SCHOOL CITIZEN SCIENCE IN CLIMANTOPIA

DESIGN OF LABORATORY PRACTICES ON CLIMATE CHANGE FOR DISSEMINATION THROUGH SCHOOL STANDS AT TOURIST SITES

Francisco Sóñora Luna Aitor Alonso Méndez Marina Elisa Arévalo González

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INTRODUCTION

Citizen science or demo-science, defined by some authors as a kind of scientific democracy, seeks to move scientific knowledge beyond the boundaries of the laboratory. The citizenry thus becomes a fundamental agent in the advancement of science, taking on knowledge and contributing to its progress, while at the same time raising awareness of environmental issues, thus forming more conscious and responsible citizens.

Image 1: *Example of a citizen science activity carried out at Ciencia Viva.*

With this practical manual we aim to transfer this scenario of networked and transdisciplinary collaboration to the educational sphere, converting citizen science into a form of service-learning practices. It is based on problems and situations that invite teachers and students to investigate in order to answer a socially relevant question or respond to a detected need: what is the origin of climate change, how does ocean warming affect food security?, what about the formation of hurricanes?, why does the ocean become more acidic?, and how does climate change relate to soil erosion?

At the same time, innovative methods and dissemination strategies are proposed to broaden the influence of this environmental practice through dissemination in the tourism sector. The main objective of disseminating these practices in the tourism sector is to raise awareness of climate change and its impacts, as well as to promote climate action through sustainable tourism. By promoting these practices among tourists and industry stakeholders, it aims to create a multiplier effect, encouraging responsible behaviour and environmental protection measures.

INTRODUCTION

Ultimately, the aim is to promote environmentally conscious and respectful tourism that contributes to the conservation of natural resources, the mitigation of climate change and the sustainable development of tourist destinations. The aim is to amplify the impact of these practices, disseminating and integrating them into the tourism sector, in order to promote a transition towards a more sustainable and responsible tourism that benefits local communities and the environment.

1.1. WHY IS THE TEMPERATURE RISING?

Image 2: *Photograph of the atmosphere.*

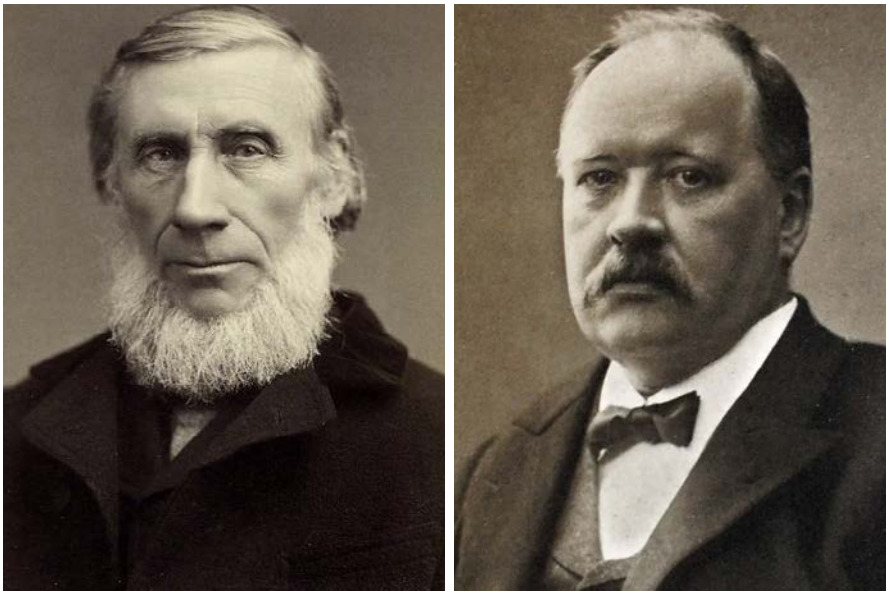
Introduction

Since the Industrial Revolution, according to the IPCC, the global temperature has risen by 1ºC since the Industrial Revolution. The causes of this increase are clear and unequivocal: the exponential anthropogenic emission of greenhouse gases that has taken place in recent years..

Eunice Foote was a 19th century American scientist who made important contributions to the field of atmospheric science. In 1856, she conducted a series of pioneering experiments to study the effects of gases on atmospheric warming. In particular, Foote conducted experiments with transparent glass containers filled with different gases. He exposed these containers to sunlight and measured the temperature inside to determine how the different gases affected heat absorption.

Image 3: *Eunice Foote.*

Her experiments showed that carbon dioxide had a significant effect on temperature rise compared to ordinary air. Eunice Foote concluded that the presence of carbon dioxide in the atmosphere could contribute to global warming. Although her discovery was revolutionary, Eunice Foote was not recognised at the time. However, her work provides the basis for understanding the greenhouse effect and the role of greenhouse gases in climate change. In recognition of her contributions, Eunice Foote is now regarded as a pioneer in the scientific study of climate change. The invisibility of the role of women in science at the time meant that historically the clarification of the role of carbon dioxide in global warming has been mainly attributed to John Tyndall for his contributions in discovering how molecules such as carbon dioxide or methane block infrared radiation (1859) and Svante August Arrhenius for his calculation of how doubling the CO_2 in the atmosphere would raise the temperature by 5-6°C (1896).



Images 4 & 5: *John Tyndall and Svante Arrhenius.*

Today, there is no doubt in the scientific community about the anthropogenic origin of current climate change, as well as its causes and consequences. In this practical exercise, we will take an approach to their experiments to demonstrate the role of carbon dioxide in anthropogenic climate change.

CHAPTER 1: LABORATORY PRACTICALS

Contents

- Greenhouse gases
- Greenhouse effect
- Anthropogenic climate change

Objectives

1. Highlight the role of carbon dioxide as a greenhouse gas.
2. Learn about Eunice Foote's experiments.
3. Understand the anthropogenic origin of current climate change.
4. Appreciate the greenhouse effect as a fundamental requirement for life on Earth.

Material required

- Two flasks
- Two thermometers
- Bicarbonate
- Vinegar
- Aluminium foil

Protocol

1. Label the flasks: one will act as a control and one as a case study.
2. Cover the control flask with aluminium foil.
3. Add baking soda and vinegar to the flask that will act as a case study. Immediately cover the flask with aluminium foil to allow carbon dioxide to accumulate inside the flask. This will act as the carbon dioxide-enriched case study with respect to the control case.
4. Expose both flasks to the sun or an intense source of light
5. Carefully inject the thermometer through the aluminium foil, making sure that as little gas as possible is lost.
6. Compare the temperature after a certain time of exposure to light of both flasks.

Issues

1. What conclusion can you draw regarding the role of carbon dioxide?
2. How is the greenhouse effect produced and is the greenhouse effect positive or negative for life on the planet?

Guidance and answers (teacher's guide)

1. **What conclusion can you draw regarding the role of carbon dioxide?**

After exposing both flasks to sunlight, we observed that the flask enriched in carbon dioxide has a higher temperature, which is evidence of the role of this gas as a greenhouse gas.

2. **How is the greenhouse effect produced and is the greenhouse effect positive or negative for life on the planet?**

Solar radiation reaches the Earth in the form of visible light and ultraviolet light, and is absorbed by the Earth's surface, which heats up as a result. This results in terrestrial emission of infrared light, characterised by a longer wavelength. Greenhouse gases, such as water vapour, carbon dioxide or methane, act as traps against this infrared radiation, which is absorbed and re-radiated in all directions, so that some of it is returned to the earth's surface.

The greenhouse effect is essential for life on our planet, allowing a global average temperature of 14.5ºC. However, the problem lies in the increasing concentration of these gases due to the burning of fossil fuels since the Industrial Revolution, which has resulted in a global increase of 1ºC. In 2022, according to measurements from the Mauna Loha Observatory in Hawaii, the concentration of carbon dioxide exceeded a record 418.81 ppm.

1.2. IS THE ALBEDO IMPORTANT?

Image 6: *Ice, thanks to its ability to reflect light, is an important factor in climate regulation due to the albedo effect.*

Introduction

The albedo is defined as the percentage of radiation that is reflected by a particular surface with respect to the total incident radiation. In this practical exercise we will compare the albedo of two different cases and how it affects the increase in temperature: a dark coloured glass and a white coloured glass. The former could represent the ocean and the latter could represent Arctic and Antarctic ice.

Contents

- Albedo
- Positive feedback loops
- Climate adaptation

Objectives

1. Understanding the albedo affect.
2. Compare the albedo of different surfaces and extrapolate it to reality.
3. Propose climate adaptation measures considering the albedo effect.

Material required

- Dark tape (blue or black)
- White ribbon
- Two glasses
- Water
- Two thermometers

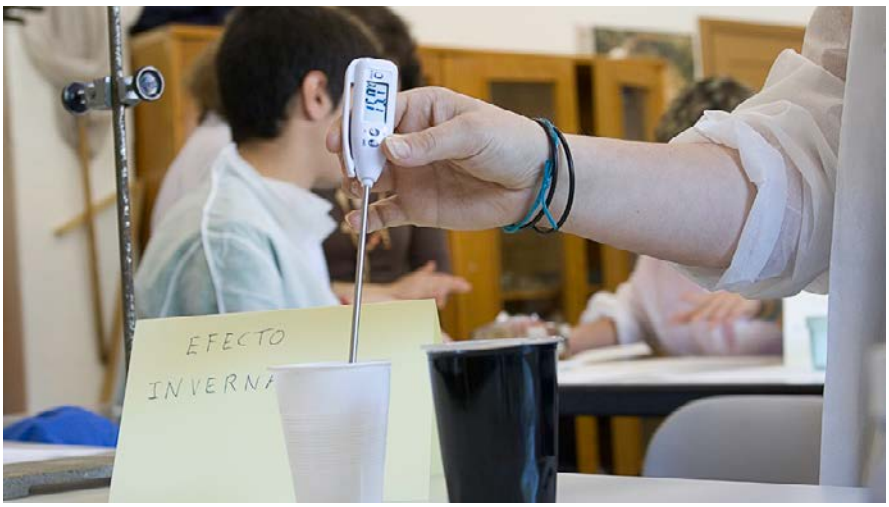


Image 7: *Greenhouse effect.*

Protocol

1. Surround one of the glasses with white tape on the outside and the other with the dark tape.
2. Fill the glasses with water and put a thermometer inside each one.
3. Leave the glasses in the sun and compare the temperature of each after the same time of exposure to sunlight.
4. Put 3 ice cubes on 3 pieces of cardboard of equal surface, one white, one red and one black, and see what has happened after 10 minutes.

