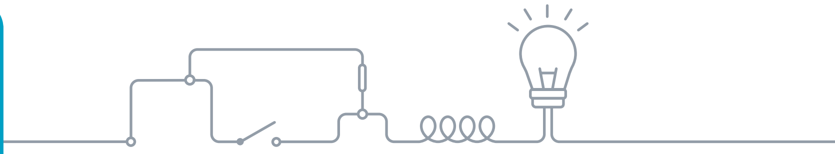
KEYWORDS
Whaling industry, polar exploration, economy, whale oil

INQUIRY METHOD
Documentary analysis

PREPARATION 20 MIN

MATERIALS
- **WORKSHEETS D3.1, D3.2, D3.3**;
- Long paper sheet (to produce a timeline);
- Computer / tablet / mobile with Internet access;
- World map.

LESSON PREPARATION
1. List the websites that can be used for the documentary study (a first list is provided below).
2. Print the **WORKSHEETS D3.1, D3.2, D3.3**, one per student (or group of students).



INTRODUCTION 10 MIN

Start by asking the students: *What were the main sources of energy before the use of oil, gas and coal? What was used to power city lighting before gas and electricity?* The answer is whale oil.

PROCEDURE 1 H 40

PART 1 (50 MIN) – WHALE OIL

1. Calculate the number of whales needed every day to light the 5,000 lamps in the city of London in 1740, considering that:
- A sperm whale could provide about 30 barrels of oil (a barrel being 158 litres of oil);
- A lamp would burn around 2 litres in 10 hours.

Answer: about one whale per night was "burnt" in the city of London.

2. Ask the students to put together a timeline of the whale industry from Basque whaling, through to Antarctic and South Georgia whaling using the links provided in **WORKSHEET D3.1** as information sources. With the help of **WORKSHEET D3.1**, they can conduct their online research independently.

3. Using the information they find, highlight the link between the exploration of the Arctic and Antarctic and the whale industry. Think about the impact exploration had on the economy. The students can write a small text or give a small talk. Make sure you also discuss the reliability of the different information sources provided.

PART 2 (50 MIN) – TODAY'S OIL

4. With **WORKSHEETS D3.2** and **D3.3** the students can analyze and answer the questions about the new maritime routes that are opening up due to sea ice melting in the Arctic.

Following the questions in the end of **WORKSHEET D3.3**, debate with the class on what they think the causes and implications of the opening of these new maritime routes are.

WRAP-UP 10 MIN

Discuss the parallel between the consumption of whale oil and today's consumption of fossil fuels (as two examples of exploited resources) and the search for new maritime routes that will allow access to new oil fields. (The Arctic is considered to have high potential for new oil field finds, which are currently too expensive to exploit due to their inaccessibility, but this will change as sea ice melts and new maritime routes facilitate exploitation. Not only maritime transport companies will benefit from sea ice melting, but also oil companies).

BACKGROUND FOR TEACHERS

From the 11th to the 17th century, maritime exploration helped shape the global economy. The main fuel used from the 16th to the 19th century was wood, but most lamp oil was from whales. Whale oil was also used for heating and cooking. Moreover, the oil of sperm whales was used for the lubrication of high-quality engines. Baleens were used for making women's corsetry and whale meat was commonly eaten.

Due to their multiple uses, whales were intensively hunted, and their populations decreased very rapidly until the early decades of the 20th century. Whale hunters were forced to seek new whale populations living in places further from European coasts in order to address the increasing demand for whale oil. For example, the discovery of Spitsbergen (part of the Svalbard archipelago, in northern Norway), which was known for its large whale population, attracted many whale hunters and led to fishery disputes, especially between Dutch, English and French vessels. Later on, the decrease in Arctic whale populations due to overfishing, and the exploration of new territories and polar lands, pushed whaling fleets to seek places where they could find migrating whales, such as South Georgia and Antarctica.

Nowadays, commercial whale hunting has almost stopped and whale populations are recovering.

The importance of whale products at the end of the 20th century can be seen as a parallel to today's fossil fuel consumption: it is widespread, used in all sectors of our society, our economy depends very strongly on it and… it is a finite resource with multiple impacts on the Earth's ecosystems.

WORKSHEET D3.1

POLAR EXPLORATION

→ https://en.wikipedia.org/wiki/History_of_Antarctica
→ https://en.wikipedia.org/wiki/Arctic_exploration
→ https://www.rmg.co.uk/discover/explore/exploration-endeavour/polar-exploration
→ https://www.canterbury.ac.nz/media/documents/oexp-science/gateway-antarctica/gateway-antarctica-activities/The-History-of-Antarctic-Exploration.pdf

WHALING

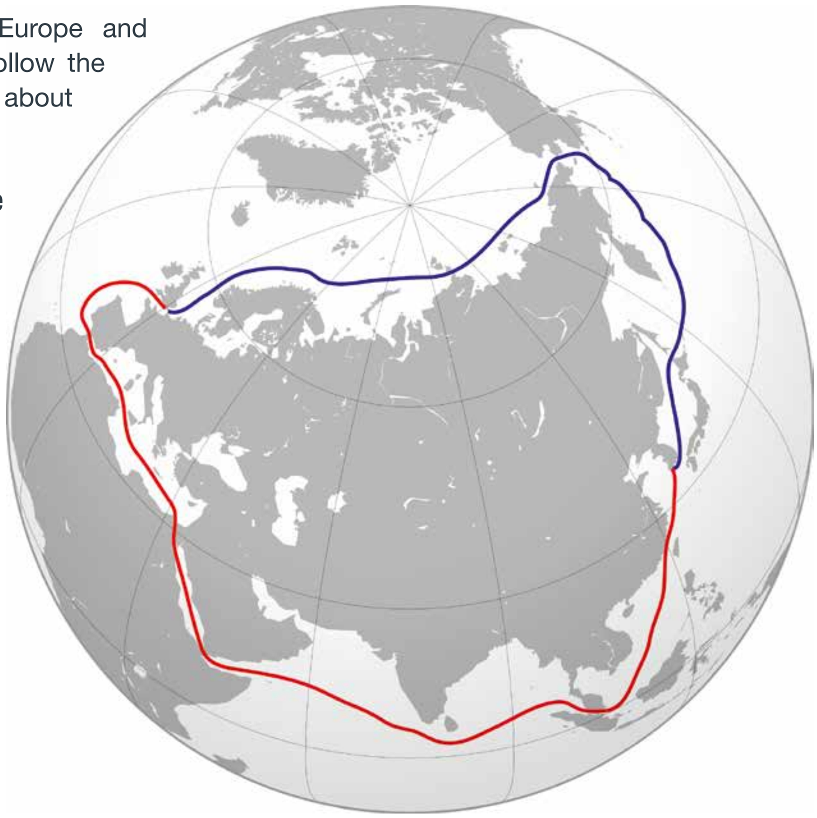
→ https://en.wikipedia.org/wiki/Whaling
→ https://www.whalefacts.org/whale-hunting/
→ https://www.whalingmuseum.org/learn/research-topics/overview-of-north-american-whaling/whales-hunting
→ http://www.scran.ac.uk/packs/exhibitions/learning_materials/webs/40/whaleoil_overview.htm
→ http://www.petroleumhistory.org/OilHistory/pages/Whale/prices.html

SHIPPING ROUTES

→ https://www.maritime-executive.com/editorials/the-arctic-shipping-route-no-one-s-talking-about
→ https://www.britannica.com/place/Northwest-Passage-trade-route
→ https://en.wikipedia.org/wiki/Northeast_Passage
→ https://en.wikipedia.org/wiki/Northwest_Passage

The figure below shows a photo of a container ship. Container ships are cargo ships that transport their load in truck-sized containers. A large share of maritime cargo is transported with container ships.

When transporting goods between Europe and Asia, large container ships currently follow the red path (called the maritime silk road): about 21,200 km in approximately 50 days!



Why do you think they can't follow the blue path (the Northern sea route)? It is only around 14,062 km long and travel time would be two weeks shorter.

WORKSHEET D3.3

Look again at these images that you already know from a previous lesson.

- Do you remember what the difference was between these two images?
- Can you draw the blue path of the previous figure on both images?
- Do you think large container ships could take the blue path in 1979? What about in 2015?

Source: NASA – https://svs.gsfc.nasa.gov/4435

Nowadays, some vessels already take the Northern sea route, but they usually have to be escorted by expensive icebreakers (which are very strong ships capable of breaking the sea ice to create a passage for vessels that follow). Since this is dangerous and expensive, few maritime transport companies choose to use this route.
For container ships, it was almost impossible to take the Northern sea route until very recently: In September 2018, the ice-class ship, Venta Maersk (in the figure of **WORKSHEET D3.2**), finally made it: it was the first container ship to take the Northern sea route (the blue path), and only needed an icebreaker escort for a few days.

- Why do you think Venta Maersk finally made it in 2018, almost without an icebreaker escort?
- Do you think this is good or bad? Why?
- Who do you think will benefit most?

Note: Ice-class ship – a ship capable of navigating through sea ice.

SEQUENCE E

WHAT CAN WE DO?

Once the consequences of climate change for oceans and the cryosphere are understood, and the value of what is at stake is grasped, there is just one more aspect needed before taking action: accepting responsibility for what is happening. This is the objective of this last sequence, that precedes the action projects. The students will discover which is their share of responsibility, and that of their family and country, for climate change, and also their exposure and vulnerability to it. They will learn about the social inequalities intrinsic to climate change, and about climate justice. Finally, they will discover that there are already many people in many places around the world taking action to mitigate and to adapt to climate change, and then they will decide what they can do themselves. This sequence is strongly rooted in the social sciences and is aimed at pushing students to think beyond the exclusively environmental and self-preservation aspects of climate change.

LESSON LIST

◉ Core lesson ○ Optional lesson

○	E1	**Our carbon footprint** Social sciences / Natural sciences The students use a carbon-footprint calculator to assess their carbon footprint and discuss what they can do to reduce it.	page 129
○	E2	**Climate justice: debate** Social sciences (advanced students) The students debate about questions that raise the issue of climate justice.	page 132
◉	E3	**Climate justice: role-playing game** Social sciences Through a role-playing game, the students discover the inequalities between the countries with respect to wealth and greenhouse gas emissions. Another role-playing game helps them to realise that the vulnerability to climate change is not the same for all countries – the most vulnerable not always being the most responsible.	page 136
◉	E4	**Adaptation and mitigation solutions worldwide** Social sciences / Natural sciences The students realise that there are many solutions to deal with climate change, either through adaptation or mitigation, and that many people and organisations are already active. The students choose a climate adaption/mitigation project to work on.	page 144

LESSON E1
OUR CARBON FOOTPRINT

MAIN SUBJECTS
Social sciences / Natural sciences

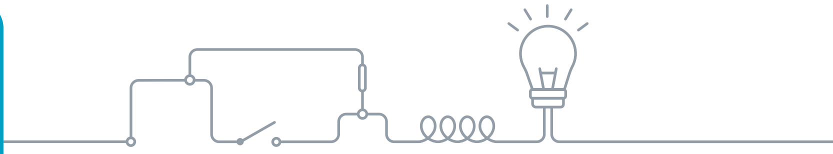
DURATION
~ Preparation: 10 min
~ Activity: 2 h

SUMMARY
The students use a carbon footprint calculator to assess their carbon footprint and discuss what they can do to reduce it.

KEY IDEAS
~ We all have a carbon footprint, but we can help mitigate climate change if we reduce our individual emissions of greenhouse gases.
~ Each country and each person have a different carbon footprint.

KEYWORDS
Carbon footprint, greenhouse gas emissions

INQUIRY METHOD
Data collection



TEACHER TIP
This session is compulsory if the class chooses a mitigation-oriented project (see part 2 of this guide), but can also be done in the case of an adaptation-oriented project. It is, by far, more suitable for classes living in developed countries, where greenhouse gas emissions per capita are higher than in developing countries.

PREPARATION 10 MIN

MATERIALS

- **WORKSHEET E1.1** and / or interactive online questionnaire;
- Computers (at least one for each pair of students).

Multimedia resource: carbon footprint calculator. See page 182.

LESSON PREPARATION

1. Print **WORKSHEET E1.1** (one per student).
2. The interactive calculator can be used both online and offline (you may download it beforehand). If no computers are available in the school, this session can also be done as an "unplugged" activity (with a printed spreadsheet) or at home (if the students have an internet connection at home).

INTRODUCTION 10 MIN

Explain that in order to efficiently reduce our greenhouse gas emissions, we must know which, in our daily lives, are the behaviours that emit more greenhouse gases. This is why we must calculate our "carbon footprint".

To begin the lesson, you can use **WORKSHEET E1.1** to discuss with the students on their ideas on the amount of greenhouse gases emitted by different everyday life activities. Since they are possibility not familiar with this exercise, you can start by telling them that a car emits 20 Kg of CO_2-eq per 100 km and per passenger.

PROCEDURE 30 MIN

1. Explain the purpose of the activity and the importance of truthfully answering all questions (it is not a "who has the smallest emissions" challenge but a tool that is useful to understand what each one can do).

2. Let each student complete the interactive online questionnaire and discuss it with his / her group.

3. Compare the results and discuss the actions that could be undertaken to reduce the carbon footprint of individuals, schools, families, etc. Hand out **WORKSHEET E1.1** to each student so they can take it home and discuss with their family and friends.

TEACHER TIP

Keep in mind that the greenhouse gas emission values provided in this lesson are indicative, since they depend on multiple factors, such as the country considered, the individual, the year, etc. You may try to find more precise values for your own country/region if you wish.

WRAP-UP 20 MIN

Compare the average carbon footprint of the class with the average footprint of different countries. Discuss the importance of reducing carbon emissions on a global scale and the importance of implementing this reduction in countries where carbon emissions per capita are higher, while the other countries may focus on adaptation.

TEACHER TIP

Carbon footprints only measure one aspect, namely our greenhouse gas emissions, of the myriad of ways in which we impact the environment. Students should be aware that there are other environmental impacts associated to the goods and services we consume – things they might want to consider at the same time as they act to reduce their carbon footprint. For instance, for food-buying choices, were any trees cut down or pollutants released to produce the product? Did the farmers receive a fair price?

BACKGROUND FOR TEACHERS

A carbon footprint is usually defined as the total amount of CO_2 and other greenhouse gases emitted by an entity, such as a person, a country, an activity or a product and is expressed as kilograms of CO_2 equivalent (CO_2-eq).
CO_2-eq is a measure based on the Global Warming Potential of each greenhouse gas (see the Background for Teachers of Lesson B3) that is used to express the warming effect of the emissions from different greenhouse gases. The warming effect of each greenhouse gas is thus measured in terms of the amount of CO_2 that would generate the same amount of warming.
For instance, in the case of a product, the CO_2-eq is a measure of the effect of the different greenhouse gases emitted during the entire life cycle of that product - production, transport, use and disposal/recycling.

Calculating the footprint will help you, or the group you belong to, identify which of your activities produce the most CO_2-eq, and therefore which are the most critical to target. Rather than trying to get a precise estimate of each of the contributions to the footprint, the key is to get a rough estimate of their relative sizes, so you can identify which are the largest and thus most important to act on. Pages 20-22 of the Scientific Overview provide some tips on how to reduce your carbon footprint.

WORKSHEET E1.1

AVERAGE VALUES OF CARBON EMISSIONS DUE TO…

COMPUTERS [1]

- → A desktop computer used for 8 hours a day produces 175 kg of CO_2 per year.
- → A laptop used for 8 hours a day produces between 44 and 88 kg of CO_2 per year.
- → A computer in standby mode consumes a third of the energy of a computer turned on.

INTERNET [2, 3]

- → An email with a 1 MB attachment emits 20 g of CO_2, equivalent to a 60 W lamp used for 25 minutes.
- → An email (text only, without attachment) emits 4 g of CO_2.
- → One text message via telephone network (SMS) produces 0.002 g of CO_2.
- → One text message via Internet (social media) produces 4 g of CO_2.
- → An internet user conducting 2.6 web searches per day emits about 10 kg of CO_2 per year.

TRANSPORTATION [4]

- → A car emits 20 kg of CO_2 per 100 km and per passenger.
- → An airplane emits 10 kg of CO_2 per 100 km and per passenger.
- → A scooter emits 8.4 kg of CO_2 per 100 km and per passenger.
- → A bus emits about 10 kg of CO_2 per 100 km and per passenger.
- → A train emits from 0.6 up to 4 kg of CO_2 per 100 km and per passenger.

FOOD [5]

- → 1 kg of beef = 20 kg of CO_2 emitted = 100 km travelling by car.
- → 1 kg of chicken = 6.2 kg of CO_2 emitted = 30 km travelling by car.
- → 1 kg of Brazilian beef consumed in Europe = 335 kg of CO_2 emitted = 1675 km travelling by car.
- → 1 kg of potatoes = 0.08 kg of CO_2 emitted = 0.4 km travelling by car.

ONE TON OF CO_2 EQUALS [6]

- → 1 round-trip flight for one person between Beijing (China) and Moscow (Russia).
- → about 10 round-trip flights for one person between Buenos Aires and Cordoba (Argentina).
- → 5,000 km car journey.
- → The averaged energy consumption of a person living in France to heat their home for one year.
- → A tree will sequester 1 ton of CO_2 in its life.

Note: for simplicity, carbon emissions are expressed in kg of CO_2. Scientists measure carbon emissions in CO_2-eq units, which consider the warming effect of the CO_2, but also of other greenhouse gases.

1 Sibelga - https://www.energuide.be/
2 Sibelga - https://www.energuide.be/
3 How bad are bananas? The carbon footprint of everything, Mike Berners-Lee
4 https://www.carbonfootprint.com/
5 Journal of Life Cycle Assessment, ADEME
6 Adapted from Direction Générale de l'Aviation Civile

LESSON E2
CLIMATE JUSTICE (ADVANCED STUDENTS)

MAIN SUBJECTS
Social sciences

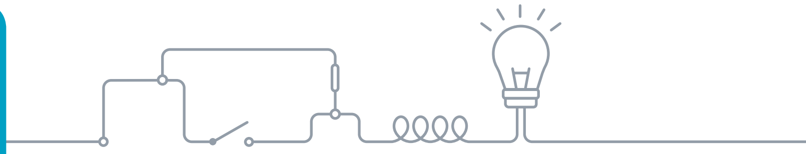
DURATION
~ Preparation: 1 h
~ Activity: 1 h 30

SUMMARY
The students discuss topics that raise the issue of climate justice.

KEY IDEAS
~ Not all countries emit the same amount of greenhouse gases, nor are they equally vulnerable to climate change impacts.
~ The wealthiest countries emit the greatest amounts of greenhouse gases.
~ Droughts, storms and floods exacerbated by climate change mainly impact people living in developing countries who have contributed least to climate change.
~ The majority of the world's people live in rapidly developing countries; this will have an impact on future greenhouse gas emissions.
~ There is a growing consciousness of the need for urgent and widespread action to limit climate change and protect the most vulnerable.
~ Science can explain the origins and mechanisms of what is happening, but it is the choices of each citizen and the countries' legislations that guide actions.

KEYWORDS
Responsibility, vulnerability, equity, climate justice

INQUIRY METHOD
Debate



PREPARATION 1 H

MATERIALS
- Documents prepared according to the topic chosen (see item 3 of the "Procedure");
- Sound recorder;
- One "talking stick".

LESSON PREPARATION
1. Prepare documents according to the topic chosen.
2. Place all classroom chairs in a circle with no tables.

TEACHER TIP
This lesson is presented in the form of a "philosophical workshop".
It is recommended that you intervene as little as possible during a lesson of this type, in order to avoid biasing the discussion. The idea is not to reach a specific conclusion, or express what is true or false, but to have the students realize the difficulty of the dilemmas with which our society is confronted. Here, the science (and the facts) provide food for thought, but it is the moral or ethical choices that allow each person to form his / her own opinion.
The discussion should be organised in a way that facilitates freedom of expression. The question that opens the debate must be chosen according to the local context, current events, etc. The questions we propose are just examples.

INTRODUCTION 10 MIN

We have learned about the greenhouse effect and the consequences of climate change. We have seen that many of the ecosystem services we need may be affected. We are now going to think about the potential implications in terms of social justice.