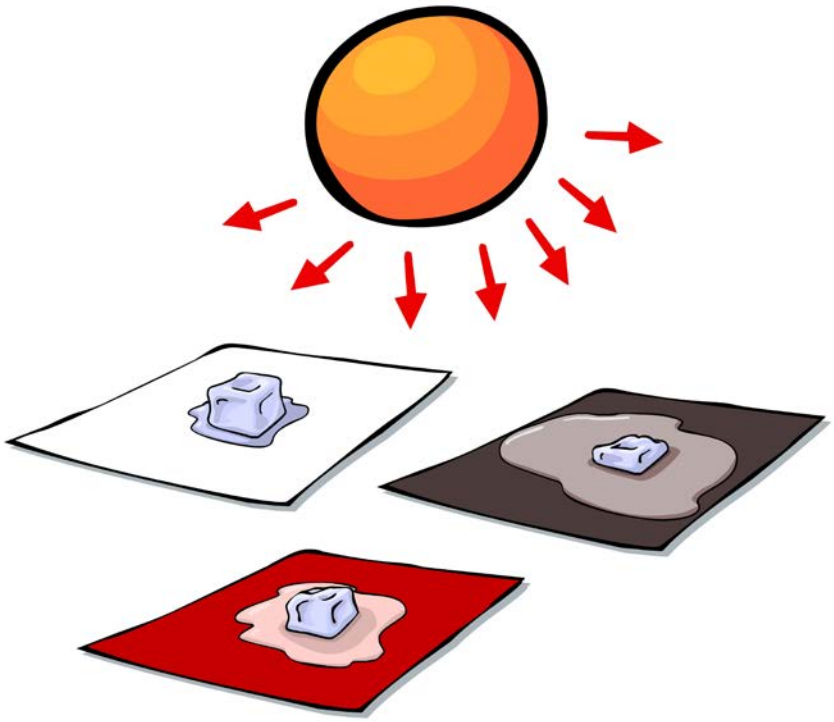


Image 8: *Ice on white, black and red cardboard.*

Issues

1. How do the results relate to the albedo effect?
2. Is the observed change in the ice on the cardboard related to the experience of the glasses surrounded by tape?
3. How is this practice extrapolated into reality, and what are the implications of climate change for this?
4. Can you envisage any feedback loops arising from the reduction of the albedo effect?
5. Now that you know about the albedo effect, what implications do you think it should have on the design of our buildings?

Guidance and answers (teacher's guide)

1. How do the results relate to the albedo effect?

After a certain time, the water in the dark glass has a higher temperature than the water in the white glass. This is because the white ribbon has a higher albedo, so that most of the radiation is reflected and not retained as opposed to what happens in the dark glass.

2. Is the observed change in the ice on the carboard related to the experience of the glasses surrounded by tape?

Yes, it does, because the white cardboard reflects all the radiation, while the black cardboard absorbs it all, transforming it into heat, which justifies the fact that the ice on the white cardboard is the least melted and the ice on the black cardboard is the most melted.

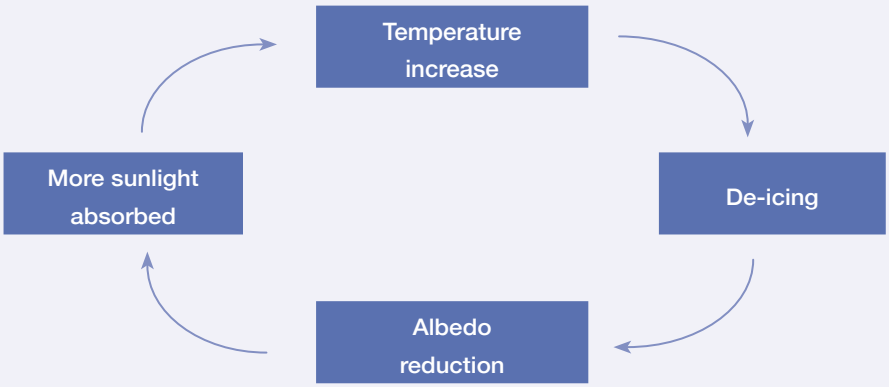
3. How is this practice extrapolated into reality, and what are the implications of climate change?

In reality, this practice highlights the importance of the ice surfaces on our planet, which reflect between 60 and 70% of incident radiation, preventing an increase in the global temperature of the planet that would make it incompatible with life as we know it today. This is why the vast expanses of Arctic and Antarctic ice are fundamental in the regulation of the Earth's climate.

Climate change has strong implications for this, as the melting of ice due to the increase in global temperature leads to a strong reduction in albedo, so that more radiation is absorbed, contributing to the increase in global temperature.

4. Can you envisage any feedback loops arising from the reduction of the albedo effect?

Different feedback loops can be derived from this process, with varying degrees of complexity. The simplest loop that could be envisaged would be the following:



5. Now that you know about the albedo effect, what implications do you think it should have on the design of our buildings?

One of the implications could be in relation to the colour of the façades of our buildings, so that in those areas with high incident solar radiation it is advisable for them to be white in order to reflect more sunlight and be more efficient during the summer months.

1.3. IS THE OCEAN WARMING UP?

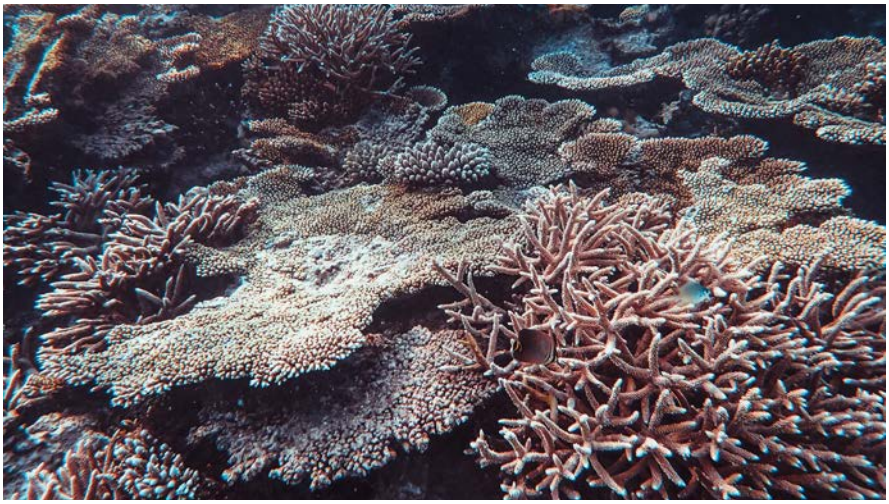


Image 9: *Coral bleaching due to rising ocean temperatures.*

Introduction

The ocean occupies more than 70% of the planet's surface. It is in contact with the atmosphere and since the Industrial Revolution, according to the latest IPCC report on Oceans and Cryosphere, it is estimated that it has stored more than 93% of the heat from anthropogenic climate change. This has provided a valuable thermal buffer for terrestrial life, but nevertheless has important consequences for marine life, as we will see below, many of which are discussed in more detail in "Climantopia: the school textbook" and in the film "Climantopia Cinema".

Contents

- Specific heat
- Thermal cushioning
- Ocean warming

Objectives

1. To highlight the ocean's role as a global thermal buffer.
2. To demonstrate the high specific heat of water.
3. To understand some of the impacts of rising ocean temperatures.

Material required

- Various balloons
- Water
- Lighter

Protocol

1. Inflate one of the balloons and fill another with water.
2. Carefully approach the flame of the lighter first to the air balloon and then to the water balloon.
3. Compare the response of each.

Issues

1. What happens to each of the balloons?
2. *Specific heat* is defined as the heat that must be contributed to a unit mass of a given substance to increase its temperature by one unit. Given this definition and the results of the experiment with the air-filled and water-filled balloon, which of the two fluids has a higher specific heat?
3. Water has a particularly high heat capacity (4.18 J/g/°C) and the surrounding ground usually has a much lower heat capacity, which is usually lower (1 J/g/°C). In view of the data, which is easier to heat the ground or the seawater? Which cools faster?
4. Since warmer air rises because its density decreases, allowing cooler, denser air to move to the bottom, how is it that on a hot summer day we can feel cool ocean air on our bodies and at night on the beach we feel cold wind from the continental terrain?
5. Hurricanes originate in the ocean as warm, moist air rises, causing a sharp drop in temperature. Why do these phenomena cause significant damage in coastal areas near the equator? To what extent can climate change affect this type of extreme weather event?
6. Given that the ocean has absorbed more than 93% of the heat from climate change, what do you think are the implications for the specific heat of water? What does the increase in ocean temperature actually produce?
7. Research on the ecological impacts of rising ocean temperatures.

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Guidance and answers (teacher's guide)

1. What happens to each of the balloons?

The air-filled balloon explodes while the water-filled balloon resists the temperature rise.

2. *Specific heat* is defined as the heat that must be contributed to a unit mass of a given substance to increase its temperature by one unit. Given this definition and the results of the experiment with the air-filled and water-filled balloon, which of the two fluids has a higher specific heat?

Logically, water has a much higher specific heat: we observe how it increases in temperature much more slowly and, as a consequence, the balloon does not explode. On the other hand, the air-filled balloon experiences a rapid rise in temperature that causes it to burst. Specifically, water has a specific heat of 1 cal/g/°C, while air has a specific heat of 0.24 cal/g/°C.

3. Water has a particularly high heat capacity (4.18 J/g/°C) and the surrounding ground usually has a much lower heat capacity, which is usually lower (1 J/g/°C). In view of the data, which is easier to heat the ground or the seawater? Which cools faster?

The higher capacity makes it more difficult to heat up, which occurs more slowly in the sea than on the continent, but it also makes it more difficult to cool, retaining more and better heat. Coastal continental land is therefore easier to heat and cools faster than seawater.

4. Since warmer air rises because its density decreases, allowing cooler, denser air to move to the bottom, how is it that on a hot summer day we can feel cool ocean air on our bodies and at night on the beach we feel cold wind from the continental terrain?

Because continental air warms faster than air over the ocean, during the warm hours of the day in a coastal region the warmer air from the coastal continent rises and the air over the ocean water, which warms more slowly and is therefore cooler, moves over the surface, from the ocean to the continent, resulting in a cool wind current known as the daytime breeze. At night the ocean air cools more slowly because the ocean retains more heat than the continent, and so the cold surface air current moves from the continent to the ocean, giving rise to the *night breeze*.

5. **Hurricanes originate in the ocean as warm, moist air rises, causing a sharp drop in temperature. Why do these phenomena cause significant damage in coastal areas near the equator? To what extent can climate change affect this type of extreme weather event?**

In areas close to the equator, people are prepared for hurricanes in the summer because the strong warming of the ocean at these latitudes during the summer season significantly increases the risk of hurricanes. With the increase in global temperature and the consequent warming of the ocean, these extreme events are expected to intensify. It is therefore important that tourist facilities and tourists themselves are prepared for such extreme events. It is also essential to generate insurance policies from the administrations and the agents involved to deal with the possible risk of an increase in these extreme phenomena.

6. **Given that the ocean has absorbed more than 93% of the heat from climate change, what do you think are the implications for the specific heat of water? What does the increase in ocean temperature actually produce?**

The high specific heat of water, together with the large volume of ocean water, means that although the amount of heat absorbed by the ocean as a result of anthropogenic climate change is very high, the temperature increase is much smaller. In this regard, since 1971 the ocean has warmed by 0.015°C per decade in the 700 m of the surface water column. This increase in temperature is due to the fact that, since the ocean is in contact with the atmosphere, it absorbs most of the heat accumulated in the atmosphere as a consequence of the emission of greenhouse gases, as we have shown in the first practical lesson of this manual.

7. **Research on the ecological impacts of rising ocean temperatures.**

The impacts of rising ocean temperatures are many and varied. Some of the most relevant are ocean stratification, coral bleaching, the appearance of invasive species from warmer areas or the rise in sea level due to thermal expansion and, with it, the consequent increase in coastal erosion.

1.4. WHY DO HURRICANES FORM IN OCEANIC REGIONS CLOSE TO THE EQUATOR AND USUALLY IN THE WARM SEASON?

Image 10: *Hurricane.*

Introduction

Concern continues to grow throughout the 21st century that ocean warming may be affecting the frequency and intensity of hurricanes. This is because, in general, hurricanes form when seawater is warm enough to generate a decrease in pressure and provide the energy necessary for the formation and maintenance of an extreme cyclonic event.

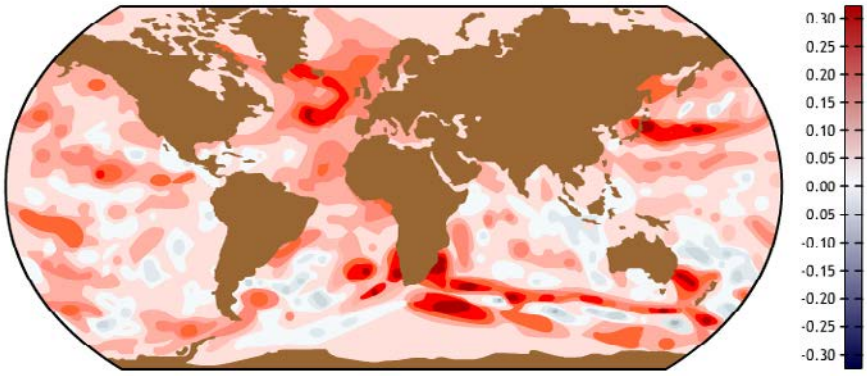

Image 11: *World map with ocean warming.*

As the ocean warms, the surface temperature of the water increases, providing more energy to fuel the formation of tropical storms that can reach hurricane magnitude. In addition, ocean warming can increase the amount of water vapour in the air, which can provide more moisture for storm formation. Both factors can increase the frequency of hurricanes and their intensity.

In addition, ocean warming can increase the depth of the warm water layer, which can allow hurricanes to remain stronger and last longer before weakening. This may increase the intensity of hurricanes, making them more likely to cause significant damage in coastal areas.

A hurricane is formed by the clustering of tropical storms close to each other, with a diameter of up to 500 km, which, due to the sudden drop in pressure, generate rapid gyres of hot and humid rising wind. The central part, about 40 km wide, remains calm.

The seawater temperature in an area where a hurricane originates is usually at least 27ºC, reached by strong insolation at latitudes close to the equator, which generates intense evaporation capable of producing strong convection that generates upward gyrations, following the Coriolis acceleration and the formation of large storm clouds of enormous vertical development. As it moves away from the equator, the Coriolis acceleration increases and this causes an increase in angular acceleration in the counterclockwise spiral spin in the northern hemisphere. When hurricanes make landfall, they lose their moisture supply and become tropical storms.

Ocean warming can have a significant impact on the frequency and intensity of hurricanes, and is an important factor to take into account when considering the future evolution of climate change and its effects on vulnerable coastal communities.

Contents

- Ocean surface warming and evaporation
- Pressure decrease due to warming and humidity and formation of convective clouds
- Increasing spin as it moves away from the equator
- Transformation of hurricanes into tropical storms upon landfall
- Different names for the same reality: typhoons, hurricanes and cyclones

Imagen 12: *Hurricane in Florida.*

Objectives

1. Understand the formation of hurricanes and their relationship to ocean warming.
2. Interpret the energy generated in the formation and progress of hurricanes.
3. Reflect on the potential risks of increased intensity and frequency of hurricanes with increasing climate change.

Material required

- Two identical transparent bottles
- Coloured water
- Heavy duty waterproof adhesive tape
- Small fragments of cork

Protocol

1. One of the equal bottles is filled halfway, then colouring and cork fragments are added.
2. The two bottles are taped together so that they are connected.
3. The two bottles are quickly rotated together, with the liquid remaining in the lower one.
4. It is turned upside down so that the liquid remains at the top and the swirling of the descending water is observed.

Image 13: *Simulation of a hurricane.*

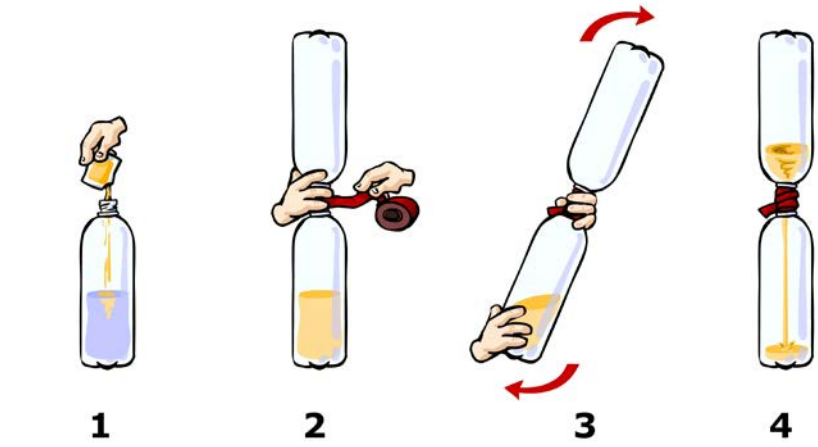

Image 14: *Simulation of a hurricane.*

Issues

1. Which way does the water turn?
2. Where does the energy that makes it spin come from?
3. How is this gyre similar to and different from the gyre that follows the strong wind of a hurricane?
4. Would the direction of rotation be the same if we were in the other hemisphere?
5. Can a hurricane affect Galicia? If so, where would it come from?
6. To what extent can climate change favour an increase in the formation of hurricanes in general and the arrival of hurricanes in particular?

Guidance and answers (teacher's guide)

1. **Which way does the water turn?**

If we are in the northern hemisphere, there is a counter-clockwise spiral rotation, just as in hurricanes.

2. **Where does the energy that makes it spin come from?**

It comes from the angular acceleration generated in the rotation and from the gravitational energy that drives the descent of the coloured water as it turns the bottles. The Coriolis acceleration is involved in the orientation of the rotation, since it is at an intermediate latitude between the equator and the north pole.

3. **How is this gyre similar to and different from the gyre that follows the strong wind of a hurricane?**

It is similar in the rotational spin of the liquid and differs in that it moves the water, and does so due to the acceleration of gravity in a downward direction, and not in the upward direction that carries the air of the hurricane due to the pressure gradient.

4. **Would the direction of rotation be the same if we were in the other hemisphere?**

In the other hemisphere the direction of rotation would be the opposite because this rotation is due to the Coriolis acceleration.

5. **Can a hurricane affect Galicia? If so, where would it come from?**

It is estimated that climate change may increase the likelihood of hurricanes making landfall in Galicia, as more and more hurricanes are expected to hit the region in the near future.

The ocean's surface is warmer and more energy is stored there. If a hurricane reaches Galicia, it is most likely to originate in the intertropical zone and the increase in Coriolis acceleration as latitude increases will facilitate its advance towards the Galician coast.

6. **To what extent can climate change favour an increase in the formation of hurricanes in general and the arrival of hurricanes in particular?**

As stated in the previous answer, climate change leads to a continuous increase in the heat content of surface water, leading to stratification, especially in the equatorial zone, the region with the highest risk of hurricanes.

In this sense, the warming of the ocean surface is worrying in terms of the genesis of hurricanes, with the aggravating factor that the affected inter-tropical areas are usually highly exposed to tourism, in addition to the fact that their activities are often carried out in facilities that are vulnerable to these extreme events and the tourist population is not usually adapted to provide adequate responses.

1.5. WHY IS THE SEA LEVEL RISING?

Image 15: *Impact of sea level rise on the coastline.*

Introduction

Sea level rise is one of the most obvious impacts of climate change, as the ocean acts as a great thermometer of the planet. The magnitude of the problem is so great that sea level rise will continue for centuries even if we were to suddenly stop greenhouse gas emissions today. Since 1850, sea level has risen by an estimated 20-24 cm globally and continues to rise at an ever-increasing rate, although this rise is not occurring evenly across the world's coastal zones.

In this workshop we will show which are responsible for the rise in sea level and which, despite being deeply rooted in the collective imagination, are not.

Contents

Material required

- Ice
- Two containers
- Water
- Rocks
- Dryer (optional)
- A beaker
- Heat source

Image 16: *Arctic and Antarctic model.*

Protocol

First part of practice:

1. Design with one container the Arctic model (where we find floating ice) and with another the Antarctic model (where we find ice on the continent).
    a. For the Arctic model, we will put 3 ice cubes and add water without filling the container completely.
    b. For the Antarctic model, we will put rocks in one half of the container (which will simulate the continent) and add water to equal the level of the Arctic model container. Finally, we will put 3 ice cubes on top of the continent.
2. Expose both models to the sun to allow them to melt, the process can be accelerated with the help of a hairdryer.
3. Compare the water level after ice melting in both models.