PROCEDURE 1 H 10

1. The students sit in a circle. The teacher remains outside of the circle.

2. Explain to the students the rules of the philosophical discussion:
→ A "talking stick" will be passed from student to student. Each student has the right to say whatever his / her thoughts are on the question that will be asked, but only while holding the stick.
→ There are no right or wrong answers.
→ No one has the right to speak at the same time as the holder of the stick.
→ No one is allowed to judge or make fun of the person talking. Everyone must listen to and respect the others' ideas.

- No one is obliged to speak when his/her turn arrives. The student can simply pass on the stick if he/she does not wish to speak.
- You can record the answers.

3. Ask the students to think about one of the following issues (choose only one question, the one that seems most relevant for your class):

- *Should we welcome in our country climate refugees from other countries?*
- *Should developed countries pay a higher price to mitigate climate change than developing countries, even if, today, some developing countries emit more greenhouse gases?*
- *Why should we take action? Isn't it governments' (or industries') responsibility to do something rather than ours?*
- *Should the cost of fighting climate change be borne by those most responsible, or by those that will benefit the most from mitigating climate change effects?*
- *In order to help the poorest countries, is it more efficient to fight against climate change or to continue maximising economic growth?*
- *Why should we make an effort if others (other countries, other people) are not ready to make an effort themselves?*
- *Fighting against climate change implies drastic changes in our way of life. Won't these drastic changes cause even more serious social problems?*
- *Why should we pay for the consequences of our parents' and grandparents' actions?*

4. After a few minutes, give the "talking stick" to a random student and ask him/her to share his/her reflections on the subject. When the stick returns to the initial student, ask the students who did not speak if they wish to do so now. At the end, stop the recording.

5. Ask the students if they want to give their opinion on how the exercise went (*Was everyone heard and respected? Was it a hard exercise? Were the opinions interesting?*)

6. Replay the recording to the students and, afterwards, tell them to point out all the pros and cons that were mentioned. Write them on the whiteboard.

7. Distribute the documents that you prepared to each student. *In view of the previous discussion, which arguments (in the documents) are for or against each point of view?*

WRAP-UP 10 MIN

Conclude the lesson by asking the students: *Given what you have learn about who is responsible for and who is most vulnerable to climate change, do you think climate change is "fair"?* The issues of wealth, greenhouse gas emissions and differences in exposure and vulnerability to climate impacts should be discussed. (The wealthiest countries are the biggest greenhouse gas emitters per capita but are the less exposed to and vulnerable to the impacts of climate change. This is due to their geographic location and to the resources they have available to adapt to and cope with climate change consequences.)

BACKGROUND FOR TEACHERS

Current **greenhouse gas emissions are unevenly distributed among countries**. In 2017, 58% of the world's CO_2 emissions from fossil fuels were produced by China (27%), the United States (17%), the European Union (10%) and India (7%). Per person (per capita), the order is different: the United States produce 16.2 tons per person; China and the European Union produce 7 tons per person and India produce 1.8 tons per person. This means, for example, that even though China is the greatest emitter, since its population is the largest in the world, the emissions per capita may be lower than in the United States, whose population is around a billion people fewer, but where each average person emits more than the average Chinese person.

Looking at the past, developed countries contributed heavily to the current CO_2 concentration: during the century between 1880 and 1980, the United States and Europe each contributed to 30% of the CO_2 emitted by fossil fuel burning. Still today, developed countries are the biggest greenhouse gas emitters. The increase of the Asian contribution (China and India) began around the year 2000, with their industrialisation and demographic increase.

Not all countries contribute equally to global greenhouse gas emissions and not [...]

[...] all countries are equally affected by climate change consequences; frequently, the most affected are not the most responsible (see pages 18-23 of the Scientific Overview for further details on exposure and vulnerability).

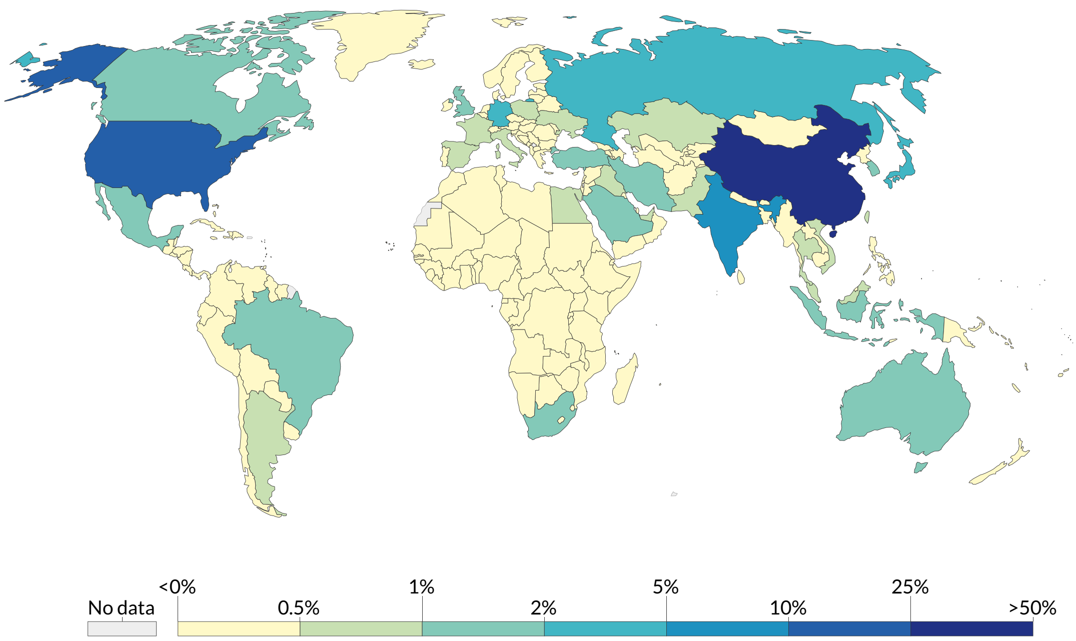
Ensuring there is **climate justice** in a given action thus requires the weighing up of different factors: Are the most industrialised countries – which acquired their wealth, and still do, thanks to energy from fossil fuel combustion – to be considered responsible for the damages caused by climate change, in less wealthy countries? If, for example, a carbon tax is to be implemented to reduce CO_2 emissions (e.g. taxing petrol engine use), how can we make sure that it does not further worsen the living conditions of the less wealthy part of the population? If new "zero-carbon" energy power plants are installed in developing countries, which badly need energy, who should cover the extra-cost this represents, compared to more classical installations (e.g. a gas-fired power plant for electricity production)?

These questions, and the search for solutions, illustrate the complexity of the Earth's system, which in the human era includes human societies. Nearly everything is interdependent on everything else: an action may have zero or negative feedback, but also positive feedback, making the overall situation worse.

Science can and must give the facts and the evidence, improve the projections for the future, estimate probabilities of events as best it can, and do its best to establish conclusions based on rationality, and make them known and understood by everybody. However, **science alone cannot provide the rules for the steps to be taken, nor say what is fair or prove that there is justice in global solidarity**. With such complex and global issues, the **ethical and moral values of both individuals and societies are ultimately the sources of judgment and decisions.**

SHARE (IN %) OF GLOBAL CUMULATIVE CO_2 EMISSIONS IN 2017

Each country's share of global carbon dioxide (CO_2) emissions. This is measured as each country's emissions divided by the sum of all countries' emissions in a given year plus international aviation and shipping (known as "bunkers") and "statistical differences" in carbon accounts.



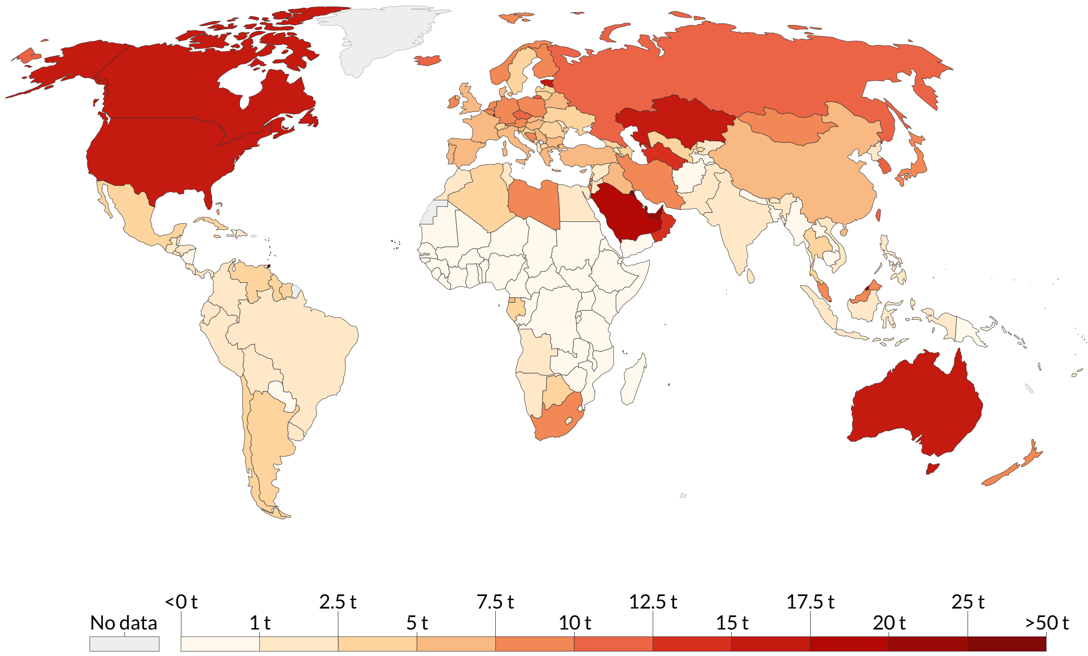
Source: Our World in Data based on Global Carbon Project (2018).
http://OurWorldInData.org/co2-and-other-greenhouse-gas-emissions

[...]

[...]

CO_2 EMISSIONS PER CAPITA IN 2017

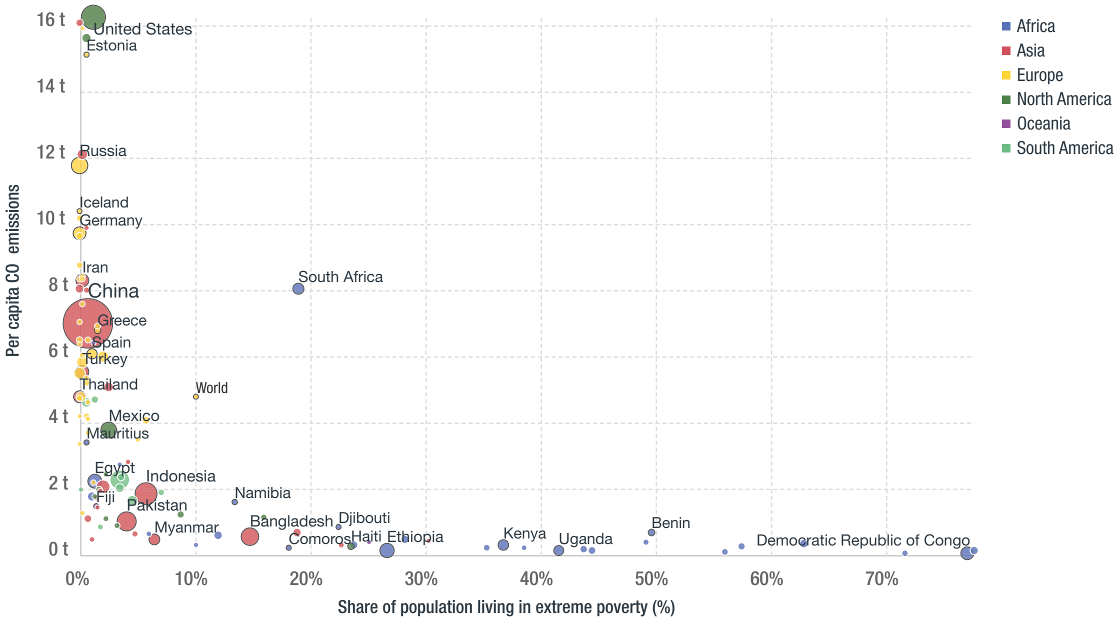
Average carbon dioxide (CO_2) emissions per capita measured in tonnes per year.



Source: OWID based on CDIAC; Global Carbon Project; Gapminder & UN.
http://OurWorldInData.org/co2-and-other-greenhouse-gas-emissions/

CO_2 EMISSIONS PER CAPITA IN 2017 VS SHARE (%) OF PEOPLE LIVING IN EXTREME POVERTY

Average CO_2 emissions per capita are measured in tonnes per year. Extreme poverty is defined as living at a consumption (or income) level below 1.90 "international-$" per day. International $ are adjusted for price differences between countries and price changes over time (inflation).



Source: Global Carbon Project; World Bank; Gapminder & UN.
http://OurWorldInData.org/co2-and-other-greenhouse-gas-emissions/

LESSON E3
CLIMATE JUSTICE [1]

MAIN SUBJECTS
Social sciences

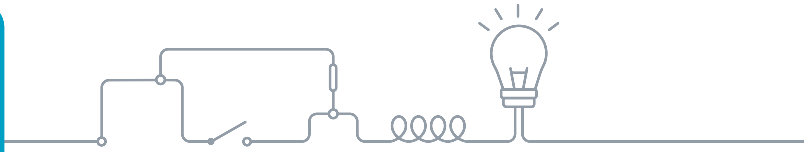
DURATION
- Preparation: 15 min
- Activity: 2 h

SUMMARY
Through a role-playing game, students discover the inequalities between countries with respect to wealth and greenhouse gas emissions. Another role-playing game helps them realise that vulnerability to climate change is not the same for all countries – the most vulnerable not always being the most responsible.

KEY IDEAS
- Not all countries emit the same amount of greenhouse gases, nor are they equally vulnerable to climate change impacts.
- The wealthiest countries emit the greatest amounts of greenhouse gases.
- Droughts, storms and floods exacerbated by climate change mainly affect people living in developing countries who have contributed least to climate change.
- The majority of the world's people live in rapidly developing countries; this will have an impact on future greenhouse gas emissions.
- There is growing awareness of the need for urgent and widespread action to limit climate change and protect the most vulnerable.
- Science can explain the origins and mechanisms of what is happening, but it is the choices of each citizen and the countries' legislations that guide actions.

KEYWORDS
Climate change, greenhouse gases, responsibility, vulnerability, inequity, climate justice

INQUIRY METHOD
Role-playing game



PREPARATION 15 MIN

MATERIALS
- **WORKSHEETS E3.1** [2], **E3.2** (or a set of toy cars), **E3.3, E3.4, E3.5;**
- Sheets of paper or stickers;
- Optional: a world map.

LESSON PREPARATION
This lesson contains two independent activities. You can choose to do one or the other, or both.

Activity 1
- Make sure that the room contains one (and only one) chair per student;
- Print out **WORKSHEET E3.1** (one copy for you);
- Gather a set of small toy cars (one car per student) or, if not possible, print out **WORKSHEET E3.2** (one copy for the whole class);
- Place the continent labels at different locations in the room (either on the floor or on the wall).

Activity 2
Print out **WORKSHEETS E3.3, E3.4,** and **E3.5** (one of each for each group of 6 students).

TEACHER TIP
See background for teachers in the previous lesson (E2).

INTRODUCTION 20 MIN

We have learned about the greenhouse effect and the consequences of climate change. We have seen that many of the ecosystem services we need may be affected. Debate with the students if they think that everyone in the world is equally responsible for climate change and will be equally affected.

1 This lesson was inspired by Lesson 4 of the "Creating Futures" resource, produced in the scope of the Education for a Just World initiative, by Trócaire and the Centre for Human Rights and Citizenship Education, DCU Institute of Education (Dublin, Ireland); it was also inspired by the education resource *Ma maison, ma planète et moi!* produced by La main à la pâte Foundation. The OCE is grateful to the authors.

2 An Excel version is available on the OCE's website if you need to adapt/update the lesson (data-chair-game.ods).

PROCEDURE 1 H 20

ACTIVITY 1 (45 MIN): WHO IS MOST RESPONSIBLE FOR CLIMATE CHANGE?

TEACHER TIP
You can also choose to do this activity with small figurines on a table instead of using chairs.

1. Ask the students to form a standing circle: They shall represent the (almost) 8 billion earthlings. You may choose gender to explain the concept of the following activity. Discuss what proportion of the world is male and what proportion is female and ask the students to divide themselves accordingly. The 8 billion people in the world can roughly be divided into 4 billion females and 4 billion males. Half the class should stand on one side of the room and half the class on the other side (regardless of actual gender).

Students in a circle, outdoors.

2. Following this example, ask the students to form a large circle again. Ask them to consider the population of each of the continents labelled around the room and to divide themselves up accordingly – based on what they think to be true, as they don't have any numbers yet.

3. Using the first table provided in **WORKSHEET E3.1**, inform the class about the true distribution of the population among the continents and let the students reposition themselves as needed. Each student now represents a number of people in a particular continent. There are so few people in Oceania, compared to the other continents, that the continent does not even have one "full" student. Each student will continue to represent his/her continent for the remainder of this activity. Discuss with the class their responses to the true population breakdown.

4. Each student now retrieves a chair and sits around his/her assigned continent label as a small group. Tell the students that all of their chairs combined represent the wealth of the world. In their groups, the students discuss how they think the chairs (wealth) are divided amongst all the people of the world in each continent. Each group shares their thoughts with the rest of the class. The class decides together if some chairs should be moved to a different continent. The chairs are moved as the class thinks is appropriate. Remember, the students do not move with the chair but stay with their continent.

Students representing the African population and its wealth.

Students representing the European population and its wealth.

5. Using the second table provided in **WORKSHEET E3.1**, inform the students about the true distribution of wealth. Move the chairs to different continents as needed. Ask the students to sit on a chair without leaving their continent group. In some continents, some students will be left without a seat (or will have to share a chair), while in other continents there will be a surplus of chairs on which they can rest their feet.

6. Discuss with the class about how this feels and what is demonstrated, including ideas related to conflict, migration, justice and inequality.

7. The students remain in their continents with their assigned number of chairs. They start by discussing in their groups if each person in the world, within and between continents, emits the same amount of greenhouse gases. The students also discuss on which continents in the world people emit more greenhouse gases per capita and on which continents they emit less.

You can use a world map to summarize the activity and have the class mark on the map population, wealth and greenhouse gas emissions. This map is provided only as an example: it was made by a class some years ago, so the distributions are outdated and do not correspond to today's values.

8. The toy cars (or their equivalent in **WORKSHEET E3.2**) represent the average amount of greenhouse gases emitted in a year. Give each group the amount of cars that represents the corresponding average greenhouse gas emissions of each continent (see the third table in **WORKSHEET E3.1**). *How many cars per person are there in each continent?*

Discuss the greenhouse gas emissions with regard to the population and the wealth of their continent. Highlight that the greenhouse gas emissions per capita are not the same for all continents. *What will happen if more and more people around the world adapt the lifestyle of people in Europe and North America? Does every person on a given continent emit the same amount of greenhouse gases?* (Compare the number of chairs to the number of cars in the different groups.)

ACTIVITY 2 (35 MIN): WHO IS MOST VULNERABLE TO CLIMATE CHANGE?

9. Now that they have discussed who is most responsible for climate change, the class will find out who is most vulnerable to climate change. Divide the class into groups of up to six students and give each member of a group a different role-play card from **WORKSHEETS E3.3** and **E3.4.**

10. Ask the students to stand in a line across the middle of the room holding their role-play card so that the others can see their role. Read the "Forwards" and "Backwards" statements of **WORKSHEET E3.5** and ask the students:

- To step forward for each of the first set of statements, if it applies to their role;
- To step backwards for each of the second set of statements, if it applies to their role.

Forwards and backwards with climate change.

11. Discuss with the students who in the world is most vulnerable to climate change and why.

WRAP-UP 20 MIN

Conclude the lesson by asking the students: *Given what you have learn about who is responsible for and who is most vulnerable to climate change, do you think climate change is "fair"?* The issues of wealth, greenhouse gas emissions and differences in exposure and vulnerability to climate change should be discussed. (The wealthiest countries are the biggest greenhouse gas emitters per capita but are the less exposed to and affected by the impacts of climate change. This is due, for most cases, to their geographic locations and to the resources they have available to adapt to and cope with climate change consequences.)