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Second part of practice:

1. A volume of water is measured in a measuring cylinder and the volume is placed in a water heater without allowing it to boil so that there is no significant loss of matter through evaporation.
2. Once hot, it is put back into the measuring cylinder and the new level is measured, noting the new measurement.
3. Compare the two volume measurements and note possible changes.

Issues

1. What happens in each of the models with rising sea levels? If there are differences, what are they due to?
2. If any of the models do not influence sea level rise, does their melting have any global impact?
3. What do you observe in the second part of the practice and how does it relate to the previous practice?
4. Considering both sides of the practice, what are the drivers responsible for sea level rise?
5. Research on the possible impacts of global sea level rise.

Guidance and answers (teacher's guide)

1. **What happens in each of the models with rising sea levels? If there are differences, what are they due to?**

In the Arctic model, because it is floating ice that is already occupying a certain volume in the water, there is no sea level rise. In contrast, in the Antarctic model (analogous to the Greenland model), sea level rise does occur. This is because it is continental ice that, as it melts, takes up extra volume within the sea level that was previously sitting on top of the continent.

2. **If any of the models do not influence sea level rise, does their melting have any global impact?**

The melting of floating ice (Arctic model) does not contribute directly to sea level rise, but indirectly, e.g. by reducing the albedo effect, contributing to an increase in global temperature and thus also to thermal expansion of the water.

3. **What do you observe in the second part of the practice and how does it relate to the previous practice?**

In the second part of the workshop, the second factor responsible for sea level rise is highlighted: thermal expansion, often forgotten both in the collective imagination and in many textbooks.

As its heat content increases, the water increases in volume, contributing to sea level rise. This is related to previous practice where it has been shown that the ocean accumulates more than 93% of the heat from anthropogenic climate change.

In fact, the latest IPCC report puts the contribution to sea level rise from thermal expansion at 1.15 mm/year compared to that of Antarctica, which is estimated at 0.19 mm/year. These aspects are discussed in more detail in Chapter 2 of 'Climantopia: The School Textbook'.

4. **Considering both sides of the practice, what are the drivers responsible for sea level rise?**

We can summarise that there are two drivers of sea level rise: the melting of continental ice and the thermal expansion of water.

5. **Research on the possible impacts of global sea level rise.**

The impacts of rising sea levels are manifold. These include increased coastal erosion, loss of coastal land, intensified migration of climate refugees, increased river flooding and saltwater intrusion into coastal freshwater aquifers.

Common learning difficulties

One of the main alternative ideas about sea level rise is to equate the melting of the Arctic model with that of the Antarctic. Furthermore, once students are aware of the difference between the two, it is essential to stress that the melting of floating ice also has serious planetary consequences, relating it to the loss of biodiversity and the reduction of the albedo effect.

Another common learning difficulty is defining thermal expansion as another driver of sea level rise, often referred to as the 'hidden factor' in sea level rise. For this purpose, the simulation of thermal expansion in a beaker is an interesting resource on which to begin to fix this idea in students' mental models of sea level rise.

1.6. WHY ARE WE SO CONCERNED ABOUT GLOBAL WARMING?

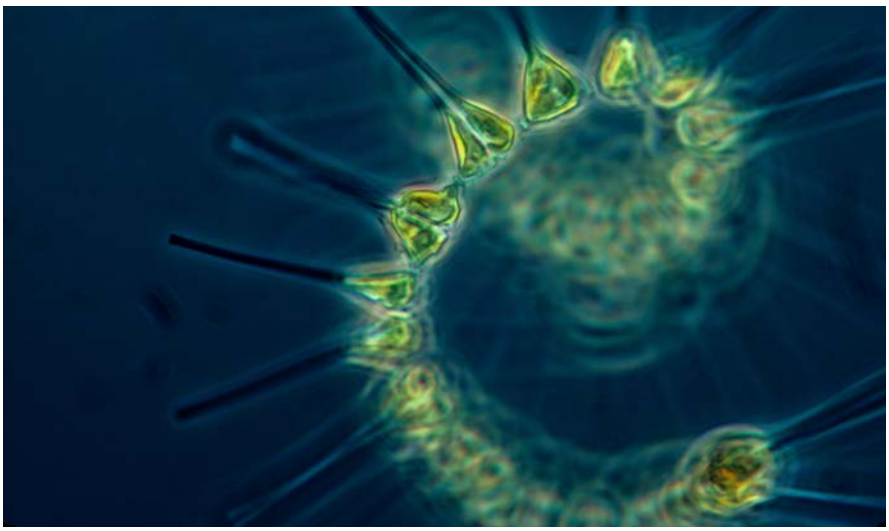

Image 17: *Plankton.*

Introduction

Oceanic primary production resides primarily in phytoplankton: photosynthetic algae found in the surface part of the water column, where they have access to the sunlight needed to carry out photosynthesis. It is a fundamental component of the marine food web, so that small impacts on it have a large amplification throughout the entire food web.

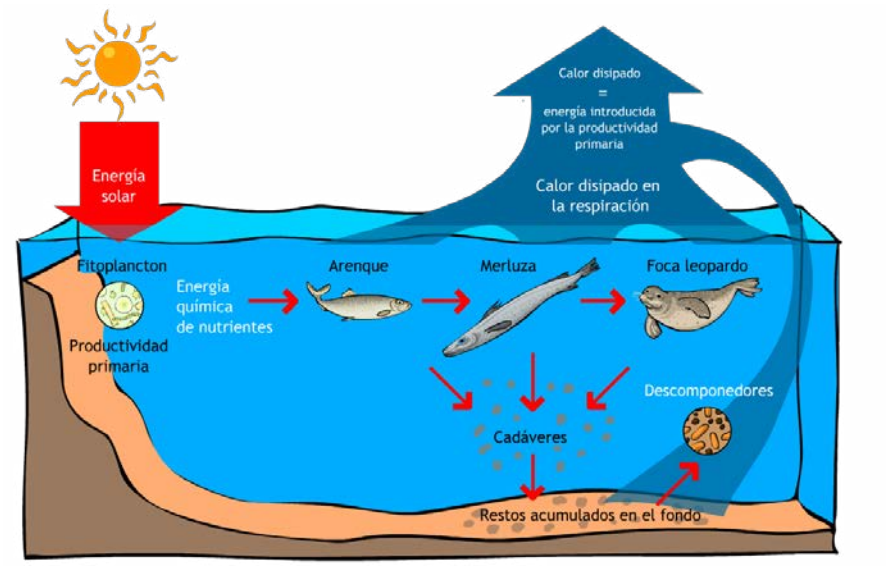

Image 18: *Energy flow in a marine ecosystem.*

In the present practical we will study the effect of a phenomenon described in recent years known as **oceanic stratification**, which directly affects phytoplankton and therefore has global consequences. This stratification hinders the upwelling of mineral salts from the ocean floor, which is the main way in which phytoplankton are fertilised.

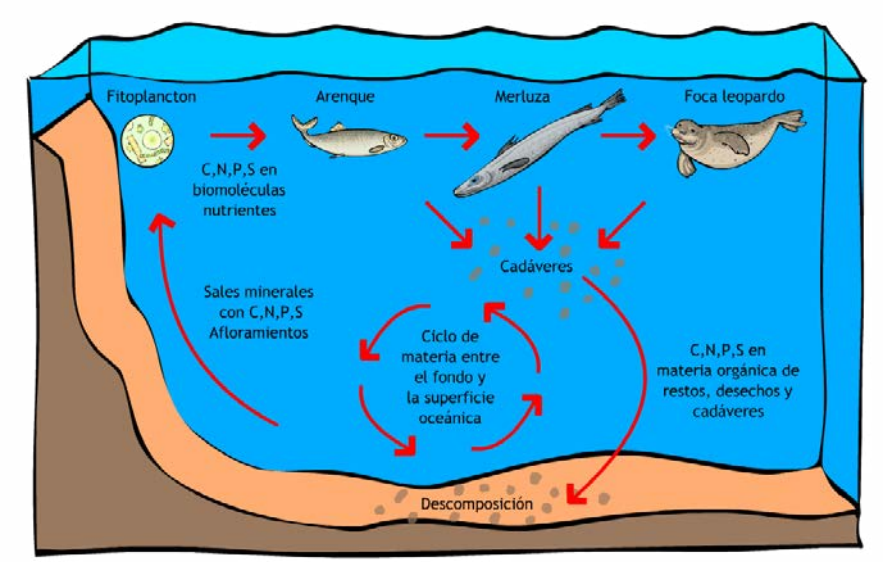

Image 19: *Cycle of matter in a marine ecosystem.*

Ocean stratification is mainly due to two main drivers. First, **ocean warming**, which since the Industrial Revolution has stored more than 93% of the heat resulting from climate change. Secondly, the **melting of the poles** as a result of the global rise in temperature. In both cases what happens is that a sheet of surface water is formed that is less dense than the deeper water. In the first case, this surface layer is due to the warming of the surface water, which reduces the density of the surface water. In the second case, it is due to the fact that the fresh water from the melting ice is of lower density than the sea salt water. This lower density surface layer makes mixing with the deeper water more difficult.

This inability provides a barrier for mineral salts from the ocean floor to reach the surface plankton, as they are “ablated” by the decomposition of corpses and the alteration of seafloor rock. This lamination of surface ocean water explains the decline in ocean productivity at mid-latitudes, as the entire ecosystem depends on phytoplankton production, which is diminished by nutrient limitation. A different process occurs at polar latitudes, where a slight increase in productivity is expected due to oceanic stratification, since the limiting factor there is access to light, as phytoplankton are subjected to turbulent currents that transport them at depth.

Image 20: *Thawing.*

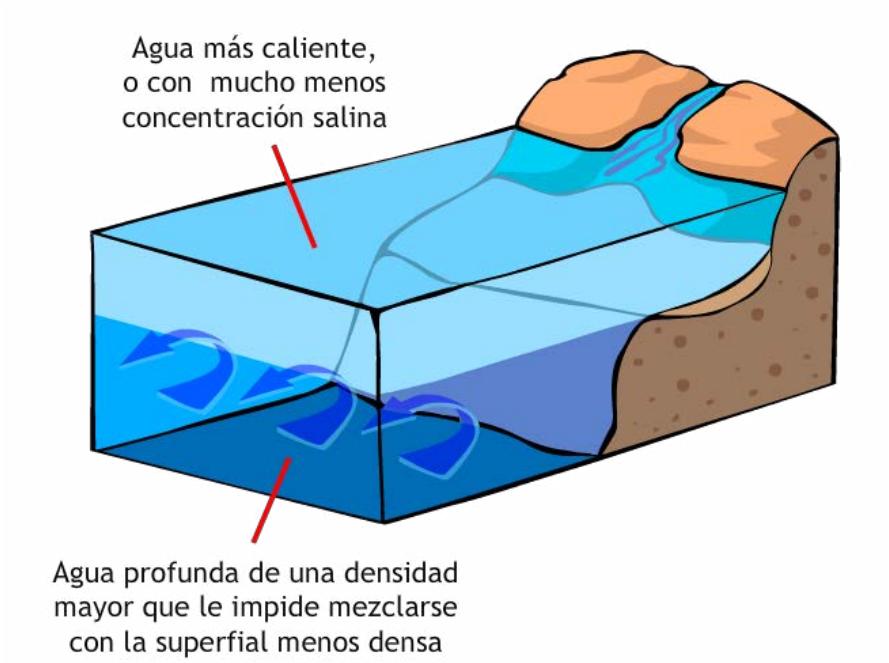

Image 21: *Ocean lamination.*

Contents

- Oceanic primary production and phytoplankton
- Surface warming and thawing
- Ocean stratification and impacts on phytoplankton
- Water density
- Food safety

Objectives

1. Simulate the upwelling of inorganic nutrients from the ocean floor to the surface layers where phytoplankton are found.
2. Simulate the effect of a density change in the surface layer on this ascent.
3. Understand the ecological and social consequences of oceanic straification.
4. Acquire the knowledge, skills and methodologies necessary for the dissemination of this impact to the public.

Material required

- 2 beakers
- Small cardboard cut-outs (1-2 cm)
- Water
- Oil
- Hot plate
- Blue and yellow acrylic paint
- Rectangular container with dividing structure

Protocol

First part of practice:

1. Fill one beaker with cold water and one with hot water.
2. Dissolve blue paint in the beaker containing cold water and yellow paint in the beaker containing hot water.
3. Add hot water to one tank compartment and cold water to the other.
4. Check what happens when the partition wall is removed.

Second part of practice:

1. In a beaker, add the cardboard cut-outs to the water. These will simulate the inorganic nutrients on the ocean floor (nitrogen, phosphorus, etc.).
2. Push them until they are deposited on the bottom.
3. Place the beaker on the hot plate and observe what happens to our inorganic nutrients.
4. Add a layer of oil and see what happens to our inorganic nutrients.

Issues

First part of practice:

1. What do you observe when you remove the splitter tank and why does this happen?
2. How do you think this phenomenon can be related to climate change in reality?

Second part of practice:

1. How does this second part of the practice relate to the previous one, and to reality?
2. What does the movement of the cards represent in reality?
3. What happens when an oil layer is added, and how will it affect oceanic primary production?
4. At polar latitudes, phytoplankton are subjected to large ocean currents that transport them to deeper areas. How do you think ocean stratification will affect polar areas?
5. How can ocean stratification affect the oxygen concentration of the ocean?
6. Will changes in ocean productivity affect all countries in the world equally? Research the impacts on food security on the web.

Guidance and answers (teacher's guide)

First part of practice:

1. **What do you observe when you remove the splitter tank and why does this happen?**

When the dividing tank is removed, the hot water (less dense and yellow in colour) and blue water (denser and blue in colour) come into contact, so that the hot water is at the top of the water column and the cold water at the bottom. This is due to the difference in densities generated by the difference in temperature, generating a stratification.

2. **How do you think this phenomenon can be related to climate change in reality?**

This stratification phenomenon happens in reality due to two main reasons. At mid-latitudes, surface water is in contact with the atmosphere, so it absorbs up to 93% of the heat from climate change, acting as an important thermal buffer. However, this heat is not distributed evenly throughout the water column; rather, it is the upper 700 m that is heated most intensely. This causes the surface layers of the ocean to become less dense, mak-

ing mixing with the cooler and denser lower layers more difficult. Thermal stratification occurs.

In polar latitudes, due to the melting of the ice caps, freshwater enters the ocean. This fresh water is less dense, so that salt stratification occurs.

Second part of practice:

1. **How does this second part of the practice relate to the previous one, and to reality?**

Oil, in reality, would represent the upper (less dense) water layer and water the lower (denser) layer. At mid-latitudes, oil would therefore represent the water layers with a higher heat content. At polar latitudes, oil would represent the upper layers of fresh water from melting ice.

2. **What does the movement of the cards represent in reality?**

They represent the upwelling of inorganic nutrients from the ocean floor to the surface water layers, where phytoplankton are found and need access to light in order to carry out photosynthesis and these inorganic nutrients.

3. **What happens when an oil layer is added, and how will it affect oceanic primary production?**

By adding the oil layer we are generating a very intense stratification that prevents nutrients from coming to the surface. This is directly related to what happens in mid-latitudes and tropical latitudes. The thermal stratification generated reduces the upwelling of inorganic nutrients to the surface layers where phytoplankton are found, thus reducing oceanic primary productivity.

Thus, the decline of the food web is transferred and amplified along the food web. This phenomenon is already observed today and is expected to intensify in the coming decades.

4. **At polar latitudes, phytoplankton are subjected to large ocean currents that transport them to deeper areas. How do you think ocean stratification will affect polar areas?**

In polar latitudes, the opposite impact is expected. Since the phytoplankton are subjected to large turbulent currents that transport them to deep areas, it is expected that due to the generated salt stratification they will stay longer at the surface and thus slightly increase the primary productivity in this area.

5. How can ocean stratification affect the oxygen concentration of the ocean?

Stratification is linked to oceanic deoxygenation: decreased mixing of the surface and deep layers decreases the ability of this gas to access the deep zones, leading to conditions of hypoxia and anoxia.

6. Will changes in ocean productivity affect all countries in the world equally? Research the impacts on food security on the web.

No. A study by Barange et al. (2014) showed that areas with a higher dependence on fisheries in their diet are expected to see a decrease in their potential fish catches. Conversely, other areas with a much lower dependence on fisheries in their diet will see their catches increase slightly. The food security of many countries is therefore expected to be put at risk, contributing to a more unequal world.

1.7. WHY IS THE OCEAN ACIDIFYING?

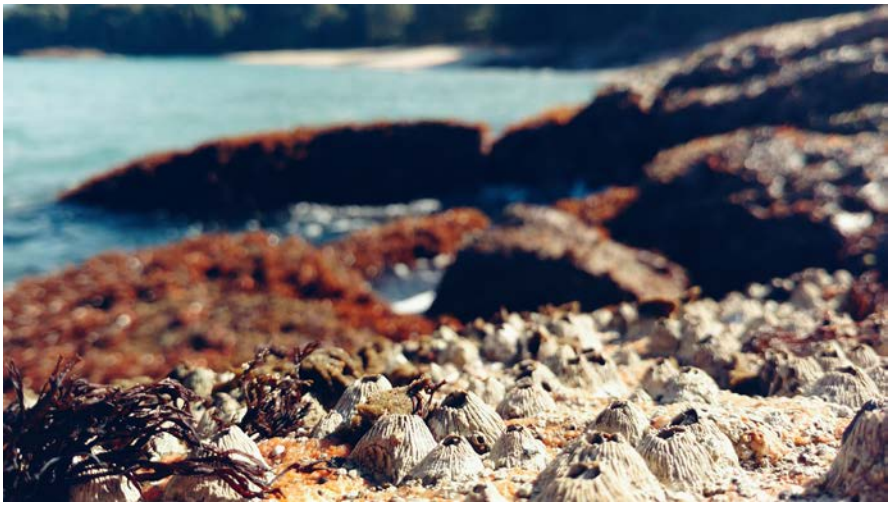

Image 22: *Calcareous organisms.*

Introduction

The ocean's uptake of CO_2 represents an important way to reduce its atmospheric concentration, but this accumulation of CO_2 has an important consequence: ocean acidification. Since 1980, according to data published in the IPCC report on oceans and the cryosphere, it is estimated that 20-30% of global CO_2 emissions have been absorbed by the ocean.

The accumulation and reorganisation of this CO_2 in seawater results in a decrease in pH and calcium carbonate saturation level. It is estimated that since 1980 the ocean has lost 0.017 to 0.027 pH units per decade. The ocean has an average pH of 8.1. Therefore, the term acidification does not imply that the ocean is becoming acidic, but rather that it is becoming less basic. As we will see in this workshop, this has important consequences, especially for calcareous organisms.