WORKSHEET E3.1

		NUMBER OF STUDENTS PER CONTINENT															
CONTINENT	POPULATION %	Class with **15** students	Class with **16** students	Class with **17** students	Class with **18** students	Class with **19** students	Class with **20** students	Class with **21** students	Class with **22** students	Class with **23** students	Class with **24** students	Class with **25** students	Class with **26** students	Class with **27** students	Class with **28** students	Class with **29** students	Class with **30** students
Africa	**17%**	3	3	3	3	3	3	4	4	4	4	4	4	5	5	5	5
Asia	**59%**	9	9	10	11	11	12	12	13	14	14	15	16	16	17	18	18
Europe	**10%**	1	2	2	2	2	2	2	2	2	3	3	3	3	3	3	3
Latin America	**8%**	1	1	1	1	2	2	2	2	2	2	2	2	2	2	2	2
North America	**5%**	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	2
Oceania	**1%**	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Total	100%	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30

Source: https://www.worldometers.info/world-population/#region

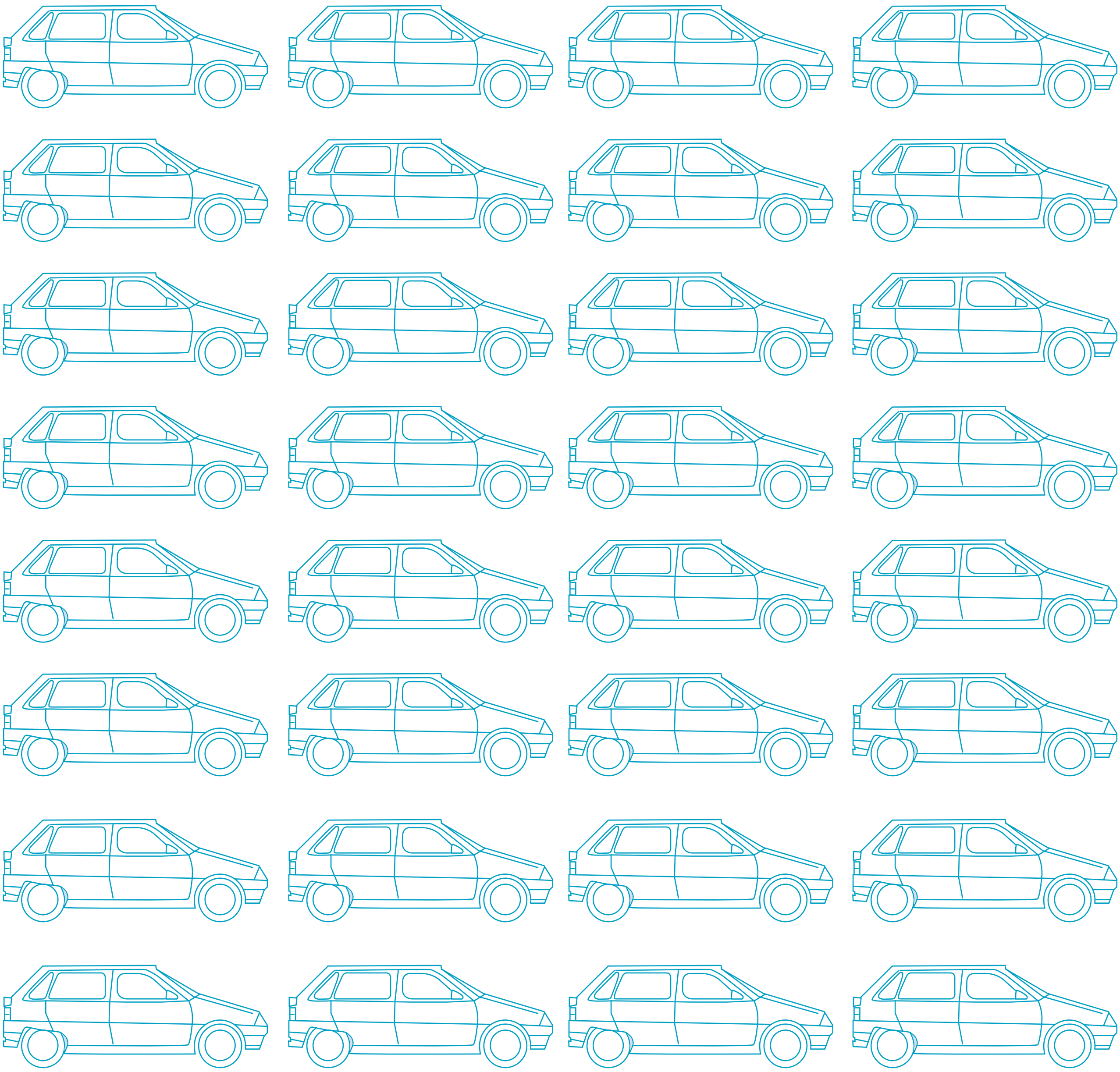
		NUMBER OF "CHAIRS" PER CONTINENT															
CONTINENT	WEALTH %	Class with **15** students	Class with **16** students	Class with **17** students	Class with **18** students	Class with **19** students	Class with **20** students	Class with **21** students	Class with **22** students	Class with **23** students	Class with **24** students	Class with **25** students	Class with **26** students	Class with **27** students	Class with **28** students	Class with **29** students	Class with **30** students
Africa	**5%**	1	1	1	1	1	1	1	1	1	1	1	1	1	1	2	2
Asia	**49%**	7	8	8	9	10	10	10	11	11	12	12	13	13	14	14	15
Europe	**21%**	3	3	4	4	4	4	4	4	5	5	5	5	6	6	6	6
Latin America	**7%**	1	1	1	1	1	2	2	2	2	2	2	2	2	2	2	2
North America	**17%**	3	3	3	3	3	3	4	4	4	4	5	5	5	5	5	5
Oceania	**1%**	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Total	100%	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30

Source: https://www.dsw.org/landerdatenbank/

		NUMBER OF "CARS" PER CONTINENT															
CONTINENT	GHG EMISSIONS %	Class with **15** students	Class with **16** students	Class with **17** students	Class with **18** students	Class with **19** students	Class with **20** students	Class with **21** students	Class with **22** students	Class with **23** students	Class with **24** students	Class with **25** students	Class with **26** students	Class with **27** students	Class with **28** students	Class with **29** students	Class with **30** students
Africa	**4%**	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
Asia	**49%**	7	8	8	9	9	10	10	11	11	12	12	13	14	14	15	15
Europe	**16%**	2	2	3	3	3	3	3	3	4	4	4	4	4	5	5	5
Latin America	**12%**	2	2	2	2	2	2	3	3	3	3	3	3	3	3	3	4
North America	**18%**	3	3	3	3	4	4	4	4	4	4	5	5	5	5	5	5
Oceania	**1%**	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Total	100%	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30

Source: Our world in Data, based on UN "global carbon project" and World Bank (https://ourworldindata.org/co2-by-income-region)

WORKSHEET E3.2



JIAO-LONG FROM CHINA

My name is Jiao-Long and I am 10 years old. I live with my mum in a small apartment at the top of a 40-floor building, in the city of Shanghai. My mother says it is the second-biggest city in the world in terms of inhabitants.

I love seeing all the lights from the buildings, the cars and the advertising screens in the great avenues of the city at night. I also love eating noodles with chicken! I wish I had a brother to play all my videogames with me. We could go together to the technology fair and it would be so much fun.

My mum takes me to school every morning, since I was little. We take the Shanhgai metro. I like riding the metro, but sometimes there are too many people and I feel squished. There are always lots of people everywhere in my city. Sometimes I wish there were less people, like in my grandpa's village, where I can run everywhere. My mum says that there are more people every year in our city, because life is getting harder and harder in the countryside and people seek a better life.

MAHLET FROM ETHIOPIA

My name is Mahlet. I'm 13 years old and I live with my family in a small village in Northern Ethiopia. My sister's name is Shewit and my brother's name is Samuel. I enjoy school. My favourite subject is biology. I want to be a doctor when I grow up.

My family grows vegetables on our land. We grow maize, sorghum, potatoes and tomatoes. We eat these vegetables and then sell some at the market to earn money. We use this money to buy more seeds, books for school and things for our house.

When my father was a young boy, there was enough rain for the vegetables to grow. Now, there is not always enough rain for the crops to grow. My family and our neighbours are ready to sow, but the land is too dry. Together we are building an irrigation system. This is a long pipe that will bring water from a place far away. This will help the crops to grow.

ARIANNE FROM PHILIPPINES

My name is Arianne. I live in a house with my mother, father and younger brother. When I was little, we lived in a nice house just in front of the beach. I liked playing with the seashells and watching the baby turtles coming out of their eggs and walking towards the sea. I liked seeing from the window of our house my father arriving in his fishing boat after a long day at sea.

One day, at high tide, the water came further up the beach than usual and our house was flooded. I remember it was a very windy day. In the following months, this happened more and more regularly. We decided to move, and now we live in a new house a bit further away from the beach. It is built on stilts, so that it can avoid being flooded in the future. We feel much safer here.

I really like living near the beach and I hope we will not have to move even further inland in the future.

WORKSHEET E3.4

RORY FROM IRELAND

My name is Rory and I am eight years old. I live with my mummy, daddy and my brother Eoin in a small village. We drive to school in another small village near Downpatrick.

I like school and I really enjoy sports and music. I play Gaelic football for my local team. Because it rains a lot in Ireland, we often have to cancel training as it's too wet to play! Last spring the lane to our house got flooded as the river overflowed so we couldn't get in or out.

Most years we get some days off school because of heavy snow. Our country roads don't get gritted which means that they are often too dangerous to drive on in the snow. I don't mind though as I get off school and we can go sledding down the hill beside our house. It's great fun. We always build a snowman in the garden too.

Last summer we went to Spain on our holidays as it was sunny and hot there. Sometimes I wish we had nicer weather here, but Mummy says Ireland wouldn't be known as the Emerald Isle then.

RENATA FROM CHILE

My name is Renata. I am nine years old and I live in Valparaíso with my mother, my brother, my sister and my dog, Gasparín. I don't see my father every day, because he works in the mines in the north of Chile. When he comes home a few weekends per year, he always brings candies for me and my siblings.

During summer holidays, we drive a long way in our car with our uncles and cousins to a really nice wood house in the countryside, near the mountains. Gasparín is also very happy because he can run a lot. My brother likes fishing with my uncle. My older sister doesn't come all the time, because she prefers staying in the city and going out with her friends or watching videos on the internet. The old people that live in the mountains say that the mountain tops used to have snow that didn't melt in summer. Now I don't see that much snow.

WESTON FROM USA

My name is Weston and I am 11 years old. I live in Boston with my mom and dad and my twin sisters, Anna and Melissa. We live in a house in a nice neighbourhood where I have a lot of friends. My parents drive us to school every day.

I like playing baseball on the local team with my friends. We love going out to eat Mexican food at the big mall after our Saturday match. When we don't have a match, we stay home playing video games.

Every year we fly to California with my family for summer vacation. I love going to the beach there. We even tried surfing once, with my sisters, and then we had huge burgers at the beach restaurant! Last summer we visited Silicon Valley. It was so impressive! I wish I could work for one of those tech companies when I grow up.

I heard on the news last week that huge fires are ravaging California forests. It makes me sad to know this, I really like going to California on holidays!

WORKSHEET E3.5

FORWARDS AND BACKWARDS WITH CLIMATE CHANGE

Some people contribute more to climate change than others.
Some people are more vulnerable to climate change than others.
Thinking about your role…

FIRST SET OF STATEMENTS

Take a step forward if your person's family...

→ Travels in a car.
→ Flies abroad for a holiday.
→ Has money to buy enough food for all the family.
→ Eats meat as often as they want.
→ Has adapted because of climate change.
→ Has a government that could help them adapt to climate change.
→ Uses technology in their everyday life.

SECOND SET OF STATEMENTS

Take a step backwards if the following relates to your person's family...

→ They rely on the food they grow to survive.
→ As sea levels rise, flooding could affect their home.
→ If ocean acidification affects coral ecosystems, they may struggle to have enough food to eat.
→ As the temperature rises, they suffer from drought.
→ If there is a drought, they might go hungry.
→ If glacier melting continues, one day they may not have enough freshwater to drink.

LESSON E4
ADAPTATION AND MITIGATION MEASURES WORLDWIDE

MAIN SUBJECTS
Social sciences / Natural sciences

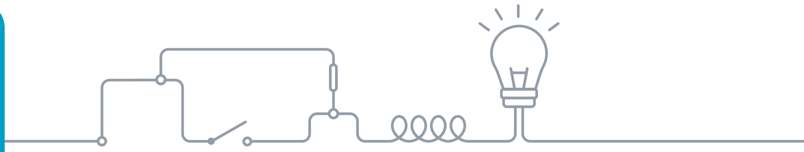
DURATION
~ Preparation: 10 - 30 min
~ Activity: 1 h

SUMMARY
The students realise that there are many solutions to deal with climate change, either through adaptation or mitigation, and that many people and organisations are already taking action. The students choose a climate adaption / mitigation project to work on.

KEY IDEAS
~ We must adapt to the impacts of climate change and we must do our best to reduce greenhouse gas emissions.
~ There are many people, communities and organisations around the world implementing adaptation and mitigation solutions. We can all do many things to help.
~ Adaptation will benefit us in the short term, while mitigation will be fundamental in the long term. Both must be considered together.
~ Adaptation measures help reduce vulnerability and / or exposure to climate change, reducing the risk of negative impacts.
~ We can implement measures of adaptation to climate change effects.
~ We all have a carbon footprint, but we can help reduce climate change if we decrease our emissions of greenhouse gases.

KEYWORDS
Adaptation, mitigation, solutions, vulnerability, exposure

INQUIRY METHOD
Documentary analysis



PREPARATION 10 - 30 MIN

MATERIALS
- Video projector + computer + Internet connection
- **Multimedia resources:** multimedia activity ("How can we act?").
- If the class cannot use the online activity, the WORKSHEETS E4.1, E4.2, E4.3, E4.4 (one of each for the class) can be used.

LESSON PREPARATION
Feel free to use other material to illustrate different adaptation, mitigation and awareness measures being implemented worldwide. It is a particularly good idea to show measures that have been implemented in the student's "vicinity" (in their region or in their country).

TEACHER TIP
This lesson provides an introduction to Part 2 of the lesson plan. Hence, the 1 h duration is merely indicative, as it can take you and the class longer to choose which project to carry out.

INTRODUCTION 10 MIN

After a short reminder of the different impacts of climate change on the ocean and cryosphere, and their consequences for ecosystems and human societies, ask the students to think about what kind of action can be taken to cope with these problems.

PROCEDURE 40 MIN

1. Let the students present their solutions to the whole class and write them on the whiteboard, without commenting on them. These should be actions that can be taken by the students themselves, as individuals, or by their families or small communities (school, village, etc.). This avoids a discussion on what others (governments, industry, etc.) could / should do.

2. As soon as a few dozen actions have been identified, ask the students to propose a way of sorting them (by defining appropriate criteria). Different kinds of sorting can emerge:

→ Mitigation / adaptation (some actions will reduce greenhouse gas emissions and thus the magnitude of global warming, whereas others will reduce the impact of global warming on our societies);
→ Individual / collective;
→ At home / at school / at the store / transportation, etc.

3. During this activity, let the students discuss the relevance of each action (and reasons). Some difficulties may appear during the classification as sometimes the same action can be relevant from an adaptation point of view and not from a mitigation point of view (example: using air conditioning is good from an adaptation point of view, because you can cool down rooms that are too warm, but it is harmful from a mitigation point of view because of energy consumption).

4. As soon as all the actions have been discussed and categorised, the students may want to use the multimedia resource with which they can discover different kinds of initiatives already underway.

5. Explain that they should try to do something tangible, and help them choose an action they want to implement.

WRAP-UP 10 MIN

As a conclusion, define the project the class will be involved in (some examples of projects are proposed below).

BACKGROUND FOR TEACHERS

In order to reduce the impacts of climate change on human societies and Earth's ecosystems, two lines of action exist: **mitigation** and **adaptation**. Pages 20-23 of the Scientific Overview offer a detailed outline of both.

These two complementary strategies are to be considered at different levels: individuals, local groups (e.g. school, city), national or regional entities, international or global actors (United Nations, international treaties). All levels have a role to play, even if their relative impacts vary. Both strategies involve knowledge, engineering and societal changes. Even in a simple case (school action), the timescales and the multiple possible consequences of a given action have to be considered.

AGRICULTURE AND FOOD

Permaculture (Guatemala)

On the shores of Lake Atitlan, the Mesoamerican Permaculture Institute aims to raise awareness and educate local populations about permaculture, following the footsteps of their Mayan ancestors. Permaculture is a technique that combines different crops in the same plot of land, capitalising on the biological interactions between the various plant species. It is particularly effective, does not require polluting chemical fertilizers, and contributes to the conservation of biodiversity.

ENERGY

Cycling (Netherlands)

Amsterdam is probably the most welcoming capital if you enjoy cycling. The facilities include cycle paths, free bicycle parking and two-way lanes. Car use, on the other hand, is strongly discouraged. As a result, in this city of one million inhabitants, more than 60% of the trips are made by bicycle.

Cycling is cheap, does not emit greenhouse gases, does not contribute to urban air pollution, and allows moderate physical effort that is very beneficial to health. It is also one of the fastest means of transport in the city.

ENERGY

Football (Spain)

The teenagers who play football on Spanish streets probably do not realize that they are saving energy (and that is probably not their goal). Yet, reading a book, playing sports and meeting friends are much better activities for the environment (but also for health and social interactions) than just sitting in front of the screen of a computer or a smartphone.

Storing and sending the data from computers and smartphones require a lot of energy: about as much as global air traffic. Why not unplug from time to time?

ENERGY

Repair Café (France)

Throw it away? No way!

At a time of disposability and programmed obsolescence, some people are opting for more sustainable consumption.

“Repair Cafés”, invented in the Netherlands, are being created all over the world. There are more than 1500 of them, found on all continents. They are used in schools, bars, cafés, municipal halls, etc.

For example, in Quimper, France, Do It Yourself workshops where people bring an everyday object to repair (bicycle, coffee machine, computer or toy for example). While meeting other people, the local residents can find help and learn simple methods to give a second life to their belongings. This approach is also used for holiday internships adapted to young people, who dismantle the equipment, understand how it works and then see how it can be diverted and reused. This saves energy, raw materials... and also money!

HABITAT

Bioclimatic “low tech” constructions (Burkina Faso)

Unlike other schools in Burkina Faso, this primary school in Gando is not built of cement... but of raw earth. It is a locally available material, it’s very cheap, and doesn’t require transport or processing. The raw earth offers great thermal comfort, saves a lot of energy in comparison to cement, and is 100% recyclable.

Adobe, pisé, cob... these raw clay construction techniques have been around for thousands of years and are back in fashion. Homes, schools, stations... there are almost no limits!

Bioclimatic architecture takes into account the local environment to provide occupants with a comfortable, functional, water- and energy-efficient building. Some buildings are very sophisticated, but others (such as this school) use ancestral, inexpensive materials and techniques.

HABITAT

Solar cookers (Sudan)

Collecting firewood as fuel for cooking is dangerous, time-consuming and a major cause of deforestation.

This can be avoided by using solar cookers. In a solar cooker, sunlight is reflected by mirrors and concentrated into the cooking pot or pan. In very sunny and warm regions, the heat produced is sufficient to cook food. Their use makes it possible to cook with free solar energy and without emitting greenhouse gases or other pollutants. The air is cleaner, as well as the drinking water, which can be boiled. Additionally, not having to collect firewood saves time.

Some NGOs have helped to increase the use of solar cookers, thereby contributing to forest conservation and hence to climate protection, as well as improving human health.

WORKSHEET E4.3

URBAN RESILIENCY

Revegetation (Australia)

While cities have replaced trees and grass with buildings and concrete, residents are increasingly seeking to reconnect with nature and a greener environment. In Brisbane (Australia), local authorities have encouraged the replanting of trees and grass in the city center. Beyond its aesthetic appeal, revegetation makes it possible to develop biodiversity (the population of urban birds has significantly improved), increase air quality, contribute to the cooling of the city by limiting the “urban heat island” effect, and adapt to the consequences of climate change.

Many cities now allow their inhabitants to initiate reforestation projects. Sometimes, it is the schools who are in charge of such projects.

ECOSYSTEMS

Planting of corals (Malaysia)

While they cover less than 0.1% of the ocean bed, coral reefs are home to 30% of the world's biodiversity. In addition, coral reefs are of great importance to local populations, providing food security and protection against coastal erosion.