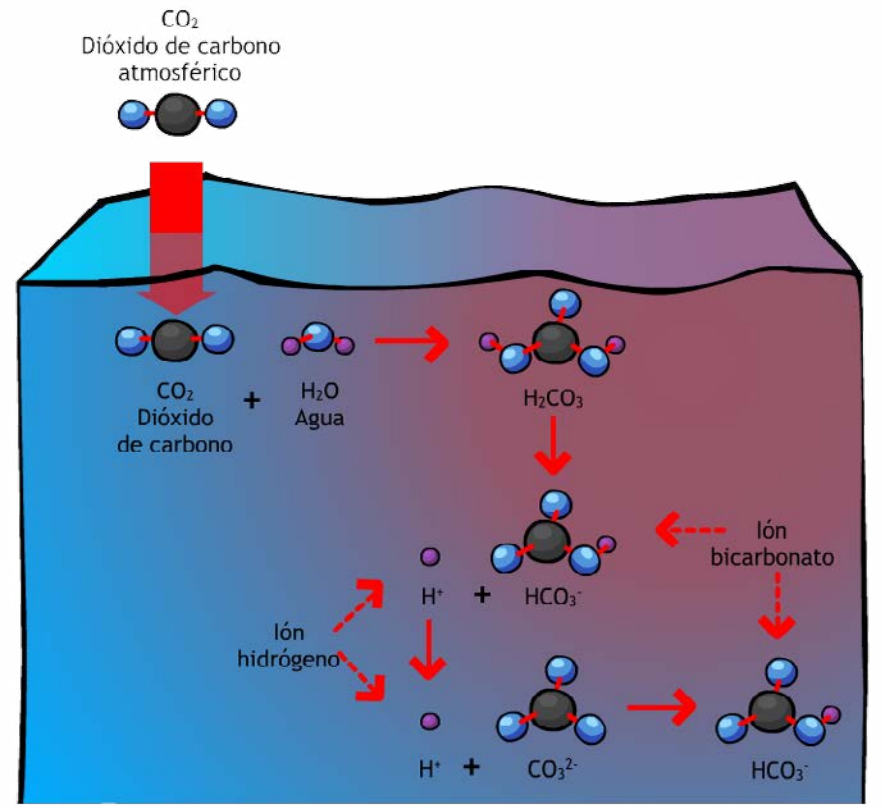

Image 23: *Acidification reactions in the ocean.*

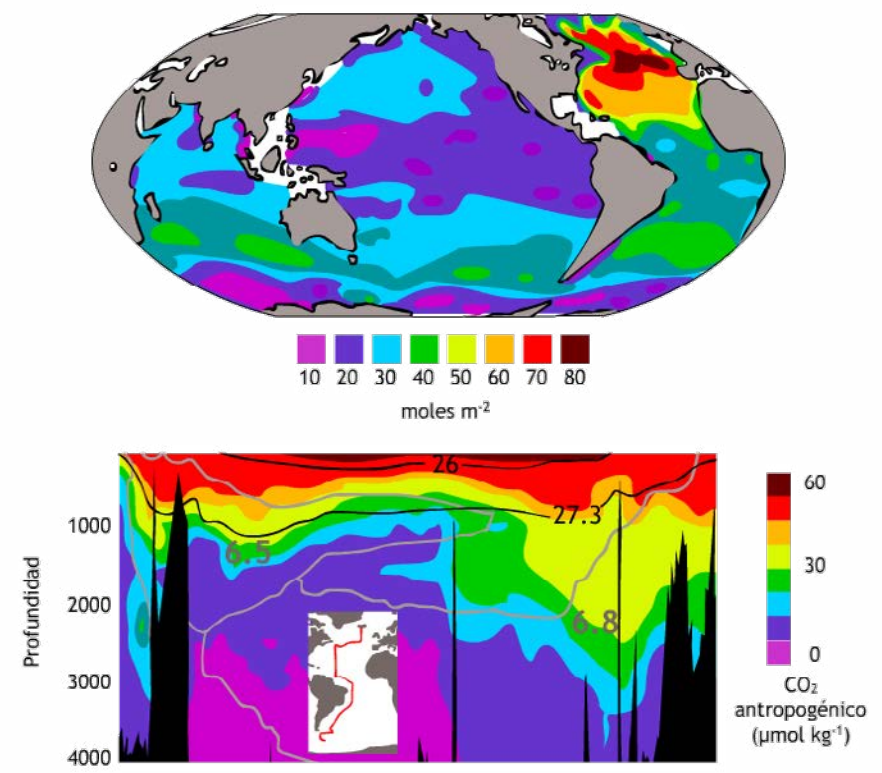

Image 24: *CO_2 concentration in the ocean.*

CHAPTER 1: LABORATORY PRACTICALS

Contents

- pH
- Ocean acidification
- Calcification
- Acid-base equilibrium

Objectives

1. Simulate and understand the process of ocean acidification.
2. Relate the process of ocean acidification to anthropogenic carbon dioxide emissions.
3. Reason how ocean warming affects the rate of carbon dioxide dissolution reaction in seawater.
4. To understand the ecological impacts of ocean acidification.

Material required

- Vinegar
- Sodium bicabornate
- A plastic bottle
- A funnel
- A balloon
- A beaker
- pH measuring liquid
- Water
- A plastic tube or, failing this, a straw
- Hydrochloric acid (or other acid instead), gown, gloves and goggles
- Heat source
- Shells

Protocol

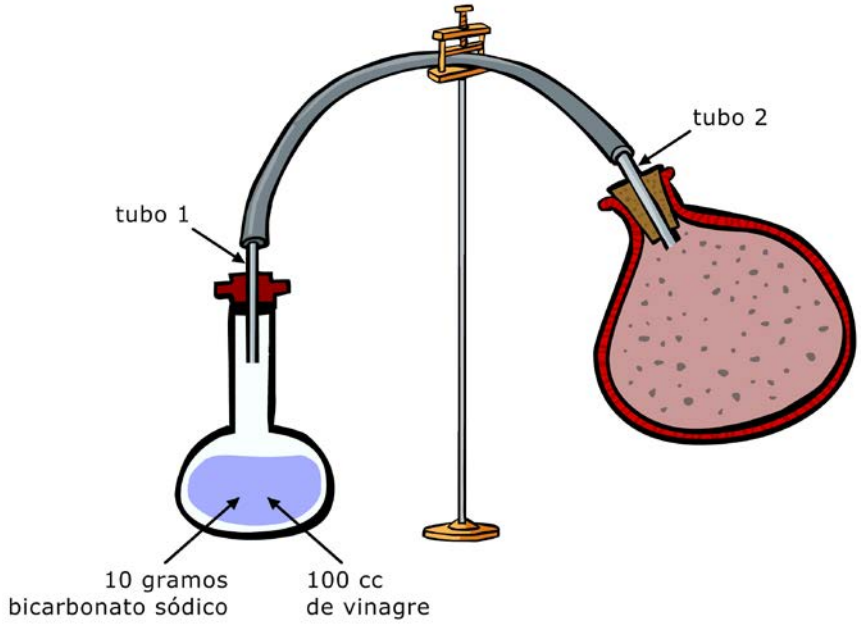

Image 25: *Infographic of the reaction of vinegar and bicarbonate.*

First part of practice – obtaining CO_2:

1. Place the mouth of the balloon in the funnel.
2. Add baking soda.
3. Add half a glass of vinegar into the bottle.
4. Place the mouth of the balloon in the mouth of the bottle without letting the bicarbonate fall into it yet.
5. Holding the balloon firmly to the bottle, allow the bi-carbonate to fall onto the vinegar, so that the following chemical reaction takes place and the carbon dioxide is stored in the balloon:

$$CH_3COOH + NaHCO_3 \rightleftharpoons CH_3COONa + H_2O + CO_2$$

Second part of practice – CO_2 dissolution:

1. In a beaker with water, add the pH measuring liquid.
2. With the help of a plastic tube, inject the CO2 obtained earlier into the water, observing what happens to the colouring provided by the pH measuring liquid.
3. Interpret the result.

Third part of practice – effect of temperature increase:

1. We will dissolve a shell of a calcareous organism in hydrochloric acid to observe, in an extreme situation, the effect of an acid medium on them.
2. Then, after grinding another shell, we will dissolve it again, but this time progressively increasing the temperature, observing how the bubbling increases and trying to draw conclusions about the effect of the increase in ocean temperature on the process we are studying.

Issues

1. What chemical reaction happens in the second part of the practical?
2. What happens to the pH of water and how does this relate to greenhouse gas emissions?
3. How does ocean warming affect this reaction?
4. What are the consequences for marine organisms?

Guidance and answers (teacher's guide)

1. **What chemical reaction happens in the second part of the practical?**

In the second part, the following reaction takes place, where, as we can see, there is an increase in the concentration of $[H^+]$ and, with it, a decrease in pH:

$$CO_2 + H_2O \leftrightarrow H_2CO_3 \leftrightarrow H^+ + HCO_3^- \leftrightarrow 2H^+ + CO_3^{2-}$$

carbon dioxide | water | carbonic acid | hydrogen ion | bicarbonate ion | 2 hydrogen ions | carbonate ion

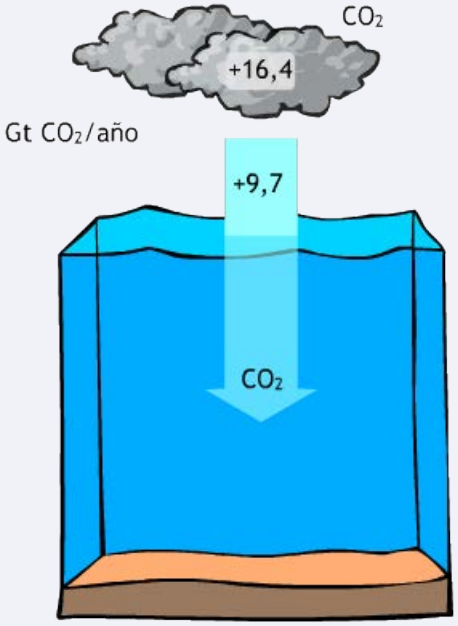

Image 26: *Acidifying atmosphere and ocean.*

2. What happens to the pH of water and how does this relate to greenhouse gas emissions?

As the colour change of the pH meter shows, there is a decrease in the pH of the water. This represents the phenomenon occurring in the reality of ocean acidification, where the dissolution of anthropogenic CO_2 has led to a decrease since 1980 from 0.017 to 0.027 pH units per decade. To assess the magnitude of this change, it is important to bear in mind that these are units defined on a logarithmic scale.

3. How does ocean warming affect this reaction?

As we can see in the third part of the practical, increasing the temperature of the water increases the reaction rate.

4. What are the consequences for marine organisms?

The consequences for marine organisms of a drop in pH are many and varied. While there are some organisms that may benefit from this process, such as some algae, most of the consequences will be devastating for multiple organisms:

- Impact on marine organisms: ocean acidification can have negative effects especially on organisms that form calcareous structures such as corals, molluscs (such as clams, mussels and marine snails) and planktonic organisms with shells, such as pteropods and foraminifera. Ocean acidification hinders the formation and maintenance of their calcareous structures,

putting their survival at risk and making them more vulnerable to potential predators.

- Effects on coral reefs: Coral reefs are highly sensitive ecosystems to ocean acidification. Decreasing water pH can hinder the formation of coral skeletons, which affects their growth and resilience, but can also intensify bleaching processes.
- Loss of biodiversity: Ocean acidification will contribute to the loss of marine biodiversity. Marine organisms that are more sensitive to the acidity of the water may experience population declines or even local extinctions, especially stenotic species.

1.8. CLIMATE CHANGE AND SOIL EROSION

Image 27: *Bare ground.*

Introduction

The 'IPCC Special Report on Climate Change, Desertification, Land Degradation, Sustainable Land Management, Food Security and Greenhouse Gas Fluxes in Terrestrial Ecosystems' points out that climate change is the main driver of soil erosion, leading to a significant loss of soil productivity.

This practice aims to demonstrate the role of vegetation in the prevention of soil erosion and thus the importance of responsible soil erosion prevention practices.

Contents

- Soil erosion
- Runoff

Objectives

1. Understand the process of soil erosion.
2. Value the role of vegetation in the prevention of soil erosion.

Material required

- 4 plastic bottles
- Earth
- Litter
- Water
- Cutter
- Wire

Protocol

1. Place the two 1.5 L bottles on the end of the table and cut a rectangle on them.
2. Fill the two bottles with soil.
3. Cut two bottles in half. Using a wire, hang the bottom half of the bottle in the mouth of the bottle cut in step 1 (which should be at the end of the table) as a cauldron.
4. Add plenty of leaf litter to the soil in one of the bottles.
5. Water both bottles with water simulating rainwater. Wait for it to infiltrate into the soil and collect the leachate in the small bottles to compare the result.