Between the 1980s and 2019, about 30% of coral reefs disappeared (IUCN Red List Index). To address this, many NGOs, companies and scientists are working with local populations to restore coral reefs (for example in Tioman Island in Malaysia). Some of these programs are funded through voluntary carbon offset programs (think about it next time you fly!).

AWARENESS

Felix and his “Plant for the Planet” organisation (Germany)

In 2007, Felix Finkbeiner, a nine-year-old boy from Bavaria, Germany, made a presentation to his class on climate change. He planted his first tree with his classmates, and decided to create the “Plant-for-the-Planet” project. At the age of 10, Felix addressed the members of the European Parliament, and at 13 he made a speech to the United Nations General Assembly.

10 years later, Felix is still involved, on a voluntary basis, in the development of “Plant-for-the-Planet”, which now has 130 employees and 70,000 members in 67 countries. In 2019, nearly 14 billion trees have been planted under this project. On average, each tree absorbs 10 kg of CO_2 per year – and a tree planted in the tropics absorbs many times this amount.

ECOSYSTEMS

Sandwatch program (Trinidad and Tobago)

Mayaro Primary School has joined the Sandwatch program, along with many other schools around the world. By “adopting”, monitoring and protecting the beach near the participating school, carrying out regular clean-up operations and studying beach evolution, biodiversity, currents and tides, the project has completely changed the way students, parents, and the whole community view the coastal ecosystem.

Many former students of Mayaro Primary School later became involved in environmental studies and activities. The project taught parents, students and teachers that education goes beyond the four walls of the classroom.

AWARENESS

Amazonian school (Brazil)

Brazil hosts the world's largest biological diversity, but its forests are among the most threatened. The president of an ecological foundation and two biologists created Escola da Amazónia in 2002, to raise awareness among Brazilian youth.

“A day in the forest” aims to provide young people aged 11 to 14 years with direct contact with the Amazonian forest and encourage them to observe the fauna and flora. Older teens (15-19 years old) participate in workshops on eco-tourism, sustainable livestock, and socio-economic development.

A twinning program links urban schools to schools located at the edge of the forest.

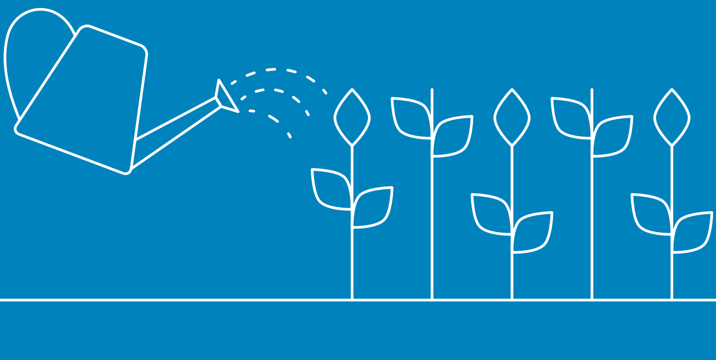
AGRICULTURE AND FOOD

Eco-school (Mauritius)

Loreton College in Mauritius is part of the “Eco-Schools” network, made up of more than 50,000 schools around the world. The students have built a small-scale aquaponic farm, which combines salad farming with fish farming, in symbiosis. Fish droppings provide nutrients to plants, which in turn filter the water in the aquarium. It is an effective and sustainable way to produce food, especially in urban areas.

A school is awarded the Eco-School label by the Foundation for Environmental Education (FEE) if it engages students in ecological and sustainable projects within the school or the community. Eco-school themes are biodiversity and nature, climate change, energy, global citizenship, health and wellbeing, litter, marine and coast, school grounds, transport, waste, and water.

Discover stories of other successful projects led by students from all over the world: https://www.ecoschools.global/stories-news



WE ACT

LESSON PLAN – PART II

WE ACT #PROJECTS

This part of this guidebook for teachers is project-based and focuses on solutions. It is about the planning and implementation of projects aimed at giving the students the opportunity to participate in solutions or measures designed to mitigate or attenuate climate change impacts. Depending on the local context, time or resources constrains, various projects can be considered. Here we propose three different projects, which are not necessarily the most adequate for your context, but are intended at giving you an idea of the kind of project that you can carry out with your students. Lesson E4 of Part 1 also provides examples of multiple solutions already being implemented worldwide that may serve as an inspiration for creating a different project on your own.

The first of these projects deals with local adaptation to climate change consequences ("adaptation" project), the second one focuses on reducing greenhouse gas emissions ("mitigation" project) and the third one aims at raising public awareness in local communities ("awareness" project). A given project can cover one or more of these three aspects. Many projects aimed at mitigating climate change often double as adaptation projects as well (e.g. improving building insulation can help cope with heat waves – adaptation – and simultaneously reduce greenhouse gas emissions from air conditioning devices – mitigation.)

The sustainability project action plan presented below[1] can be used as a guideline for designing your own project.

CREATE A SUSTAINABILITY PROJECT ACTION PLAN

VISION	CURRENT STATE	COMPONENTS OF CHANGE
What is the desired outcome for your school?	What is your school like right now?	What will you need to change to achieve your vision?

BARRIERS & CHALLENGES	STAKEHOLDERS	CHANGE AGENTS & OPINION LEADERS	TOOLS
What is standing in your way?	Who will be affected?	Who can help you make things change?	What processes can you use?

SHORT-TERM	MID-TERM	LONG-TERM
What will you do in the next few weeks?	What will you do in the next few months?	What will you do in the next few years?

1 Inspired by Redman (2013). Opportunities and challenges for integrating sustainability education into K-12 schools: case study phoenix, az. *Journal of Teacher Education for Sustainability.* 15 (2) pp. 5-24.

PROJECT LIST

Increasing beach resilience to climate change Adaptation Beaches with healthy ecosystems are more resilient to climate change. With this project, students help "their" beach become more resilient. They monitor the beach, decide on a particular problem to address and design and implement solutions. Depending on the local context, three versions of this project are proposed: one aimed at implementing solutions to reduce beach erosion, a second to address the issue of coral bleaching, and the last one focusing on helping recover coastal ecosystems.	page 154
Setting up a walking bus Mitigation In this project, students in urban areas plan, organise and set up a walking bus in order to reduce car journeys between their homes and the school. The students conduct a survey in the community, work on several itineraries and address different issues related to safety, signage, timetables, etc. They also work on communication with the local authorities and parents, in order to implement the walking bus.	page 166
Science on stage Awareness This project aims to raise public awareness around climate change issues. It is a project that brings together science, literature and theatre, with the aim of assimilating the scientific investigation process by studying the origins, the consequences and the possible solutions for climate change. By putting on a play, the students study the characteristics of theatre text, read and write texts on the climate theme, discover the stage and learn the practice of theatrical play through exercises that develop proprioception, and interpersonal and communication skills.	page 173

ADAPTATION PROJECT

INCREASING BEACH RESILIENCE TO CLIMATE CHANGE [1]

MAIN SUBJECTS
Natural sciences

GRADE
K4-9

TARGET
Schools in coastal areas

OVERVIEW
Beaches with healthy ecosystems are more resilient to climate change. With this project, students help their beach become more resilient. They monitor "their" beach, decide on a particular problem to address and design and implement solutions. Depending on the local context, three versions of this project are proposed: one aimed at implementing solutions to reduce beach erosion, a second to address the issue of coral bleaching, and the last one focusing on helping recover coastal ecosystems.

STEP LIST

Step 1 is common to the 3 examples

STEP 1 – Selecting a beach and identifying potential problems (applies to all examples)	The students select a beach case study according to several criteria and gather information for identifying potential threats to that beach that may be related to climate change. Then, they choose one problem to focus on. In this project, three examples of coastal threats ("problems") are described, with the corresponding steps 2, 3 and 4.

Steps 2 to 4 are different for each of the 3 examples

STEP 2 – Monitoring the beach	Students monitor the beach and gather data on what is happening to the beach with respect to the problem they have defined.
STEP 3 – Analysing the data	Students analyse the data to evaluate precisely how the problem they chose to focus on is affecting the beach.
STEP 4 – Implementing solutions	Once the students have established how climate change is affecting a particular aspect of the beach, they set up a mitigation plan.

1 This project is a short version adapted from the larger project proposed by Sandwatch in the Sandwatch manual on "Adapting to climate change and educating for sustainable development". Many parts of it are directly taken from this manual. For a more extensive project on beaches and coastal ecosystems, the OCE encourages you to refer directly to the original Sandwatch manual UNESCO (2010). Sandwatch: Adapting to climate change and educating for sustainable development. Paris: UNESCO), which is available for download: http://www.sandwatch.ca/images/stories/food/SW%20Docs/Sandwatch%20Manual.pdf
Depending on the project you choose to carry out with your students, your beach monitoring data may fit for inclusion in the Sandwatch Climate Change Database. Get informed about it and participate!
Sandwatch is also a network that allows Sandwatchers from all over the world to keep in contact and learn about each others' activities. So if you are new to Sandwatch and want to get involved, please consider becoming part of the network.

STARTING POINT

Start the project by debating with the students on the possible impacts the climate has on the beaches they know. *What kind of changes are to be expected?* Depending on the region, different answers are possible:

- → Rising sea levels and subsequent coastal erosion. Coastal erosion can threaten human settlements (buildings, roads, etc.) and ecosystems. Loss of ecosystems, such as mangroves, coral reefs, seagrass meadows and saltmarshes, has many consequences on people's livelihoods. Shrinking beaches may have an impact on tourism.
- → Ocean acidification can affect marine and coastal ecosystems, with consequences for biodiversity, food security, etc.
- → Ocean temperature increase will affect marine and coastal ecosystems, contributing, for example, to coral bleaching.
- → An increased air temperature in already very warm regions may make the beach too hot for tourism.

STEP 1
SELECTING A BEACH AND IDENTIFYING POTENTIAL PROBLEMS

SELECTING A BEACH

In order to carry out this project, start by selecting a beach. To do so, some key factors should be considered:

- → **Safety**: The beach should provide a safe environment for the students. If there are very strong currents and/or very high waves, for example, there is a risk. Safety must always be the prime concern.

- → **Size of the beach**: In some areas, beaches are small (less than 1 km in length) and enclosed by rocky headlands. These "bayhead" beaches, as they are known, are an ideal site for a monitoring project. If a long beach is selected for monitoring, we recommend students focus on one section only (about 1 km).

- → **Importance of the beach to the community**: Try to choose a beach which is used by the residents of the area and therefore important to the local community. This will help ensure local interest in the monitoring activities and will also be an important factor during the design and implementation of beach enhancement projects.

- → **Issues of interest**: Particular issues such as heavy use during weekends, preferred destination for local residents or tourists, and history of erosion during storms, may influence selection of a particular beach location.

Consider gathering information from the local community!

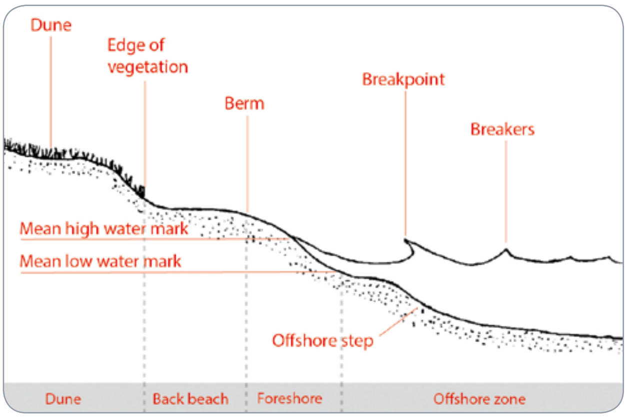
You can contact local scientists, environmental organisations or local authorities to gather further information on which beach to select. Very often, beaches that are known to be affected by climate change (or other) impacts are already being monitored, and existing data can provide a useful comparison to the data you and your students will collect, and give you an idea of how your beach has changed up to the present day. In some cases, your measurements may even be an important contribution for local scientists!

You may also consider interviewing members of the local community that have lived or developed their businesses in/near the beach for a long time: they can provide you with important empirical information on the beach changes, as well as on issues of interest of a particular beach. Fishermen, for example, are frequently aware of the changes in the amount of fish over the years, or the importance of a particular beach as a fish nursery, etc.

DEFINING THE BOUNDARIES OF YOUR BEACH

A beach is a zone of loose material extending from the low water mark to a position landward where either the topography abruptly changes, or permanent vegetation first appears. Applying this definition to the diagram shown in the figure below – which is called a cross-section (or beach profile) – the beach extends from the low water mark to the vegetation's edge. The land behind the beach may consist of a sand dune, as shown in the cross-section represented, or a cliff face, a rocky area, low land with trees and other vegetation, or a built-up area. When monitoring a beach, all its cross-section must be considered.

Beaches are often made up of sand particles, and in many places the term "beach" may be used only for sandy beaches. However, a beach may be made up of clay, silt, gravel, cobbles or boulders, or any combination of these. For instance, the mud/clay deposits along the coastline of Guyana are also beaches.



Beach cross section.

A beach is more than just a zone of loose material found where the water meets the land; it is also a coastal ecosystem. Sometimes, geologists, ecologists and others need to look at the "beach system" from a broader perspective, taking into account the offshore zone out to a water depth of about 12 meters. In tropical areas, this is where seagrass beds and coral reefs are found, and these ecosystems supply sand to the beach. Much of the sand in this offshore area moves back and forth between the beach and the sea. This broader view may also include the land and slopes behind the beach, up into the watershed, since streams and rivers bring sediment and pollutants to the beach and sea.

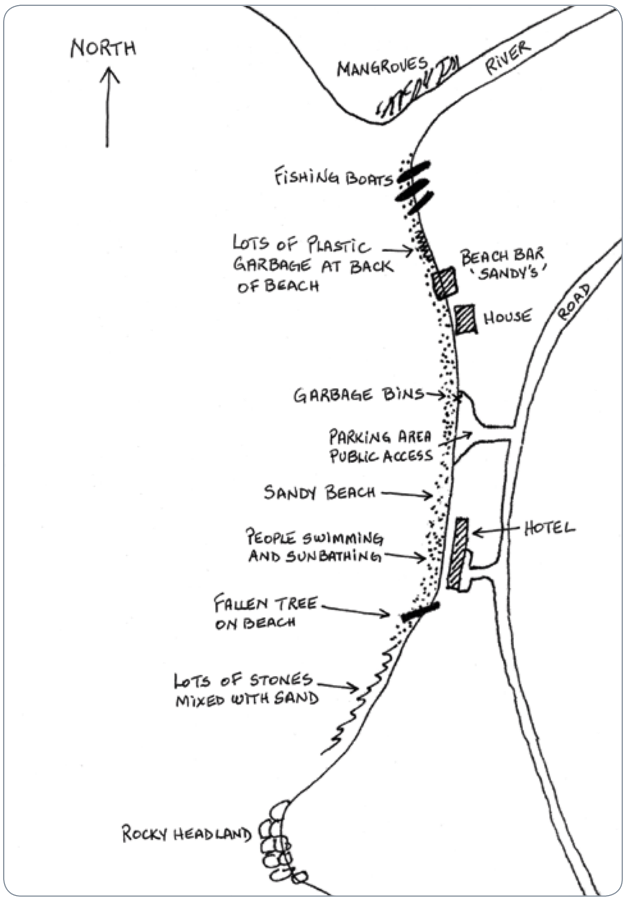
OBSERVE THE BEACH AND DRAW A MAP

Before starting the detailed monitoring of the beach, it is important to obtain an overall picture of it and gather as much information as possible through simple observations.
Divide the students into groups, and have the students walk the length of the beach, writing down everything they see. If the beach is very varied, the student groups may be given different items to look for, e.g. one group might record buildings and roads, another group vegetation and trees, a third group might record the type of activities in which people are engaged and so on. Since the purpose of this activity is to draw a map, the students should record the various items and where on the beach they are located. Items to look for include:

- Beach material: size (sand, stones, rocks), colour, variation in material along different sections of the beach.
- Animals (e.g. crabs, birds, domestic animals, shells of animals).
- Plants and trees (e.g. seaweeds and seagrasses, grasses, plants, trees behind the beach).
- Debris, litter, pollution (e.g. garbage on the beach or floating in the water.)
- Human activities (e.g. fishing, fishing boats on the beach, sunbathers, walkers, people jogging, sea bathers, swimmers, picnic groups).
- Buildings behind the beach, beach bars and restaurants, houses and hotels, public access.
- Paths to the beach, litter bins, signs, lifeguard towers, jetties etc.
- Sea conditions (e.g. whether the sea is calm or rough).
- Objects in the sea (e.g. mooring buoys, boats at anchor, buoyed swimming areas).

Encourage the students to make detailed observations (e.g. instead of recording three trees, encourage them to try and identify the trees: two palm trees and one sea grape tree).

Make a sketch map of the beach; this can be done as a class exercise, or each student or group can make their own map. An example of a sketch map is shown below. You may wish to prepare a simple map outline on which students can record their observations, or even a copy of a topographic map. The advantage of such a topographic map is that it is accurate, so the scale can be used to determine distances.



Sample beach sketch.

Sample topographic map.

CHOOSING ONE PROBLEM TO FOCUS ON AT A TIME

Now that you have drawn a map of the beach you selected, it is time to decide on which problem – related to climate change – to focus on. Here we propose three examples: beach erosion, coral bleaching and endangered beach ecosystems.

Example 1 – Beach erosion

Beaches change in shape and size from day to day, month to month and year to year, mainly in response to waves, currents and tides. Sometimes human activities also play a role in this process, for example, when sand is extracted from the beach for construction, or when jetties or other structures are built on the beach. In regions with very different wave regimes along the year, associated with seasonal changes (summer-winter weather and wave conditions), the beach profile can vary significantly between winter and summer seasons. The emerged part of the beach is usually much larger in summer than in winter, especially after big storms. Erosion takes place when sand or other sediment is washed away from the beach and the beach gets narrower. The opposite process, accretion, takes place when sand or other material is added to the beach, which as a result gets larger.

Sea level rise, associated with climate change, also contributes to beach changes: as the mean sea level rises, beaches are progressively eroded, and beach morphology has to adapt.

Before you start monitoring the beach, try to gather as much information as possible on what the beach looked like in the past. If you have already talked to local scientists, organizations or authorities, you probably have documents and information that give you an idea of what your beach looked like in the past and how it has changed up to the present day. Aerial photographs and topographic maps are particularly useful.

Aerial photographs are usually kept at government departments responsible for lands and surveys, and sometimes at planning and environmental agencies. Aerial photographs are taken from a plane looking vertically downwards. They show a bird's eye view of the beach. You may be able to find aerial photographs of the beach taken in the 1960s or 1970s. Aerial photographs, like topographic maps, can be used quantitatively to determine the length, width and size of the beach. Compare the aerial photographs with your present-day sketch map and note any changes. Sites such as OpenStreetMap or Google Earth can be viewed for free on the internet and allow you to view and save maps and present-day aerial views of your beach within minutes. These can give you another perspective of your beach.

With the help of the referred documents, discuss:

- How the beach has changed.
- If the changes are good or bad.
- Whether you prefer the beach as it was in the past or as it is now.
- How you think the beach will look in ten years time.
- From what you have learned about climate change, how you think the size of the beach will change.

In order to understand the evolution of your beach, measurements must be taken regularly and over the years. This type of project can be carried out over several years with the same class, or each year you can suggest it to a different class, keeping the data updated so the results can be compared with previous years and older existing data records.

STEP 2
MONITORING THE BEACH

MEASURING EROSION AND ACCRETION OVER TIME

→ What to measure

One very simple way to see how the beach changes over time, and whether it has eroded or accreted, is to measure the distance from a fixed object behind the beach, such as a tree or a building, to the high-water mark. The high-water mark is the highest point reached by waves on a given day. It is usually easy to identify on a beach, by a line of debris such as seaweed, shells or pieces of wood, or by differences in the colour of the wet sand reached by the waves and the dry sand closer to shore (see figure below).