Issues

1. What conclusion can you draw from the practice regarding erosion and the presence or absence of vegetation?
2. How can climate change affect soil erosion?
3. What other measures can be proposed to reduce soil erosion?

Guidance and answers (teacher's guide)

1. What conclusion can you draw from the practice regarding erosion and the presence or absence of vegetation?

The results obtained show how the presence of vegetation acts as a protective agent against water erosion.

2. How can climate change affect soil erosion?

Climate change and soil erosion are closely related in several respects:

- Increase in extreme weather events: Climate change is associated with an increase in the frequency and intensity of extreme

weather events, such as heavy rainfall, carrying sediment and causing water erosion.

- Changes in precipitation patterns: Prolonged droughts can increase the vulnerability of soil to wind erosion.
- Degradation of vegetation and loss of vegetation cover: Increased temperatures combined with a lack of precipitation can contribute to the loss of vegetation cover and thus to an intensification of erosion.

3. What other measures can be proposed to reduce soil erosion?

Other measures may include the preservation of natural vegetation areas, the use of stepped terraces in cultivation areas with steep slopes, or the construction of drainage channels and dikes to divert and control water flow, preventing rills and excessive runoff.

1.9. WHAT IS ACID RAIN?

Image 28: *Power plant.*

Introduction

Acid rain is an important local but globally distributed environmental problem. It is produced as a consequence of the emission of sulphur and nitrogen oxides during the burning of fossil fuels, although some of them may have natural origins such as those from volcanic eruptions. In the atmosphere, when they react with water, they give rise to the formation of acid compounds, as we will see in this practice, which have important local ecological consequences on the ecosystem and also on the heritage.

Contents

- Acid rain
- Sulphur and nitrogen oxides
- Chemical reactions

Objectives

1. Understanding the phenomenon of acid rain.
2. Explain their impacts on the ecosystem.
3. Establish commonalities between the origin of climate change and acid rain.
4. Understanding acid rain as a local phenomenon with a global distribution.

Material required

- Nitric acid
- Water
- 2 samples with sprouted lentils

Protocol

1. Dilute nitric acid with water (one part acid to three parts water).
2. Label the two samples of sprouted lentils as control group and case 1.
3. Irrigate the control group with water and case 1 with the prepared nitric acid solution.
4. Compare the results.

Issues

1. According to the results obtained, what impacts does acid rain have on vegetation? Does it have any relationship with erosion practice?
2. What chemical reactions take place during the formation of acid rain?
3. Is acid rain related to climate change?

Guidance and answers (teacher's guide)

1. **According to the results obtained, what impacts does acid rain have on vegetation? Does it have any relationship with erosion practice?**

Acid rain causes strong impacts on vegetation, including direct damage to leaves and other plant tissues, as well as the intense leaching of important nutrients present in the soil (calcium, magnesium, sodium, potassium), which hinders the development of vegetation.

In addition, as soil pH decreases, aluminium (hitherto insoluble and stored in rocks, sediments and in the soil cation exchange complex) becomes soluble and toxic to animals and plants.

As the vegetation cover decreases, the percentage of bare soil increases, thus facilitating and intensifying the erosion processes seen in the previous practice.

Image 29: *Plants and acid rain.*

2. What chemical reactions take place during the formation of acid rain?

$$SO_3 + H_2O \longrightarrow H_2SO_4$$

$$2NO_2 + H_2O \longrightarrow HNO_3 + HNO_2$$

3. Is acid rain related to climate change?

The relationship between climate change and acid rain is complex and multifaceted. Although climate change is not the direct cause of acid rain, there is a common point of origin: both the emission of greenhouse gases and the emission of the nitrogen and sulphur oxides that cause acid rain originate from the burning of fossil fuels such as coal or oil derivatives. It is important to dismiss the alternative idea that links acid rain with climate change, but it is interesting to note the point of convergence of the two processes in terms of their origin.

2.1. STRATEGIC PLAN TO DEVELOP THESE PRACTICES LABORATORY IN TOURIST CONTEXTS OF CITIZEN ACTION

Image 30: *Internship in Lisbon.*

This type of practice can easily be taken to contexts of citizen action in tourist contexts, taking advantage of school days when tourists gather in areas close to school towns that apply the methodologies of this project. This usually occurs around Easter and/or popular festivals of tourist interest.

It is interesting that the school educational communities are co-ordinated with the organisers of events of tourist interest, such as gastronomic celebrations or popular festivals, so that these activities can be included in the programmes of festivals and can receive financial support from the organisation for their execution. Schoolchildren should be trained in advance by following the methodological guidelines of this guide and by deepening their curricular development through the school e-book “Climantopía: el libro de texto escolar” (Climantopía: the school textbook).

The support required from the organisers will be role- ups with infographics and basic logistical support such as water, ice or tables to design the stands. Support will be sought from scientific research entities to achieve the development of the Kits whose development is illustrated in this guide following the models developed by the partner Fábrica, Centro Ciência Viva of the University of Aveiro.

To this end, stands can be adapted to the local context by attempting, through the contents addressed in this guide, to provide answers to questions such as:

- What solutions to climate change can be found in the educational context?

- How can we promote sustainable tourism in our territories?
- What is the most remarkable biodiversity in our territories? Is it at risk?
- Why is the sea level rising here when the ice is melting elsewhere?
- Why is our ocean acidifying and how does it affect our shellfish?
- Why do we have more and more heat waves?
- Can a hurricane form here?
- What is happening to our coastal plants, how does it affect us and what can tourism do to help?

For example, campaigns can be proposed to encourage tourists to calculate the loss of beaches based on the expected annual sea level rise in the tourist regions they visit. At the same time, they will be encouraged to design measures to improve the coastline, such as awareness-raising and coastal clean-up campaigns.

Once the contents to be worked on in the tourist environment have been defined, the **town square** that is a **point of reference** for tourists must be selected. Taking into account its characteristics, the municipal architects will be asked for ideas for setting up stands with the available resources and the most suitable type of marquees will be selected. Sponsors will also be sought to generate a system of banners that will make the project logo visible, following the experience of the Oceántica project of the Campus do Mar.

Image 31: *Campus do mar – Second day.*

The montage will be developed in such a way that it feeds back into the screening of the film EDUCINEMA Clima Tour Action. The aim will be to involve schools in the development of film forums on the film “Climantopia Cinema” using school material. At the same time as being prepared for the film forum, schoolchildren will also be trained to carry out the laboratory practices and simulations contained in this material. The municipalities will also be able to seek the support of their music and theatre schools to re-inforce the secondary schools in the challenge of performing the musical theatre version from which the film derives.

2.2. PRINTING OF GENERAL ILLUSTRATIONS AND CREATION OF OTHER PREMISES FOR USE IN STANDS

Map-like illustrations, possibly with accompanying machines, of the processes being simulated in practice should be available to the students who will act as disseminators. In this way they can explain the rationale for the practice while, for example, pointing out where the process they are explaining in the demonstration takes place, without the need to shift the listener's attention. To use this type of illustration at a science fair, the following steps can be followed:

1. Place a cloth or tablecloth on the table to protect it from damage.
2. Arrange the illustrations on the table in such a way that they are easily visible to visitors while they are watching the demonstration or laboratory practice, so that they are in the same field of view.
3. Print the illustrations on plasticised feather board so that they can be lifted and moved without being damaged.
4. Add labels or descriptions to help visitors understand the illustrations better.
5. Have a post-it system to record surprising and valuable ideas from visitors.

Image 32: *Campus do mar – World map stand.*

To create roll-ups for science fair stands, the following steps can be followed:

1. Create a roll-up design with the illustrations and information to be shown, taking as a reference the infographics in this material and in the school ebook Climántopía, the school textbook.
2. Send the design developed by municipal technicians, secondary school art departments and/ or design companies to a company specialised in roll-up printing for printing.
3. Select sturdy supports for roll-ups capable of making use of this resource on beaches, squares and different tourist attractions in the municipality.
4. Place the roll-up in a visible and strategic place within the stand so that visitors can easily see it and develop its information in a very intuitive way so that the student communicator does not have to turn his or her back for a long time to the public to whom he or she is explaining.

2.3. ORGANISATION OF MICROSCOPY MATERIAL, OPTICS, SIMULATION AND PRESENTATION OF SAMPLES ON THE STANDS

Image 33: *Campus do mar – Microscopy stand.*

A coherent and logical set-up should be achieved so that visitors can clearly understand the information being presented. It is also important that stand staff are available to answer any questions that visitors may have, as well as to manage these resources, leaving them back in their logical and coherent organisation, providing reassurance and motivation for the visitor to interact with the material.

Organising microscopy, optics, simulation and sample presentation material at citizen science stands is key to attracting the attention of visitors and transmitting information effectively, involving them in processes that allow them to talk about science while doing science, using the instruments specific to the discipline they are dealing with. In order to make the most of this type of instruments and resources in tourist attraction stands, these criteria should be taken into account when organising the material in the stand:

1. Microscopy and binocular lenses: Microscopes and binocular lenses should be positioned so that the eyepieces are at visitors' eye level. Adequate illumination should be ensured during visiting times to allow for be able to view the specimens correctly. The microscope should have clear instructions for use. For this, one option is to place a computer with a short demo video with the

keys to its use. At the end, the student demonstrator will show the most relevant aspects that have been visualised, giving the opportunity to watch it again if something was missed.

2. Simulation: where feasible, in the development of simulation processes or the use of models on the stand, a large screen or projector should be used to show the simulations in action. This screen, once the simulation is finished, will then provide information on how the simulations were created and how they relate to the scientific research by acting as a bridge to the science models.
3. Display of samples: If samples are displayed on the stand, they can be placed with laminated cards and labels providing information about the samples and how they relate to scientific research. They should be stable in the location and well protected from light and humidity.

2.4. STRATEGIES FOR THE PARTICIPATION OF DIFFERENT GENERATIONS

Image 34: *Differentiated access.*

In order to bring citizen science stands closer to different generations, it is necessary to use different strategies depending on the target audience, including access for children and people with reduced mobility. Some general strategies that can be used are as follows:

1. **Use clear and simple language:** it is important that the information presented on the stands is understandable for all ages. The use of scientific jargon or overly technical terms should be avoided.
2. **Use interactive activities:** interactive activities facilitate the involvement of people from different generations in citizen science activities. For this reason, the activities on the stands are interactive simulations, experiments and other practical activities so that visitors can learn in a fun way and can participate in the development of the activities, both at a manipulative level and in terms of reflection and argumentation.
3. **Adapt the contents, activities and resources to different age groups:** younger children may be more interested in fun activities, while adults may prefer activities more focused on education and the acquisition of scientific culture.