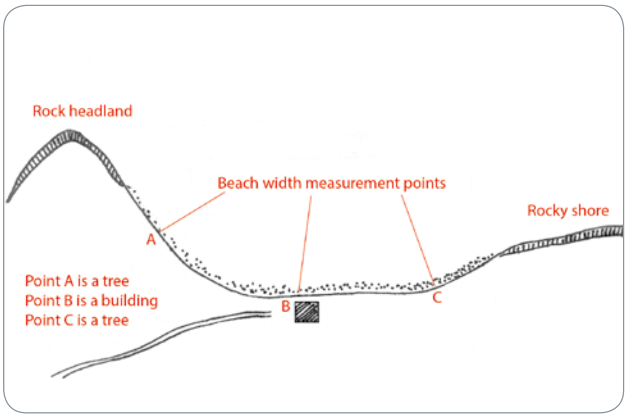
Alternatively, in countries where tide tables are published in the local newspapers (or on the internet, for example on the website of the national hydrographic institute), the visit to the beach can be timed to coincide with high tide, in which case the measurement is made to the water's edge. One note of caution: in some regions of the world, tidal range is very small, so the state of the tide – whether high, mid or low tide – does not matter very much. But in many parts of the world, the tidal range is more than one meter. In such cases, the measurements must be repeated at the same tidal state (e.g. if the first measurement is taken at high tide, then subsequent measurements should also be taken at high tide). Sometimes there may appear to be more than one line of debris on a beach. If this is the case, take the line closest to the sea; the other debris line may well be the result of a previous storm some weeks or months previously. Most beaches show variation in erosion and accretion, for instance, sand may move from one end to the other. So when monitoring the physical changes to the beach, we recommend carrying out these measurements at a minimum of three sites on the beach, one near each end and one in the middle (see figure below).

→ How to measure

At the first point, select the building or tree that you are going to use as a reference point. Write down a description (and / or take a picture). With two people, one standing at the building and one at the high-water mark, lay the tape measure on the ground and pull the tape tight. Record the measurement together with the date and time. Then proceed to the next point and repeat the measurement. If your beach or beach section is about 1 km long, then a minimum of three points is recommended. However, you can always add additional points.

→ When to measure

Ideally, these measurements could be repeated monthly, but even if only repeated every two or three months, they will still yield interesting information.



Beach width measurement points.

High-water mark on the landward edge of the band of seaweed.

MEASURING BEACH PROFILES

→ What to measure

This activity is better suited to older students in secondary school. A beach profile or cross section is an accurate measurement of the slope and width of the beach, which when repeated over time, shows how the beach is eroding or accreting. Instead of simply measuring the width of the beach, a beach profile also includes the beach slope. The figure below bottom right corner bottom right corner shows how a beach profile has eroded as a result of a tropical storm.

→ How to measure

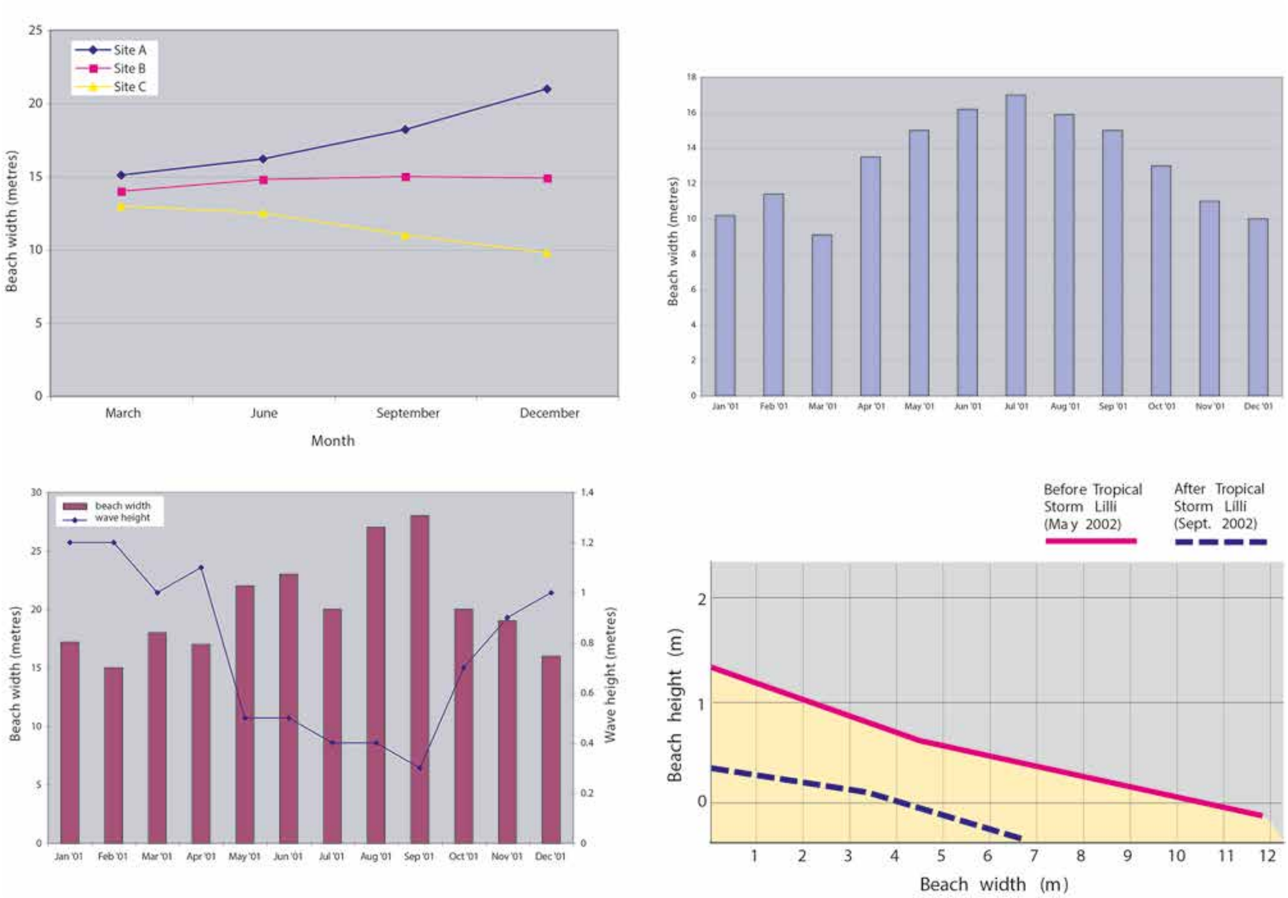
There are many different ways of measuring beach profiles: the method described in Appendix 2 of the SANDWATCH manual is one of the simpler methods. If an accurate GPS is available, it can also be used.

→ When to measure

Beach profiles should be repeated at three-month intervals or more frequently, if time permits and preferentially at low tide (to have access to a longer profile of the beach).

STEP 3
ANALYSING THE DATA

The data will show how the beach has changed over the monitoring period, and whether it has gained or lost sand – it is possible that one part of the beach will have increased in size while another section will have decreased in size. The figures below are examples of graphs that can be obtained from the data collected on the beach width and slope.



Examples of the type of graphs that can be obtained from the data on the beach width and slope.

Regular measurements of profiles can show not only how a beach responds to a storm or hurricane, but also how/if it recovers afterwards and the extent of that recovery. Only by carefully measuring beach profiles before and after each storm is it possible to give an accurate description of how the beach has changed. Government authorities, as well as beachfront house and hotel owners, may also be interested in the information collected from beach profiles. Many people think they can tell how a beach has changed simply by looking at it, but it is much more complex than that, and often people's memories are not as accurate as they like to think.

Analyze your data and try to understand what is happening to your beach.

- *Is it eroding everywhere?*
- *Is it eroding in a particular part and accreting in another part?*
- *Are there buildings, plants, animals or users of the beach that are threatened by this erosion?*

When evaluating the effects of climate change in the potential erosion of your beach, you must bear two important things in mind:

- Climate change effects are only measurable over multiyear timescales.
- There are other causes besides climate change that contribute to beach erosion, and with this kind of measurements you will not be able to tell the difference between those causes.

Nevertheless, if you bear in mind both aspects mentioned, your data can still be very useful. Consider, for example, that you observe (comparing to past measurements or data provided by other institutions) that your beach is eroding every year: even if you are not sure of the causes of that erosion, the important thing is to try slowing/stopping it! The accurate data you gathered, such as beach profiles, are the basis for developing a plan to increase the resilience of your beach to future climate change.

STEP 4
IMPLEMENTING SOLUTIONS

If after analysing your data, you concluded that your beach is effectively eroding, it is time to do some research on what kind of actions can help mitigate coastal erosion. Do not forget that we are talking here about actions that students can carry out, so building seawalls, and beach nourishment by adding sand are solutions that are not within your reach. Nevertheless, there are several examples of things you can do to reduce coastal erosion.

Healthy dunes are essential to control coastal erosion. Protecting the dunes is one way of reducing coastal erosion. You can:

- Plant/care for dune vegetation.
- Build small fences to (i) avoid people stepping on the dunes (access control fences) and (ii) avoid aeolian erosion of sand (sand trap fences).
- Employ dune thatching (dune thatching consists in covering the sand with dead branches that act as a wind barrier and/or protect newly planted vegetation).
- Draw posters and place them near the sensitive zones to let people know what is happening and the best way to behave (e.g.: "Do not walk on the dunes, we need them to protect us from coastal erosion").

Dune plants planted by students as part of a Sandwatch project.

Dune thatching on the Atlantic coast of France.

Example 2 – Coral bleaching

Changes in conditions, such as water temperature, light or nutrients, can stress corals. When they are stressed, they expel from their tissues the symbiotic algae that give them their beautiful colours, and they turn white. This phenomenon is known as coral bleaching. Coral bleaching does not imply the death of the coral: if the coral is strong and healthy, and the stressing condition does not last too long, it can recover.

Rising water temperatures, associated with climate change, are endangering corals worldwide. Between 2014 and 2017, a global coral bleach event has affected 75% of the world's reefs. This is set to continue, with 75% of coral reefs expected to be lost if global temperature rises by only a further 0.5°C, and if local stressors due to human activities, which can also influence coral mortality, are not minimised.

STEP 2
MONITORING THE BEACH

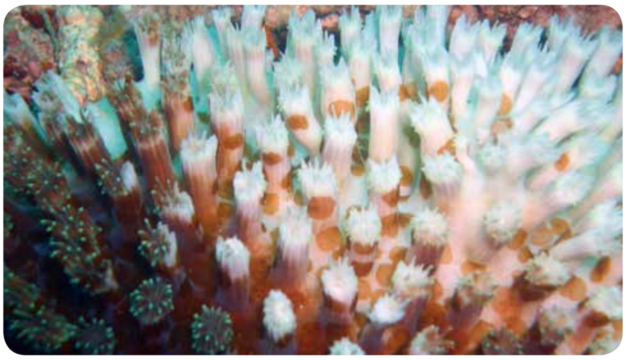
In order to understand what is causing coral bleaching, you will have to monitor your beach. However, before doing so, conduct some research into past bleaching incidents. Find out from some of the local beach users (e.g. fishermen and divers), or your national fisheries department, when the last coral bleaching incident occurred. If, for instance, it occurred in mid-August two years ago, obtain the daily temperature record from your nearest weather station, for 1 July – 30 September for the last three years. Plot the daily temperatures on a graph for each of the three years and determine whether the temperatures were higher during the year of the bleaching, and/or whether there was a prolonged period of high temperatures. This data collection and analysis will give you an overview of the evolution of your coral reef along the years.

MEASURING PRESENT DAY BLEACHING

→ What to measure
Sea surface temperature and occurrence of coral bleaching.

→ How to measure
Measure sea surface temperatures daily, or as frequently as possible, during the three hottest months of the year; remember to always measure at the same time of the day. (Sea surface temperatures often lag behind air temperatures by at least a month, so if July is the month when the highest air temperatures occur, August may be the month when sea surface temperatures are highest). If it is safe to walk out to a reef, or swim and snorkel over your reef, then do so and observe whether any white patches develop on the corals. If they do, then record and photograph your observations (the figure below shows an example of a partially bleached coral). Compare the occurrences of bleaching with the measured sea surface temperatures.

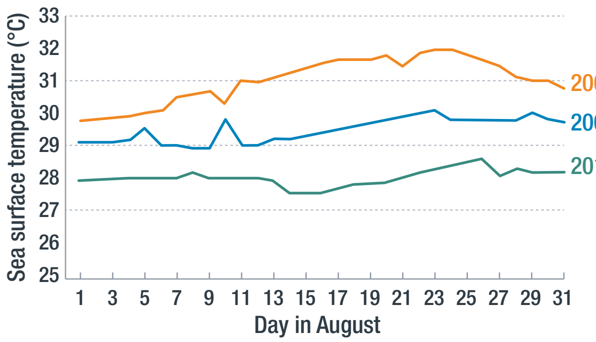
→ When to measure
During the three hottest months of the year.



Bleached coral.

STEP 3
ANALYSING THE DATA

The measurements will show that bleaching occurs during periods of very high and prolonged sea surface temperatures, probably over 30°C, although this temperature may vary in different parts of the world. Discuss with the students what happens when the corals bleach, whether there is any recovery after the bleaching event, and what effects this might have on the beach.



Example of sea surface temperature measurements in the tropics.

STEP 4
IMPLEMENTING SOLUTIONS

If after analysing your data, you concluded that the corals of your beach have suffered one or multiple bleaching events, it is time to do research on what kind of actions can help reducing coral bleaching.
Bleaching events are timed with warmer surface water temperatures: unfortunately, cooling the water is not something you can do. However, healthier corals will be more resilient to incidences of warmer water. As long as the conditions causing bleaching are sporadic, improving coral health, or replanting new healthy corals, are two measures that will help increase the resilience of the coral ecosystem.

SAMPLE SANDWATCH PROJECT: BAHAMAS STUDENTS BUILD A BEACH MURAL TO PROTECT REEF FROM TOURIST DAMAGE

After plotting data on a graph and analysing it, they concluded that one of the main issues was that visiting tourists were damaging a small reef located about 20 m from the beach. They had observed visitors standing on top of the coral reef to adjust their masks, breaking off pieces of coral to take as souvenirs and even spear-fishing close to the beach. The table below shows the action plan of this project.

ACTION	TIME SCHEDULE	PERSONS INVOLVED	ACTIVITIES AND RESOURCES NEEDED	EXPECTED OUTCOME
1. Plan and design the content of the mural.	January to February	Class 4 students and teachers for science, art, language, woodwork.	Visit to beach to assess potential sites.	**a.** Storyboard showing what the mural will display and the message it intends to convey; **b.** Sketch map and photos of beach showing where the mural will be placed; **c.** List of materials needed to construct the mural.
2. Consult with land owners, beach managers and other persons in authority to obtain permission to place the mural.	March to April	Teachers for class 4 and school principal arrange meetings with: **a.** Government departments responsible for beaches, planning and environment; **b.** Leaders from communities using the beach.	Discuss the project and obtain permission for the mural.	Written permission from relevant authorities to prepare and construct the mural.
3. Prepare and place the mural.	May to June	**a.** Identify funding and sources for materials to construct the mural; **b.** Students prepare the mural itself.	Materials to make the mural and paint.	Hold an official “opening” and related public awareness activity.
4. Sandwatch students assess the impact of the mural.	July to August	Class 4 students conduct a questionnaire survey among beach users to determine the impact of the mural, and based on the results design further awareness or follow-up activities.	Research, consultation with local experts.	Evaluation of the project and lessons learnt.

Replanting corals is another way of increasing coral resilience.

However, to be sure you do it right, try to find local scientists or organisations that can help you with setting up a project.

Coral plantation in Malaysia

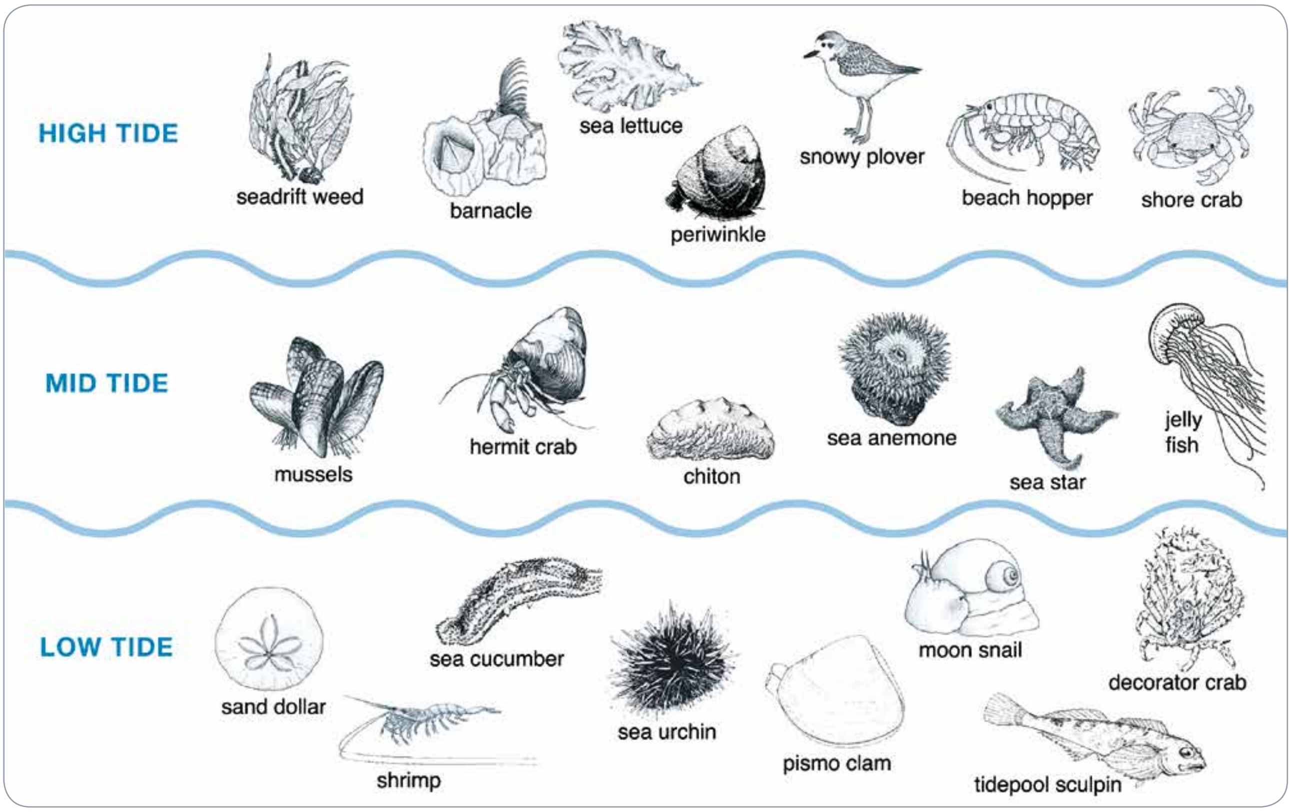
Example 3 – Endangered beach ecosystems

While at a glance beaches may appear as barren stretches of sand, in reality they are diverse and productive transitional ecosystems – called "ecotones" – that serve as a critical link between marine and terrestrial environments. The sandy beach is an unstable environment for plants and animals, largely because the surface layers of the beach are in constant motion as a result of waves and wind. This also means that organisms that live there are specially adapted to survive well in this type of environment. Many burrow in the sand for protection from waves and predators or to prevent drying out during low tide. Others are just visitors, such as birds and fish. While different animals are found in different zones, they often move up and down the beach with the tides. Zonation patterns along sandy shores are therefore not as clearly defined as on rocky shores (see figure below).

The beach ecosystem encompasses the interaction between the biological organisms and the physical environment in the beach area. The birds and crabs are as much a part of the ecosystem as the sand and the waves.

The vegetation on the beach and behind the beach also plays an important role: it helps stabilize the beach and prevent erosion. Landward of the highest high-water mark, vines and grasses predominate, which then give way to small salt-resistant shrubs, which in turn give way to trees. In tropical environments the sand runner or goat-foot (*Ipomoea pes-caprae*), a long trailing vine, is often found colonising the sand surface. Other species of vines, herbs and shrubs may also occur depending on the location of the beach. Further inland there are coastal trees, which in tropical areas might include seagrape (*Cocoloba uvifera*), seaside mahoe (*Thespesia populnea*), coconut palms (*Cocos nucifera*), manchineel (*Hippomane mancinella*) and the West Indian almond (*Terminalia catappa*). The change from low vines and grasses to mature trees is known as a vegetation succession.

Many of the projected impacts of climate change will adversely affect beach ecosystems, in particular sea level rise, ocean acidification and temperature increase. Resident and visiting species (e.g. sea turtles and migrating birds) will be affected. Beach erosion will tend to reduce the area of beach habitat for plants and animals. The most extreme effect would be the total loss of the beach, while alternatively in some areas the beach will be able to retreat inland thereby maintaining the beach ecosystem intact.



Common plants and animals found between the high and low water mark (illustration compiled by Aurèle Clemencin).

STEP 2
MONITORING THE BEACH

In order to assess how the ecosystem of your beach is being affected by climate change, you will have to monitor your beach. However, before doing so, carry out some research about how the ecosystem was in the past. Local beach users (e.g. fishermen and divers) or local organizations may have relevant information.

OBSERVING AND RECORDING PLANTS AND ANIMALS ON THE BEACH

→ What to measure

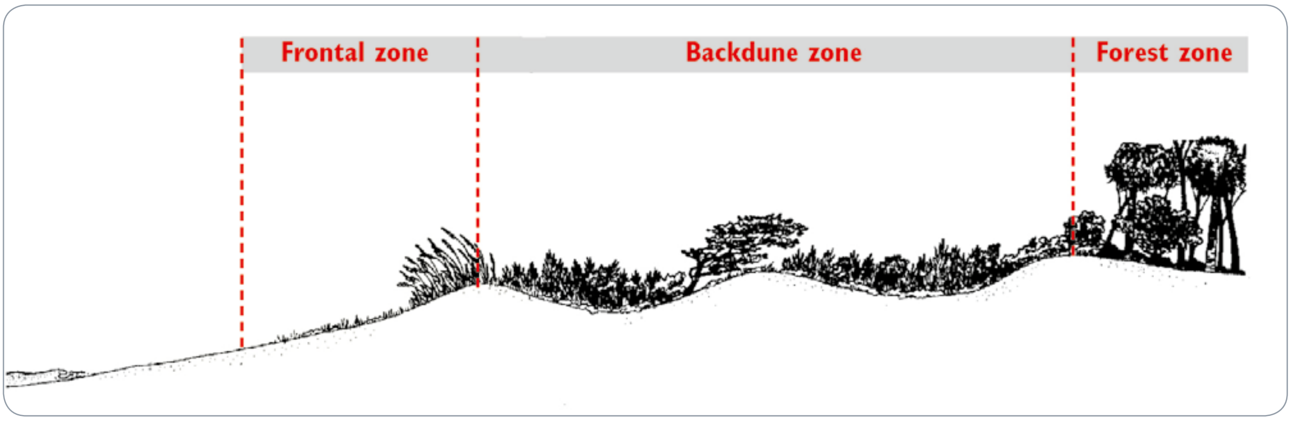
The distribution of plants and animals along the different regions of the beach, and also in the backdune zone (until the forest zone).

→ How to measure

For this activity, take containers and collect ten different objects from the beach and record where on the beach each object was found. The easiest way is to define a profile (cross-section, perpendicular to the shoreline) that stretches from the low-water shoreline to the forest zone (encompassing foreshore, backbeach, dune and backdune zones – see figure in “Step 1” in the top of page 156).
Remember not to collect live animals, and if you select a live plant, then take a small piece or leaf from the plant or – better – take a picture. The idea is to observe and conserve the flora and fauna. To better identify the zone where each specimen was collected, you can also lay out a tape measure from the most seaward edge of the beach until the forest zone, and note the distances.

→ When to measure

At low tide, in order to gather information not only on animals and plants living in the emerged part of the beach, but also in the intertidal zone (figure below).



Vegetation succession: the frontal zone is covered with grasses and vines, which gives way to shrubs and herbaceous plants and eventually the coastal woodland (adapted from Craig, 1984).

STEP 3
ANALYSING THE DATA

Separate biological from non-biological items, and plants from animals, and identify the items you collected (you can go further into detail on the identification, providing a full description with pictures, and investigating the habits – diet, movement, reproduction, protection – of each specimen). Discuss the ways in which the different species of animals and plants will be affected by climate change and how they might be protected. When discussing these different issues, make a connection between them and the environmental conditions in the different zones (e.g. the beach may be subject to wave action during storms and will receive the full force of the salt spray, while the backdune and forest zones may be more protected from the salt spray and the wind, and the soil and nutrient conditions may be better there).

Once you have finished the detailed description of the distribution of the animals and plants found in your coastal ecosystem, you need to compare it with analogous data you have gathered from previous years. When doing so, try to find out what has changed since then, and which changes can be attributed to climate change. You may find out, for example, that:

- → The distribution and/or abundance of the species along the different zones of your profile has changed.
  If your beach is narrower than before, because coastal buildings have hindered the landward retreat of the beach and the dune system that naturally follows sea level rise, there will probably be at least partially eroded dunes. Hence, the animals and plants living in this zone of the beach are probably no longer present, or are less numerous or have been replaced by other species.
  For rocky beaches, changes in the abundance and distribution of rocky shore animals and algae may be observed (mussel beds, for example, may be reduced by an over-abundance of predators). Ocean acidification may also be responsible for changes in the kind of species that thrive on a rocky beach.
  The range limits of many intertidal species may have been shifted upwards on the beach.

- → If your coastal ecosystem has saltmarshes, or mangroves, you may observe a landward migration and/or disappearance of those vegetated zones, and the animals that inhabit those ecosystems.

If local organisations or scientists are working on your beach, they may help you identify other changes to your coastal ecosystem.

STEP 4
IMPLEMENTING SOLUTIONS

Once you have identified which species of plants and/or animals are most at risk on your beach you can draw up a plan to help those habitats recover. Consult with the owners or managers of the land as to whether they agree to the idea of planting more trees on the land, or mangroves, or other dune vegetation. You will have to explain to them that the vegetation will help the beach ecosystem cope with climate change. Be sure to plant native species that correspond to species that previously existed in the region or still exist today but are struggling to thrive. These will be more resilient to climate change than species imported from other regions. Look for partners to help with your project (e.g. Agriculture Department, community group, environmental non-governmental organisations) and:

- Design your planting plan (native tree species, numbers of seedlings, space between seedlings, ecological fertilizer requirements). This must include a follow-up plan to care for the plants while they are young.
- Plant the trees and publicise the activity.
- Carefully monitor the number of seedlings that survive over the first six months, and care for the trees, in particular by providing them with water since the beach is a very harsh environment for new plants.

Students planting mangrove trees in Cambodia.

MITIGATION PROJECT
SETTING UP A WALKING BUS

MAIN SUBJECTS
Climate change attenuation: school transportation

GRADE
K1-5

TARGET
Schools in urban areas

OVERVIEW
In this project, students in urban areas plan, organise and set up a walking bus in order to reduce car journeys between their homes and the school. The students conduct a survey in the community, work on setting up several itineraries and address different issues related to safety, signage, timetables, etc. They also work on communication with the local authorities and parents, in order to implement the walking bus.

STEP LIST

STEP 1 – How do we get to school?	Students conduct an intergenerational survey among their families, to investigate how daily transportations has evolved over the past 50 years.
STEP 2 – Which itinerary is the best for our walking bus?	The class identifies, on a large map of the neighbourhood, the place where each student lives in order to decide an initial itinerary for the walking bus.
STEP 3 – What are the rules to follow?	A person from the town hall comes to the school to help validate the chosen itinerary and define the operating rules of the walking bus.
STEP 4 – Is our itinerary feasible?	Students test the routes they have identified for the walking bus and check whether they are practicable and safe.
STEP 5 – How to share informations?	The class plans how they will share information on the walking bus: for the parents, for the journey and for the municipality.
STEP 6 – Test and launch	Ready for D-day!
STEP 7 – Perpetuation	How can students ensure the project's perpetuation in the long term, involving the whole school and, beyond, the whole community?

STEP 1
HOW DO WE GET TO SCHOOL?

Start the project by debating with the students on the effects of transportation by car on climate change. Ask each student to answer a short questionnaire with basic questions like:

- *How do you usually get to school?*
- *How long does it take you?*
- *How far is the school from your home?*
- *Would you be willing to do the journey on foot, if you were accompanied by parents?*

A quick discussion shows that very often, in urban areas (at least in developed countries), students go to school by car, despite the short distance to travel.

Ask them if they think it was the same for their parents or grandparents, and how they can investigate this question. The class will then decide to conduct an intergenerational survey, targeting parents and grand-parents.

Let the students define the content of the questionnaire and organise the survey. As an example, a possible questionnaire could include the following questions:

- *How old are you?*
- *How did you get to school when you were a child?*
- *How long did this take you?* (Less than 10 min; between 10 and 30 min; more than 30 min).
- *How far away was your school?* (Less than 1 km; between 1 and 3 km; more than 3 km).
- *How do you go to work (or another destination requiring daily transportation)?* Detail this route by indicating the distances and travel times for each mode of transport.
- *In your opinion, how has the comfort of the means of transport evolved?*
- *If a walking bus (pedestrian transportation where students are chaperoned by adults) was installed, would you be willing to use this system for your child's journey to school?*
- *Would you be willing to help set up a walking bus, by accompanying children who choose to walk to school?*

After the students have conducted the survey among their families, compare the results[1]. In a lot of developed countries, we observe that while parents and grandparents had to travel long distances to school, they did so on foot or by bike. Today, although the

school is often closer to home, more and more people are taking their children to school by car.

Talk about the advantages of promoting walking as a way to get to school: it avoids CO_2 and fine particle emissions, it reduces car traffic near schools, thus improving road safety, it helps people to "rediscover" their neighbourhood, etc.

Discuss the term "walking bus" and the difference between a "free walk to school" and a "walking bus". A walking bus is public transportation with rules (stops, schedules, routes), where students are chaperoned by adults (parents, in general, called the "drivers") to go to school.

Analyse and discuss with the students the possibility of setting up a walking bus and the necessary steps. Different ideas may be suggested:

- Identify where every student lives.
- See where the bus stops can be placed.
- Define routes.
- Define schedules.
- Find "drivers".
- Check whether other classes in the school would be interested.
- Communicate with parents (give them the map and schedules, explain the principle).
- Communicate with the town hall and the police (for safety reasons).

1 This activity can also be an opportunity to work on mathematics (statistics, averages, sums) or the representation of information (tables, graphs).

STEP 2
WHICH ITINERARY IS THE BEST FOR OUR WALKING BUS?

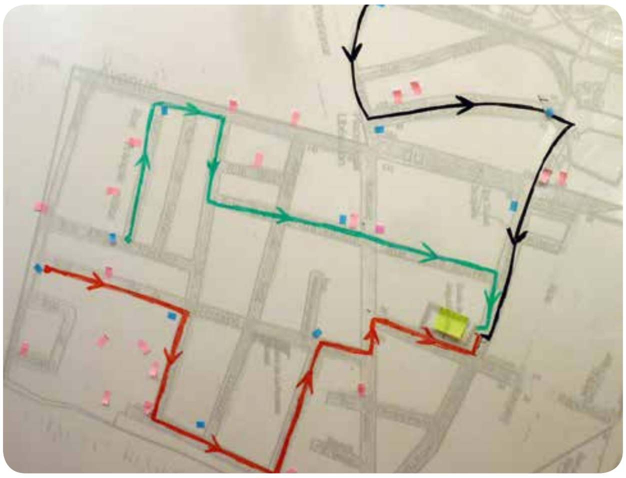
Find a large map of the city or of the neighbourhood (depending on the size of the city), and at least one small copy of this map for each student group.

> **NOTE**
> It is better to have a "satellite" view rather than a "map" view, so that you can distinguish individual houses from buildings. When it comes to choosing the location of bus stops, this information will be important because the route should be convenient for the largest possible number of students: buildings are preferable to houses, because the stop will benefit more families.

First, students locate the school and their home on the map, so that everyone can see how the students' homes are distributed.

Then, the class proposes several possible routes and discusses which ones are the most suitable (safety, traffic, ease of crossing, pavements). A walking bus can contain several "lines" that meet or separate, so that no student needs to walk for more than 15 minutes.

In order to facilitate the work of the class, and later the management of the walking bus, we recommend limiting the bus routes to three lines. Some students will note that the layout of the lines forces them to take a detour: these detours must be minimised, while understanding that it is impossible to have the walking bus pass in front of each house. Once the lines have been drawn, the stopping points (the "bus stops") need to be determined.



Three lines have been defined in this K-5 class.

STEP 3
WHAT ARE THE RULES TO FOLLOW?

For this step, even if it is not essential, it is very interesting to bring in a person from the town hall or, even better, from the police. A police officer can help validate or dismiss the proposed route(s) chosen by the students (based on safety issues). The policeman can also help to find the best stopping points for the walking bus. Otherwise, the teacher can play this role.

CLASS DEBATE
One issue, related to schedules, needs to be discussed with the whole class: *Will the walking bus be used to get to school only, or to go home from school as well?* In order to take a decision, it is necessary to first identify the arrival and/or departure times of the students (daycare, extracurricular activities, etc.), and check whether the walking bus will be useful for a large enough number of students. The class can also decide to define two different schedules and/or to "close" one line for the journey home after school.

GROUP DEBATE

→ Bus timetable

One group can work on setting the walking bus timetable taking into account the travel time, the time of arrival at school and the different stopping points. Keep in mind the travel time to school should not exceed 15 min. To avoid extending the travel time, it is important to make short stops (maximum 1 minute).

→ Number of “drivers” and “guides”

Taking into account that two to three guides are needed for 15 students, a group will have to work on a “parents’ schedule”. They will identify on the questionnaires the parents that have accepted to accompany the walking bus[2]. They can create a large schedule to display in the classroom (or school) with parent availability grids according to the days of the week and also a grid for students (in order to know when each one will be taking the walking bus). Plan a “test day” to check the itinerary and organise the walking bus.

→ Walking bus Charter

Another group can work on drafting a charter for students and parents. They will describe the rules of the walking bus: the actions to be taken if there is a delay or if a student/parent does not show up, the commitments of each person, insurance issues, etc. This charter can be signed by each student and parent.

→ Safety rules

A group will be responsible for determining the safety rules for the walking bus. The safety rules can later be included in the charter. *How do the students walk, how should they be dressed (do they need to wear a safety vest), which traffic regulations apply to the walking bus?* Students need to know pedestrian safety skills. Information can be found on different national websites[3] and taught in the classroom or sent home with students to practice these skills with their families.

→ Contact details

One group will be responsible for collecting the adress and phone number(s) of each family. The file should contain: the names and surnames of each student and his or her parents, their addresses and telephone number(s). This file will be provided to all “drivers” and “guides” of the walking bus. Conversely, parents will have the contact details of the accompanying persons.

→ Walking bus pass

One of the groups can design a “pass” that includes (at least):

- “Student pass”: name, school, class, stop, line, person to contact if there is a problem.
- “Driver pass”: name, school, line.

> **NOTE**
> The passes can be properly designed after the content has been validated.

CONCLUSION

Since the students’ groups have worked on different aspects of the project, it is important to share everything and ensure that the whole class approves (or improves) what has been done.

One issue is very important to discuss: *What do the students do if there is a delay?* For the walking bus to run smoothly, everyone must agree that the walking bus cannot wait for a student. This would lead to everyone else being late, delaying the schedules for the whole line, and resulting, in the end, in the project being abandoned. A walking bus is a public transport system, it is on time. A “real” bus would not wait for latecomers either.

STEP 4
IS OUR ITINERARY FEASIBLE?

It’s time to test the organisation of the walking bus. This test requires that some future accompanying parents be available for the outing. In addition to the parents, it is beneficial (but not essential) to have a police officer accompany the walking bus in order to monitor safety.

PREPARATION OF THE OUTING

Introduce the guiding parents and remind everyone that today’s objectives are to test the lines, check travel times, safety and the route itself.

---

2 Since the questionnaires were distributed before this work on the walking bus began, it is possible that parents replied “no”, simply because they did not really know what a walking bus involved. In this case, this question can be asked again in light of the work the students did in this lesson.

3 For example: https://www.livingstreets.org.uk/walk-to-school (UK), http://www.walkbiketoschool.org (US) or http://www.marchons-verslecole.com (France)

DURING THE OUTING

Organise the class into several groups (one group per line) or stay together as a whole class.

Under your supervision, the supervision of a few parents and, ideally, a police officer, the students will check the safety and convenience of the route.
The students take pictures and notes: this sidewalk is too narrow, this road has too much traffic, an element making it easy to identify the bus stops, etc. They mark the places/crossings they consider to be critical on the city map.
The travel time between each bus stop is timed.

BACK IN CLASS

Students share their impressions of the routes and their commented maps. The routes are validated, or modified if necessary, either due to safety or practicality constraints (for example, they may decide to add a few extra stops if the distance between two stops exceeds 5 minutes).

STEP 5
HOW TO SHARE INFORMATIONS?

CLASS DEBATE

Ask why and how the class will share information about the walking bus with the different parties.
Discuss with the whole class the advantages of walking compared to driving to school: less pollution, less CO_2 and fine particle emissions, less noise, benefits from a physical activity, discovery of the neighbourhood.

Provide some key figures to complete those mentioned below. The following information concerns France, and may be contextualised to each country before being shared with students:

- In Paris (except suburbs), 50% of the trips between home and the school are made by car[4].
- In France, 40% of the daily car trips are less than 3 km long, while 50% are less than 5 km long[5].

GROUP DEBATE

You can have each student's group work on a specific aspect of the communication. In the end, they should produce a single text, one poster and one "pass".

→ Laying out the route

This group works from a map and plots the different lines, according to what has been defined in the previous step. The stops and timetables should also be drawn on the map.

→ Final "pass" design

This group defines and finishes the final design of the student and driver "passes" so that they can easily be duplicated and filled.

→ Communication with parents

The aim of this group is to convince parents of the benefits of the walking bus. To do this, the students will have to create flyers, letters, posters, etc. containing information on the walking bus, the benefits of walking, reasons for them to get involved (do not overlook the "social" effect of the walk: discovery of the neighbourhood, citizen involvement and meetings between families, etc.).

→ Communication within the school

This group does similar work to the previous one but addresses other classes and the school administration. (The routes/stops defined by the class will need to be modified if the entire school is involved in the project).

→ Communication with local authorities

The aim of this group is to raise awareness in the town hall. To do this, the students think about events

4 Global Transportation Inquiry (Paris, 2009-2011).
5 French Ministry for the Ecological and Inclusive Transition (2018).

that they could organise: an official launch, a public debate, an article in the local newspaper, interviews.

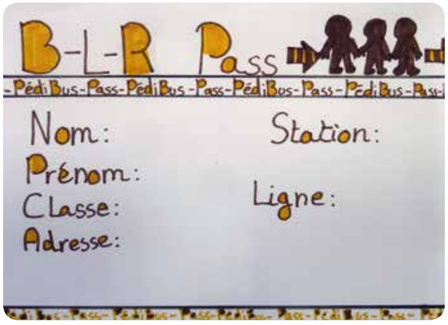
→ **Signage to be placed in the neighbourhood**
In this group, the students design the labels, posters and signs that they will place along the walking bus route, but also in the neighbourhood to inform and raise awareness among the inhabitants.

CONCLUSION

Once again, it is important to share the work of all groups and ensure that the whole class approves (or improves) what has been done by each group.

You can eventually show examples of different communication outputs made by professionals and discuss on what differences can be found between the outputs produced by the students and the professional ones. This may help the students propose suggestions to improve their visuals (to make them more efficient in terms of communication, for example), such as using a common logo (a bus with legs is often proposed), a colour code, etc.

The class can also decide to contact the local press and invite them to attend preparatory meetings, signage and set up, in order to get a wider audience aware of their project.



▲ Example of a "Student pass" in France.

Examples of street signage ▶
in Italy and Germany.

STEP 6
TEST AND LAUNCH

It is useful to plan an experimentation phase before implementing a permanent walking bus. On the one hand, this makes it possible to verify the feasibility and relevance of the action and to define the modalities of implementation with a view to sustainability. On the other hand, it gives visibility and credibility to your project.
Most often, a "test day" becomes a festive event.

BEFORE

- Choose a symbolic date for the "test day": "sustainable development week", international "I walk to school" week, etc.
- Organize a preliminary information meeting to explain your project to those who do not know it yet, to announce the date of the "test day" and to distribute the roles (parents, grandparents, associations).

DURING

- Plan to invite the local press. Prepare a press kit.
- Invite the local authorities (mayor, school director, etc.) and give them a role in the event (opening or closing speech).
- Take pictures and make videos of the event, organize fun educational activities or a welcome breakfast.

AFTER

You can consider distributing walking diplomas for the students' participation in the waking bus project, taking photos or recording some videos. This will help motivate the student to continue the walking bus!

STEP 7
PERPETUATION

The work does not stop here: setting up a walking bus is an important outcome of a climate change education project, but it takes time to become effective. It must therefore be continued over the long term and evaluated after a few months.

The walking bus will be sustainable if, day after day, the lines do not stop taking walkers.

To ensure the transition from an event-driven walking bus to a regular walking bus and to avoid a loss of momentum, several actions can be undertaken:

- Communicate the results of the project, highlighting positive developments. Give it a boost for the start of the school year and, at the end of the school year, explain that the walking bus can be restarted as soon as school starts back next year.
- Try to expand the list of "drivers" since the lack of availability of accompanying parents is the main operational obstacle. Convincing other parents to participate is key.
- In collaboration with the school's management, provide systematic information to parents who enrol their children.
- Conduct a satisfaction survey to adapt the walking bus (lines, timetables, stops) in a flexible and collaborative way.
- Organize regular festive events or challenges, for example as part of the international "Walk to school" program.

Finally, the sustainability of the project requires a gradual transition to a more institutional project responsibility: from the classroom to the school, then from the school to the municipality.

AWARENESS PROJECT
SCIENCE ON STAGE

MAIN SUBJECTS
Art, Sciences, Literature.

GRADE
K4-9

TARGET
Raise awareness among students and their community (school, families, local stakeholders) about climate change.

OVERVIEW
This project aims to raise public awareness around climate change issues. It is a project that brings science, literature and theatre together, with the aim of assimilating the scientific investigation process by studying the consequences, the origins of climate change, and the possible solutions. By putting on a play, the students study the characteristics of theatre text, read and write texts on the climate theme, discover the stage and learn the practice of theatrical play through exercises that develop proprioception, and interpersonal and communication skills.

STEP LIST

STEP 1 – The “science” part	Understanding climate change mechanisms, its consequences and possible adaptation and mitigation measures.
STEP 2 – Literature and dramatic play	Discovery of theatre through study of plays while meeting also scientific learning objectives.
STEP 3 – Creation of the show	Work on personal texts, literature, and scientific works. Study of content including videos and background sounds that will be used as media during the show.
STEP 4 – Session organisation	Work on role play, writing and performances.
STEP 5 – On stage!	Performance of the show for families, schools and local stakeholders!

OBJECTIVES

- Read and interpret literary and scientific texts.
- Ask questions, propose hypotheses, compare points of view, work across disciplines.
- Get acquainted with the scientific investigation process.
- Voice a text worked on in class through theatre.
- Reproduce a memorised text.
- Write a play.
- Get to know an artistic field: the theatre.
- Get involved in a collective project.
- Develop perseverance in activities.
- Strengthen "self-esteem".

This project is provided as an example and we encourage its modification and adaptation according to the needs of the students and their local context. In particular in STEP 4, the sessions and texts proposed must imperatively be adapted to the local context.

STEP 1
THE "SCIENCE" PART

Understanding climate change mechanisms, its consequences and possible adaptation and mitigation measures.

This guidebook can be used by the teacher for the first part of the project. The goal of this first part is to introduce climate change to students and discuss its consequences and possible adaptation and mitigation measures.

STEP 2
LITERATURE AND DRAMATIC PLAY

Discovery of theatre through study of plays while meeting also scientific learning objectives.

Students discover drama with all its features by comparing dramatic text and narrative text. Several aspects should be highlighted to the students: the differences between the two types of text, the way to make characters speak, the typographical symbols, the absence of introductory verbs and the role of stage directions.

The students then read literary texts related to the studied scientific topic. They can be excerpts of poetic texts, novels or comics, for example.

Here we provide some examples of texts that have been used by a French school in their "Science on Stage Festival" project: *The man who planted trees* by Jean Giono, *The snowman* by Jacques Prévert, *Conversation* by Jean Tardieu, *Samy has to Die* by Ahmed Madani and *Oceano Nox* by Victor Hugo. You will have to choose other texts, depending on the topic you want your students to work on, your language and culture, and your school curricula.

These texts provide a basis for both voice direction and staging exercises. The students will explore ways of talking and moving. Theatrical play techniques are very gradually introduced.

The first part of the work will help students feel confident, and accept physical and eye contact. Students are encouraged to speak loudly and articulate well their words. It is important to ensure every student feels good about and is invested in the group play.

STEP 3
CREATION OF THE SHOW

Work on personal texts, literature, and scientific works. Study of content including videos and background sounds that will be used as media during the show.

The show is built around different paintings and a corpus of texts. It aims to convey scientific discoveries and questions in a stage production, but also to include a social imaginary drawing from literature or cinema. It distinguishes the scientific truth from the irrational.

MATERIALS REQUIRED

- Plays (or narrative text transposed into theatrical text).
- Narrative texts (from the literature or other).
- Poetic texts.
- Scientific texts (from journals and specialised works or written science works).
- Writing by students.
- Student improvisations.
- Body language.
- Visual scenes.
- Video.

For this part of the project, it is useful to set up partnerships with scientists who can provide videos and background sound. This is also an opportunity to create a relationship between students and scientists and their work.

MODALITIES

- Duration: 6 to 8 months.
- Rehearsals every 2 weeks.
- Each student has a personal notebook for all the individual and collective written notes made during the project.
- In addition, a production book is written throughout the rehearsals. It is written by all students in the class, who should take notes in turn. It records rehearsals and the construction of the production.

WRITING THE SHOW

- Dramatic texts (or narrative text transposed into theatrical text).
- Narrative texts (from literature or other works).
- Poetic texts.
- Scientific texts (from journals and specialised works).
- Writing by students.
- Student improvisations.
- Body language.

STEP 4
SESSION ORGANISATION

Work on role play, writing and performances.

SESSION PROGRESSION

- The first four sessions are devoted to drama games.
- From session 5, alternate sessions of literature and drama game sessions.
- During the last three months: performance, rehearsals. Allow time and organisational flexibility.

ORGANIZATION OF EACH SESSION

The first four sessions are organised in three parts: one dedicated to a drama game, a second one to improvisation and a last one to the study of a dramatic text. The remaining sessions focus on the work on dramatic literature, while continuing the development of student's acting skills through different drama games.

- Drama game: work on voice and body language.
- Improvisation: create and play an event, a situation, etc.
- Texts: directing voice and stage.

MAIN OBJECTIVES OF THE DRAMATIC TEXT WORK

- Differentiating theatrical text from narrative text.
- Writing a play scene.
- Memorising a scene.

GENERAL OBJECTIVES OF THE DRAMA GAMES

- **Diction**: directing the voice, articulating and exploring ways of speaking.
- **Body language**: exploring body movement, unusual postures and synchronization.
- **Space**: collectively occupying and using a space.
- **Transversal**: accepting physical and eye contact and trusting each other.

THEATRAL GAME

	OBJECTIVE	DRAMA GAME	IMPROVISATION	TEXT
SESSION 1	Experiment with a form of expression: the drama game	A big person and a small one	A giant wants to enter a restaurant	*A giant with red socks* by Pierre Gripari
SESSION 2	Trust someone	The blind person	The interview	*To the market* by Georges Courteline
SESSION 3	Work on synchronization	The mirror	The choir	*The Trojan War* (based on Christine Palluy's album)
SESSION 4	Express an emotion through a frozen attitude	Photos	The accident	*Finish your sentences* by Jean Tardieu

	LITERATURE	DRAMA GAME
SESSION 5	Text sorting	Wanderings Creating situations inspired by sentences from the texts sorted
SESSION 6	Collect students' thoughts about the theatrical genre (Excerpt from Edmond Rostand's *Cyrano de Bergerac* or Gripari's *Red Sock Giant*) Identify differences and similarities between drama and narrative texts Spot the different types of text Differentiate speech and stage directions.	Stage movement
SESSION 7	Write the end of a scene Take back students' writings for improvement	Geographic features (hill, precipice, etc.)
SESSION 8	Understanding the role of the stage directions	Photos
SESSION 9	Understanding the role of an initial stage directions	A sequence of gestures
SESSION 10	Identifying the organization of a play	Handling objects: letters or important documents
SESSION 11	Writing initial stage directions based on a set drawing	The scales of laughter and crying, the metamor-phose
SUBSEQUENT SESSIONS	Reading text Interpretation, comprehension, memorisation (in connection with the theatre) Documentary research on authors	Rehearsals Memorisation of text and movements on stage Directing the voice: diction, intonation, intentions Gesturing: internalising a character Expressing feelings with voice, face and body

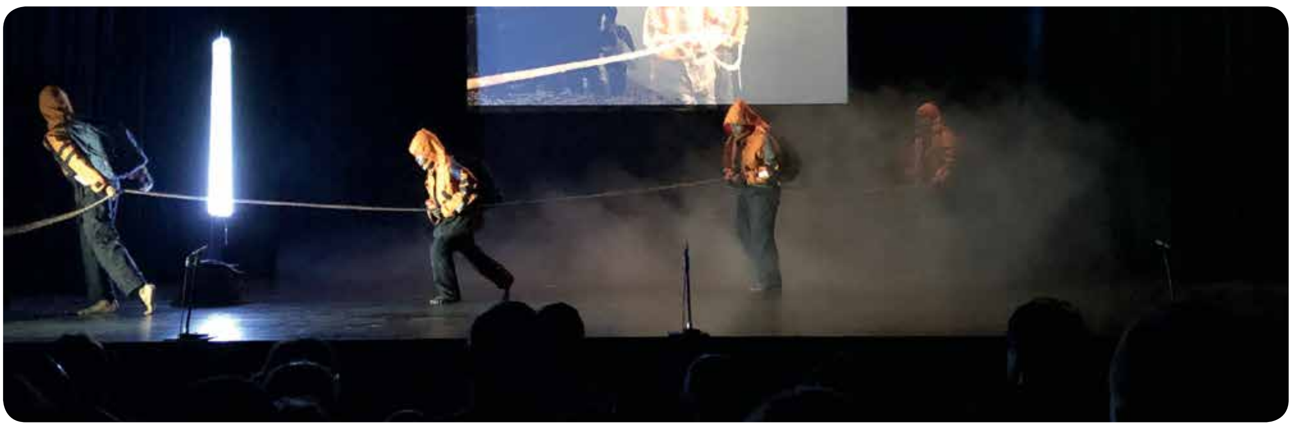
STEP 5
ON STAGE!

The project will conclude with a play in front of an audience. This aspect is very important, as it gives a full meaning to the project. It motivates the students all year long, giving them a goal. They project themselves and develop perseverance, accepting the demands involved. The existance of a final show hence pushes students to work better. It also contributes to the involvement of parents in the school work of their children. The show can also be an opportunity to involve a scientist who can present an opening talk on the topic.

The mix between art and science brings about a lot of emotion. Some parents may also discover new talents in their children! This emotion is invaluable and leaves a mark on the minds of the children and their community.

Photos illustrating the last "Science on Stage" organised by the pilot school in Nogent-sur-Oise in June 2019:

The students represent the temperature increase graph from the IPCC.



Reproduction of a scene from the Ice Memory project shared by a researcher in glaciology.

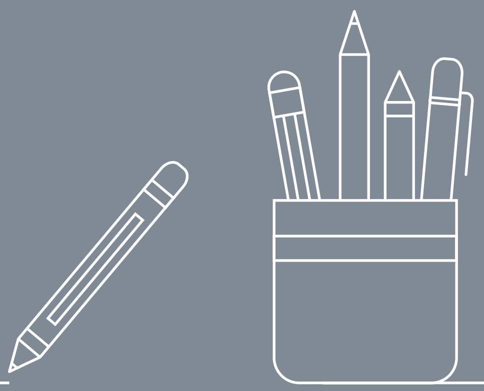
DO IT YOURSELF
PROJECT IDEAS

The table below offers an overview of topics that can inspire a project, the main school subject concerned, and the key ideas associated with it.

Protected natural areas (adaptation) Natural sciences	• Citizen projects (monitoring, biodiversity observation, etc.). • We can implement climate change adaptation measures. • We can help save already endangered ecosystems. • We can create natural protected areas. These areas support ecosystem regeneration and can be used as educational and recreational areas.
Saving water (adaptation) Social sciences / Natural sciences	Using less water limits freshwater consumption and helps maintaining the equilibrium of the water cycle.
Become a climate ambassador (awareness) Visual / Performing arts	Logos, slogans, podcasts, radio shows, YouTube videos, theatre, songs, paintings, street art, exhibitions, etc.
Managing energy consumption (mitigation) Social sciences / Natural sciences	• We can help reduce greenhouse gases emissions to mitigate climate change by making conscientious energy choices, especially at home. • Choosing renewable energy sources. • Limiting energy consumption using better building insulation, rethinking building heating and cooling systems, and changing individual energy consumption habits.
Transport (mitigation) Social sciences / Natural sciences	• We can help reduce greenhouse gas emissions to mitigate climate change by making conscientious transport choices. • For short distances: cycling or walking. • For long distances: avoiding long-distance travel for short stays except when necessary, choosing modes of transport not driven by fossil fuels, and carpooling or using public transportation whenever possible.
Consumerism and buying choices (mitigation) Social sciences / Natural sciences / Visual arts	• We can help reduce greenhouse gas emissions to mitigate climate change by making conscientious consumption choices. • Avoiding consumerism and buying less. • Promoting a circular economy in which resource input and waste, emissions and energy leakage are minimised by slowing, closing, and narrowing energy and material loops. When choosing new products, buy products produced locally and that did not travel far to get to you. Focus on sustainable products. Eat less meat, especially beef. • Avoiding products that contribute to deforestation (such as palm oil and exotic woods). • School canteens should engage in sustainable choices with food, and waste as little as possible. • Shared gardens can be created.
Promoting a circular economy (mitigation) Social studies / Science / Visual arts	• We can help reduce greenhouse gases emissions to mitigate climate change by making conscientious consumption choices. • Promoting a circular economy in which resource input and waste, emissions and energy leakage are minimised by slowing, closing, and narrowing energy and material loops. • Reusing. Repairing. Recycling. Initiating repair workshops where everyone can repair things that are broken and give them a second life, installing recycling bins at school, and starting to recycle regularly at home.

Some of our actions contribute to climate change, but we can also act to reduce this impact.

→ We all have a footprint on Earth, but we can also have a handprint.
→ We can make individual choices and influence political decisions.
→ We can choose a profession that can make a difference.
→ We can rethink our habits.
→ We can talk to friends and family so that more and more people take action.



AROUND THIS BOOK

ADDITIONAL MULTIMEDIA RESOURCES

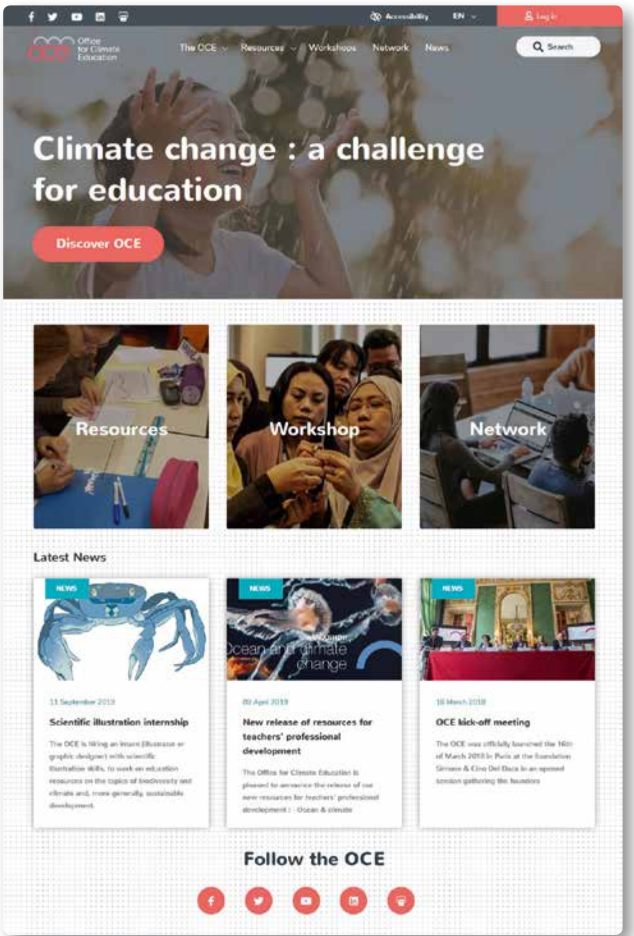
WEBSITE

The Office for Climate Education website offers many educational resources on climate change:

- Summaries for teachers of IPCC reports
- Class activities
- Multimedia activities, videos, graphs and charts for class-use
- Resources for professional development

All OCE resources are published under the CC-BY-NC-SA license (free non-commercial use and adaptation).

www.oce.global



VIDEOS

Some of our videos and multimedia activities have been explicitly designed to accompany the teaching guide *The climate in our hands – Ocean and Cryosphere*. They are presented below.

In each of the following videos, an expert speaks about a specific issue related to the ocean or the cryosphere, in the context of climate change. These videos can be used either to initiate or to conclude a discussion with the students on a specific topic.

URBAN HEAT ISLANDS

Aude Lemonsu, Meteorologist, Météo-France

Cities are very particular environments with poor vegetation. The materials used in the buildings and city infrastructures can maintain a high temperature during the day and the night. Hence, urban heat islands are urban areas that are significantly warmer than their surroundings.
With climate change, we expect cities to become warmer. In order to lower this temperature, different solutions are possible, such as urban greening, by planting trees or creating green rooftops.

GLACIERS

Etienne Berthier, Glaciologist, LEGOS

Glaciers are bodies of ice, formed by the accumulation of snow. Climate change is leading to glacier melt worldwide. This melting contributes to about one third of the total sea level rise.
Furthermore, the freshwater input to rivers from glaciers decreases. The only thing we can do to protect glaciers is decrease our CO_2 emissions.

ACIDIFICATION

Catherine Jeandel, Oceanographer, LEGOS

Water on the surface of the ocean is becoming more acidic due to the absorption of anthropogenic CO_2 emissions. This dissolved CO_2 affects calcareous algae and animals such as corals, oysters and mussels.
The best solution to limit ocean acidification is to avoid emitting more CO_2 into the atmosphere.

TROPICAL CYCLONES

Fabrice Chauvin, Meteorologist, CNRM

Tropical cyclones are huge thermal systems that get their energy from the ocean. They produce very strong winds and high levels of rainfall. Tropical cyclones are not expected to increase in frequency as the climate changes, but models predict that the most intense cyclones will become more frequent.

MARINE ENERGIES

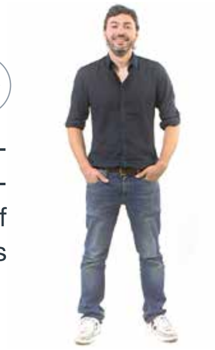
Raphaël Gerson, Deputy head of renewable energy department, ADEME

Climate change and energy security boost renewable energy demand all over the world. Wave energy, tidal energy and floating wind farms are the future of marine renewable energies: they do not produce CO_2 or waste, they create local jobs and are becoming cheaper and cheaper.

SEA ICE MELT

Martin Vancoppenolle, Sea ice expert, LOCEAN

Climate change has a direct consequence on sea ice: as it warms the atmosphere, sea ice melts. We estimate that the emissions from a Paris-New York flight cause 3 m^2 of sea ice to melt. One solution to protect the remaining sea ice is to decrease our CO_2 emissions.



THERMOHALINE CIRCULATION

Jean-Baptiste Sallée, Oceanographer, LOCEAN

Thermohaline circulation is the global marine current created by the difference in seawater temperatures and salinity levels. Climate change causes the ocean surface to warm and salinity levels to drop (consequence of melting ice). This reduces thermohaline circulation. The solution resides in mitigating our greenhouse gases emissions.

EL NIÑO

Eric Guilyardi, Oceanographer, IPSL

El Niño is a climate phenomenon arising in the tropical Pacific and involving the ocean and the atmosphere. During normal years, trade winds blow warm water from the east to the west, creating more rainfall around Indonesia and an upwelling on the coast of Peru – meaning more food for the fish. During El Niño, the entire system collapses and warm waters come back to the east. Climate change enhances the effect of El Niño and increases rainfall. But we do not know yet if climate change will affect the El Niño phenomenon itself.

MANGROVES

François Fromard, Mangroves expert, EcoLab

Mangroves are forests rooted in mud and growing in seawater. They are found on the coasts of tropical and subtropical regions, providing many ecosystem services and storing large quantities of CO_2.
Mangroves are at stake due to, for example, the development of shrimp farming.

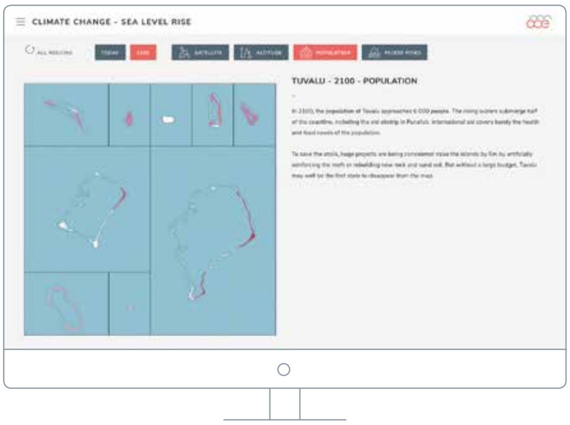
SEA LEVEL RISE

Angélique Melet, Oceanographer at Mercator Ocean International

As our planet warms, part of the heat excess is stored in the oceans. Sea level is rising due to the thermal expansion of seawater and ice melt from glaciers and polar ice sheets. IPCC scenarios predict a sea level rise of about 1 m by 2100. It is therefore very important to conserve the natural protection of our coasts.

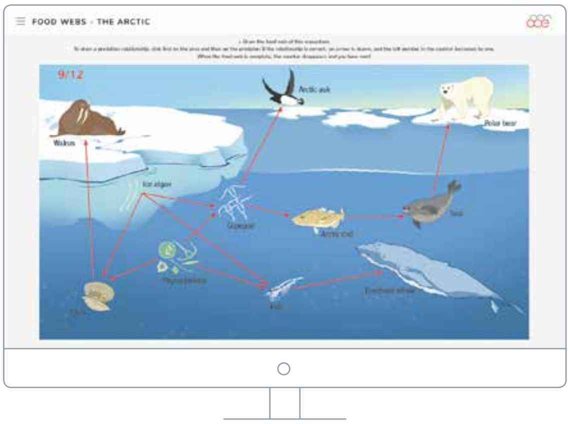
MULTIMEDIA ACTIVITIES

The following multimedia activities offer the students the possibility of working interactively in different topics related to climate change.



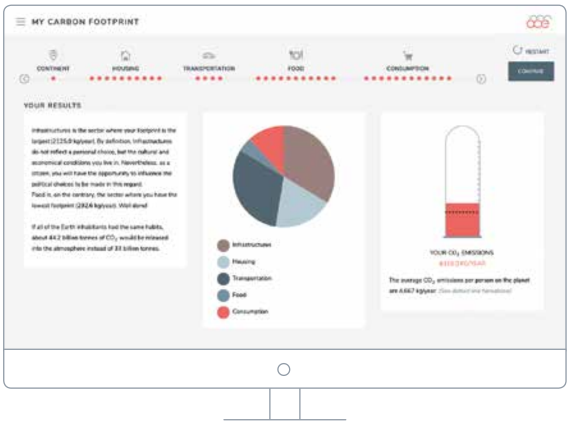
SEA LEVEL RISE

Taking into account geography and population density, this multimedia activity shows the risks associated to sea level rise in five coastal regions: the Mississippi (USA), the Nile (Egypt) and the Ganges (Bangladesh) deltas, the Netherlands, and the Tuvalu archipelago.



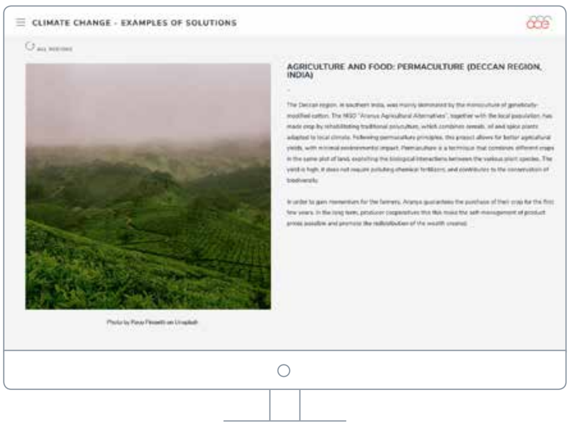
FOOD WEB

This multimedia activity allows the students to organise the food webs of six different marine ecosystems: Arctic, Antarctic, kelp forests, mangroves, North Sea and coral reefs.



CARBON FOOTPRINT

This activity allows students to calculate their own carbon footprint. It helps them realise how much our daily actions or habits contribute to greenhouse gas emissions and thus how we can reduce them.



HOW CAN WE ACT?

This multimedia activity describes around thirty tangible actions that have been carried out around the world to address climate change issues. These adaptation or mitigation “solutions” include agriculture and food, energy, housing, urban resilience, ecosystems, research and public awareness.

BIBLIOGRAPHY

SCIENTIFIC DOCUMENTATION ON THE OCEAN, THE CRYOSPHERE AND THE CLIMATE

IPCC Special Report “The Ocean and Cryosphere in a Changing Climate”
www.ipcc.ch/srocc

NASA – Global Climate Change: Graphics and multimedia
https://climate.nasa.gov/resources/graphics-and-multimedia/

National Snow and Ice Data Center: Satellite images and data showing Arctic – and Antarctic – wide changes in sea ice
https://nsidc.org/data/seaice_index/

Ocean and Climate platform
www.ocean-climate.org/?page_id=4534

UNESCO – Ocean Literacy
https://oceanliteracy.unesco.org

OCE EDUCATION RESOURCES

CLIM – Educational videos about the ocean and the cryosphere in a changing climate
www.youtube.com/channel/UCFWnXg29G9npeWgFEaaao5w

IPCC summaries for teachers
www.oce.global/en/resources/ipcc-summaries-teachers

Teachers’ professional development resources
- The greenhouse effect: www.oce.global/en/resources/professional-development/greenhouse-effect
- Ocean and climate change: www.oce.global/en/resources/professional-development/ocean-and-climate-change

OTHER EDUCATION RESOURCES

Dublin City University, Institute of Education: Trócaire and the Centre for Human Rights and Citizenship Education – “Creating Futures” resources produced in the scope of the “Education for a Just World Initiative”
www.trocaire.org/getinvolved/education/creating-futures

Eco-schools – Stories and news about sustainability projects conducted in schools
www.ecoschools.global/stories-news

La main à la pâte – The Ocean, my planet and me: A teaching unit for primary school and lower secondary school classrooms
www.fondation-lamap.org/en/20322/the-ocean-my-planet-and-me

NASA Climate Kids
https://climatekids.nasa.gov

National Oceanic and Atmospheric Administration – Teaching climate, fact sheets, lesson plans, case studies, etc.
https://oceanservice.noaa.gov/education/pd/climate/welcome.html

The Sandwatch Foundation – A network of children, youth and adults working together to enhance their beach environment and build resilience to climate change
www.sandwatchfoundation.org

TROPICSU – Resources for high-school teachers
https://tropicsu.org/un-resources/

INTERACTIVE SIMULATIONS

En-ROADS – Simulation used to understand how we can achieve our climate goals (high school)
https://www.climateinteractive.org/tools/en-roads/

University of Colorado – Simulation of the greenhouse effect (high school)
https://phet.colorado.edu/en/simulation/greenhouse

University of Manchester – Build your own Earth (high school)
www.buildyourownearth.com

GLOSSARY

ADAPTATION
The process of adjusting to current or expected climate change impacts. In human systems, the aim of adaptation is to reduce risks, increase resilience or seize on beneficial opportunities. In natural systems, human intervention may facilitate adjustments to expected climate change impacts.

ALBEDO
Meaning "whiteness", albedo is the reflective power of an object or surface. For instance, ice and fresh snow have a high albedo, ranging from 40% to 80%. This means that they reflect 40% to 80% of the incoming sunlight. The ocean is darker, so it has an albedo of less than 10%.

ANTHROPOGENIC EMISSIONS
Greenhouse gases emitted by human activities.

CARBON DIOXIDE (CO_2)
A gas produced by the combustion of carbon (for example: fossil fuels). It is also produced by living organisms while breathing. CO_2 contributes to the greenhouse effect and ocean acidification.

CARBON FOOTPRINT
A carbon footprint is defined as the total amount of greenhouse gases produced directly or indirectly by human activities. It can be calculated for an individual, a particular event or an organization.

CARBONIC ACID (H_2CO_3)
This acid is formed when carbon dioxide dissolves in water, causing an increase in the acidity of the water.

CLIMATE
An average pattern of weather conditions – such as temperature, precipitation, humidity, wind, air pressure – for a particular region over a long time period of time (months, years, decades, centuries or more).

CLIMATE CHANGE
Climate change refers to several global phenomena. For example: changes in temperature, precipitation, extreme events, sea level rise and ocean acidification. The term is most commonly used to describe the current human-induced climate change that started around 1850 due to an increase in the global average temperature. The term "global warming" is also used.

CLIMATE JUSTICE
This term is used to acknowledge the social and political dimensions of the challenges associated to climate change, rather than considering only their environmental dimension. It relates the differences observed between those more responsible for climate change, and those more affected by its consequences, to the notion of justice (in particular, social and environmental justice).

CO_2 UPTAKE
All the processes that contribute to the removal of CO_2 from the atmosphere. CO_2 can be removed by biological processes such as ocean or land photosynthesis, or by more physical processes such as carbon absorption in water.

COASTAL ECOSYSTEMS
Coastal ecosystems exist where land and water meet. In these areas, the mixture of freshwater and seawater creates unique environments and ecosystems with distinct structures and diversity. They include saltmarshes, mangroves, coastal wetlands, estuaries and bays.

COASTAL EROSION
Coastal erosion is a natural process that can be exacerbated by human action. It consists in the removal and transport of sediments or rocks along the coastal zone, through the action of waves, currents, winds and tides. A long-term loss of sediment from beaches results in beach erosion and consequent shoreline retreat. Climate change (in particular sea level rise and increased precipitation) can enhance coastal erosion.

COMPLEX SYSTEM
A system (such as the climate system) regulated by many factors that interact with and influence each other: atmosphere, ocean, land and biosphere, for example.

CONTINENTAL ICE
All the ice on land. Continental ice is formed by the accumulation and compaction of snow over a long period of time.

CRYOSPHERE
All the ice and snow on Earth, on land and in the water (glaciers, ice sheets, seasonal snow, sea ice, permafrost, and frozen lakes and rivers).

ECOSYSTEM
The totality of living beings in a given environment, plus the environment itself. In an ecosystem, everything is interconnected and interdependent.

ECOSYSTEM SERVICES
All benefits, material and immaterial, that an ecosystem can provide humans with. Examples: oxygen (through photosynthesis), food, raw materials, energy (hydroelectric power plants), climate regulation, coastal protection (by healthy coral reefs and mangroves), recreation (tourism).

EQUITY
Justice, fairness: when the same opportunities are given to all – education, health, rights, etc.

EXPOSURE
How much a population is exposed to a certain climate hazard, due, for example, to its geographic location. Example: low-lying lands are more exposed to sea level rise than mountain regions.

EXTREME EVENTS
Unusual events that have a high negative impact on humans and ecosystems. Example: tornadoes, storm surges, landslides, droughts and heat waves.

FEEDBACK LOOP
A feedback loop can be seen as a vicious circle in which some elements can exacerbate or attenuate one or several causes of global warming.

GLACIER
A large mass of ice on land that slowly moves downhill.

GLOBAL WARMING
(see definition of Climate Change).

GREENHOUSE EFFECT
Solar radiation crosses the atmosphere, is absorbed by the Earth's surface and warms it. The absorbed solar radiation is transformed into infrared radiation (heat). Some of this infrared radiation is "trapped" on its escape towards space by greenhouse gases in the atmosphere and is sent back towards the Earth's surface – heating it up even more. This is called the greenhouse effect.

GREENHOUSE GAS (GHG)
Greenhouse gases cause the greenhouse effect. Greenhouse gases are mainly water vapour, carbon dioxide, methane, nitrous oxide and ozone.

HEAT SINK
In the context of climate change, a heat sink is a body – for example, a forest or the ocean – that absorbs heat from a warmer body – such as the atmosphere. This results in cooling of the warmer body. The most important heat sink in climate change is the ocean which, so far, has absorbed over 90% of the heat that has resulted from global warming.

HEATWAVE
A period of abnormally and uncomfortably hot weather with high day temperatures and no or little cooling down at night. A heatwave can last up to several weeks.

ICE SHEET
A very large and thick layer of ice on a continent.

INDUSTRIAL REVOLUTION
Historical period between 1760 and the 1840s. It has marked the transition from agricultural to industrial societies. The Industrial Revolution started in Europe and the United States and led to a rapid development of productivity, technologies and science, and therefore to population growth.

INFRARED RADIATION
Infrared radiation is the invisible part of light that we can feel as heat. It plays a key role in the greenhouse effect.

MARINE CURRENTS
A flow of water through the ocean. Warm and cold currents redistribute heat and nutrients around the globe.

MITIGATION
Human intervention to reduce global warming by reducing GHG emissions or by enhancing GHG sinks.

NATURAL VARIABILITY
Variations in the climate system that are not related to human activities (for example, alternation of glacial and interglacial eras).

OCEAN ACIDIFICATION
Increase in the acidity of seawater, caused by the dissolution of CO_2 from the atmosphere in the ocean's surface water. When CO_2 reacts with water, the water becomes more acidic.

PERMAFROST
Soil, rock or sediment that is permanently frozen (for at least two consecutive years).

pH
pH is a measure of the acidity and alkalinity of a solution on a scale from 0 to 14, in which 7 represents neutrality. A lower value indicates a more acidic solution whereas a higher value means a more alkaline one.

PRIMARY PRODUCTION
Primary production is the process by which a primary producer (a cell or an organism) produces its own organic matter using mineral materials. For example, photosynthetic living beings only use water, CO_2 and light to grow.

SEA ICE
Frozen seawater that floats at the ocean's surface.

SEA LEVEL RISE
Because of climate change, the global mean sea level has increased by about 15 cm since 1900 until 2018. The current increase rate is between 3 and 4 mm / yr. The sea level is projected to rise by a further 20 cm to over 1 m by the end of this century, depending on how much greenhouse gases we emit.

SUSTAINABLE DEVELOPMENT
Development that meets the needs of the present without compromising the ability of future generations to meet their own needs.

THERMAL EXPANSION
The increase in the volume of a material as a result of rising temperature. Global warming leads to seawater thermal expansion: when the ocean gets warmer, it expands and occupies more space.

THERMAL INERTIA
Property of matter to approach the temperature of its surroundings. The slower its temperature changes, the higher the thermal inertia.

THERMOHALINE CIRCULATION
Deep and surface marine currents generated by differences in salinity and temperature of different water layers. Colder and saltier water sinks to the depths of the ocean, whereas warm and less salty water upwells. This is known as the "conveyor belt" which transports heat around the Earth.

VULNERABILITY
Sensitivity of a population when exposed to climate change hazards and its consequences. Example: a low-lying region with important coastal protection infrastructures and resources is less vulnerable to sea level rise that a low-lying region with no coastal protection infrastructures and few economical resources.

WEATHER
The state of the atmosphere at a particular time and place. To define it, many variables such as temperature, precipitation, cloudiness or wind are taken into account.

ACKNOWLEDGEMENTS

This educational project is the result of extensive collaboration between the Office for Climate Education team and many scientific and educational partners.

The authors would like to thank:

The experts who support the OCE, who participated in the writing of the scientific and pedagogical overviews or who, through their critical review and proposals, contributed to the design of the pedagogical activities. In alphabetical order: **Juan Carlos Andrade, Laurent Bopp, Badin Borde, Caroline Coté, Sanny Djohan, Randy Fananta, Serge Janicot, Jean Jouzel, Pierre Léna, Maria Martin, Claudia Martinez, Valérie Masson-Delmotte, Cliona Murphy, Anwar Rumjaun, Jean-Baptiste Sallée, Pramod Kumar Sharma, Aline Tribollet, Martin Vancoppenolle and Gabrielle Zimmermann**.

Teachers who have tested the activities in their classrooms. In alphabetical order: **Christine Barbier, Catherine Broch, Elisabeth Cochet, Sylvie Decitre, Véronique Delachienne, Sébastien Garreau, Mathias Hoppe, Kévin Faix, Catherine Legrand Marcq, Sébastien Lhomme, Marie-Laure de Miguel-Braban, Anne-Hélène Monfort, Katell Senabre, Sinead Lally, Yvonne Naughton.**

The following organizations, which have authorized the use of content from their own publications. In alphabetical order: **Fondation La main à la pâte** (*Le climat, ma planète et moi!*, *Ma maison, ma planète et moi!*, *Je suis écomobile* and *L'océan, ma planète et moi!*), **The Ocean & Climate platform** (scientific factsheets), **Science Museum UK** (*Exploring climate science – Atmosphere*), **The Conversation** (article by Kieran Baxter), **Trócaire and the Centre for Human Rights and Citizenship Education**, **DCU Institute of Education** (*Creating Futures*), **UNESCO** (*Sandwatch - Adapting to climate change and educating for sustainable development*).

The experts who participated in the development of the interactive activities and video clips which accompany this teaching guide. In alphabetical order: **Etienne Berthier, Sébastien Carassou, Fabrice Chauvin, François Fromard, Raphaël Gerson, Eric Guilyardi, Mathieu Hirtzig, Catherine Jeandel, Aude Lemonsu, Angelique Melet, Emma Michaud, Jean-Baptiste Sallée and Martin Vancoppenolle.**

The graphic designers and directors who contributed to the usability and attractiveness of these resources: **Dorothée Adam, Romain Garouste, Claire Mazard and Mareva Sacoun.**

Finally, the OCE would like to thank the following organizations, whose scientific, operational and financial support has been essential to the production of these educational tools. In alphabetical order:

ADEME, CASDEN, IPCC Group 1 Technical Support Unit, Institut Pierre Simon Laplace (IPSL Climate Graduate School), Institut de Recherche pour le Développement, Investissements d'avenir, Fondation La main à la pâte, Fondation Luciole, Météo France, association Météo et Climat, Fondation Prince Albert II de Monaco, Siemens Stiftung and Sorbonne-Université.

COPYRIGHTS

Published by the Office for Climate Education, www.oce.global
ISBN 978-2-491585-01-3

The climate in our hands is a collection of educational resources for primary and secondary schools created by the Office for Climate Education and its partners.

This first volume, ***Ocean and Cryosphere***, offers a ready-to-use lesson plan for students to understand climate change and the ocean and cryosphere in both their scientific and societal dimensions, at local and global levels, to develop their reasoning abilities, and to guide them to take action (mitigation and/or adaptation) in their schools or communities.

As the Intergovernmental Panel on Climate Change has stated:

- **The ocean and cryosphere sustain us.**
- **They are under pressure.**
- **Their changes affect all our lives.**
- **The time for action is now.**

This resource:

- Targets students from the upper end of primary school to the end of lower-secondary school (ages 9 to 15).
- Includes scientific and pedagogical overviews, lesson plans, activities, worksheets and links to external resources (videos and multimedia activities).
- Is interdisciplinary with lessons covering disciplines including natural sciences, social sciences, arts and physical education.
- Promotes active pedagogies: inquiry, role-play, debate and project-based learning.

UNESCO
United Nations
Educational, Scientific and
Cultural Organization

Office for Climate Education
UNDER THE AUSPICES OF UNESCO

Fondation La main à la pâte · Météo France · IRD Institut de Recherche pour le Développement France · Météo et Climat Société météorologique de France · Institut Pierre Simon Laplace Sciences de l'environnement · IPCC Intergovernmental Panel on Climate Change Working Group I - The Physical Science Basis · Siemens Stiftung · PIK Potsdam Institute for Climate Impact Research · iap Science Research Health the interacademy partnership · Investissements d'avenir · Ministère de l'Éducation nationale et de la Jeunesse, République Française · Ministère de la Transition écologique et solidaire, République Française · Sorbonne Université Créateurs de futurs depuis 1257 · ADEME Agence de l'Environnement et de la Maîtrise de l'Energie · Fondation Luciole Institut de France · Fondation Prince Albert II de Monaco

ISBN 978-2-491585-01-3
9 782491 585013