4. **Provide relevant information:** it is important that the information presented on the stands is relevant and has an impact on people's daily lives. This can be especially important for older adults, who may be more interested in health or wellness issues.
5. **Challenges must be planned and rehearsed to facilitate interaction with visitors and for tourists to be able to express the relevance of these contents in their living, professional and everyday environments:** it is in the interest of the stand staff to interact with visitors and answer their questions, but also to dare to return questions when they respond to those they ask, seeking in this return that the tourist brings to the stand a new experience. The questions are especially important for children, as they are very curious, spontaneous, active and need effective guidance to understand scientific concepts. The questions are especially important for children, as they are very curious, spontaneous, active and need effective guidance to understand scientific concepts.

2.5. CREATION OF DESIGNS FOR STAND PRACTICE KITS

Creating designs for science fair booth practice kits can be a creative and challenging process. Below are some general steps that can be followed to create a practice kit for a science fair:

1. Once the topics have been identified, the learning objectives have been designed and the practical activities have been selected, the materials should be illustrated.
2. In the necessary cases, as in the practice of oceanic stratification, a kit design should be established that can be taken to a glass-maker to develop the material to carry out this simulation activity. In this particular case, a photo-design of the tank needed for the stratification should be made, with the necessary materials as expressed in this example tank. This may include construction materials, tools, equipment, instructions and any other element necessary to carry out the practices.

Image 35: *Stratification of the ocean..*

3.1. EXAMPLES OF CITIZEN SCIENCE PROJECTS

The examples given in this e-book of good practice projects that involve students in training other students are the ones that have been taken as inspiration for this task. They are the following projects:

- Meteoschools
- Oceántica
- EduCO_2Cean
- Zosteco project
- Inno EduCO_2
- Four Climates

Meteoescolas emerged in 2007 from the collaboration of the Galician weather forecasting service, MeteoGalicia, with the Climántica project, which was located as an educational pillar of the Galician Plan of Action against Climate Change for the introduction of climate change in the inter-disciplinary projects of the curriculum of the then Organic Law in force in Spain: LOE.

Images 36 & 37: *MeteoGalicia and Climántica project logos.*

Oceántica is a project funded by the Spanish Foundation for Science and Technology (FECYT) in the 2013-2014 academic year, whose school science was located in the Galician estuaries and whose citizen science dimension was inspired by Meteoescolas. Its development focused on the estuaries and inspired its transfer to Europe through EduCO_2ean, an Erasmus Plus project that focused on the participation of schoolchildren in school science based on the conclusions obtained from research into the ecosystems served by bivalve shellfishing.

Images 38 & 39: *Oceántica and EduCO_2cean logos.*

The importance of seagrass meadows in this type of intertidal ecosystem service in the estuaries gave rise to the Zosteco project funded by the Biodiversity Foundation. The approach of schoolchildren to citizen science oriented towards the conservation of these meadows, in the context of COVID-19, inspired the e-InnoEduCO_2 project, financed within the extraordinary educational innovation modality KA226 of Erasmus+ to achieve the development of educational technologies for experiential learning about these meadows and their relationship with health.

The comparison of the comparative application of this project to the prairies of the Rías Baixas, the Cantabrian marshes in Cantabria, Doñana in Andalusia and the Mediterranean meadows on Tabarca Island resulted in Cuatro Climas, funded as a cluster by the Subdirección General de Cooperación Territorial e Innovación Educativa.

Image 40: *Four Climates logo.*

3.2. METEOSCHOOLS

Image 41: *Pontevedra.*

It was a programme that emerged in 2007, financed by the Galician Plan of Action against Climate Change and developed in collaboration between the Climántica and MeteoGalicia teams. This programme continues to operate today within MeteoGalicia, Galicia's meteorological forecasting centre, although without the dimension of demonstration activities on stands in schools, once the interdisciplinary project ceased to be developed with the change of organic law and that of the Galician Climate Change Action Plan ceased. Each school in the Meteoescolas network receives a MeteoGalicia weather station with maximum and minimum thermometers and a rain gauge. The daily data are uploaded to an application developed by MeteoGalicia, which has a filter to be integrated into its meteorological data set if they are consistent with the data. Qualitative observation data are also uploaded.

The Climántica team developed didactic material that was used by the students of those schools implementing the LOE's Interdisciplinary Project. The schools received teacher training to enable students to work with the weather stations. They also received training from the Climantica team to train students in the explanations they would make in the spaces open to the public about the functioning of the climate system, the microclimatic characterisation evidenced by the data from their meteorological stations and the possible effects of climate change on the climate system at a general level and at a particular level.

Image 42: *Noia.*

3.3. OCEÁNTICA

Oceántica is an educational project on science, technology and society that is structured in five cross-cutting stages that encompass the main challenges in the knowledge of the marine environment and its sustainability, and which is contextualised in the Galician estuaries. It was developed in the 2013-2014 biennium and was funded by the Spanish Foundation for Science and Technology (FECYT). It was promoted by the Spanish-Portuguese Campus of International Excellence Campus do Mar led by the University of Vigo.

Image 43: *Cíes.*

Oceántica set up research teams made up of young university researchers and secondary school students. The schoolchildren were in charge of communicating the results through stands where they presented their findings. These presentations took place in various public spaces, including the Samil beach (Vigo). There, the interest aroused in tourists by the opportunity to learn about the sustainability of the coastal environment they were enjoying through the teachings of the schoolchildren who had previously investigated environmental conservation on the beaches was visualised.

To do so, they studied the differences in the anthropic intervention on the Cíes beach, which is subject to conservation as a national park, and the Samil beach, which is affected by public works, especially the promenade. To achieve this visualisation, they checked the differences in the profile of the beach. They then checked the abundance and distribution of sea fleas on both beaches, as a bio-indicator of the decrease in anthropic intervention on the beach.

Image 44: *Profile measuerments in Cíes.*

They also measured the abundance and distribution of invasive algae on both beaches. In addition, they studied the possible effects of climate change on these invasions. The results were organised into papers to be passed on to the content of the stands.

Image 45: *Seaweed in Cíes.*

3.4. EDUCO2CEAN

This project transferred to Europe the lessons learned from the involvement of schools in citizen science developed in Oceania. The EDUCO2CEAN project was funded by Erasmus+ within the KA201 educational innovation modality for the 2016-2018 biennium. It aims to generate a Science-Technology-Society (STS) pedagogical model with the potential to be applied throughout the European Union and to convey to society the importance of research on the impacts and mitigation of climate change in the sea, with special emphasis on the Atlantic Ocean and the Baltic Sea.

Image 46: *Stand in Noia.*

The project proposes the development of key competences necessary for the promotion of creativity in the communication needed to raise awareness in society of the relevance of research in the face of climate change and in favour of the sustainability of the oceans; and for the promotion of the entrepreneurial scientific spirit necessary for the transfer to society of the relevance of this knowledge.

To achieve this, it focuses on involving students in initiatives aimed at creating ideas, communication aimed at environmental awareness. It assumes that these academic youth challenges will generate basic concerns and knowledge that will enhance participants' future job opportunities in the search for solutions to global change in the oceans.

The conjunction and comparative analysis of the challenges of climate change and sustainability in the Baltic and the Atlantic will also create opportunities for the development of a new, more sustainable and more sustainable future for the Baltic and the Atlantic.

The European dimension of education will be further developed. Therefore, the Atlantic and Baltic educational and scientific communities will collaborate in the generation of an STS educational model that will allow the comparative analysis of the environmental impacts of the two oceans, caused by overfishing, pollution, rising sea temperatures, the presence of hazardous materials and other environmental risks.

In this sense, the project is linked to the objectives of Horizon 2020, as it works on the societal challenges facing the EU, promotes industry leadership in Europe related to the Baltic and Atlantic Oceans and responds to climate change and pollution of the two oceans. Because of the relevance of these responses for Europe, it is strategic that from these STS areas it is possible to provide basic training for young people that will lead to further training to become better European professionals in the future in areas related to these challenges. It also reinforces the excellence of their scientific base, since with this project many students will collaborate with professional research t e a m s and act as communicators and sensitisers of the relevance of this challenge, thus putting into practice the principles that nothing is learned better than research and that he who teaches learns twice.

In short, EduCO_2ocean's commitment to leadership, scientific work in professional teams, communication skills and rigorous scientific training will enable them to learn more, better and more professionally, reaching 2020 in better conditions and with better opportunities to work in a knowledge society that will stimulate a more competitive and environmentally friendly European economy.

This project was assessed as an example of good practice. It was subsequently selected as case study no. 15 as the Science Technology and Society (STS) model for the development of projects on sustainability in the six-year period 2021-2027.

Its citizen science consisted of communicating in stands set up in Noia, Lisbon and Madrid the experience developed by a research community composed of scientists from Campus do Mar and students from IES Virxe do Mar, who jointly carried out an empirical study involving key research techniques to study the possible global impact on the recruitment of cockles (*Cerastoderma edule*) n the main mollusc bank of this mollusc of high commercial value in Galicia – Spain. For this purpose, the distribution and abundance of this bivalve was studied.

Image 47: *Stand in Lisbon.*

The research focused on the initiation of a time series of data that allows to know the possible effects of global change on the bivalve of commercial interest *Cerastoderma edule* in the Testal mollusc bed in Noia (Galicia – Spain). It is the main economic resource of Noia and this mollusc bed is one of the most important in the world for this marine resource.

The research was proposed as the beginning of a series that they intend to repeat over the next few years, at the same time of the year, before the start of the closed season, in the last week of molluscs, just before the recruitment or passage from swimming larvae to clam recruits found in the sediment.

Images 48 & 49: *Testal, Noia.*

3.5. ZOSTECO

ZOSTECO – Conservation of *Zostera noltii* grasslands in the NW Iberian Peninsula: a research based on participatory mapping of uses and ecosystem services, was funded by the Pleamar programme of the Biodiversity Foundation to be implemented in 2020.

The project is aimed at generating knowledge and useful instruments on fishing and recreational activities and their relationship with the spatial distribution of their RN2000 habitats with the participation of the different relevant stakeholders (administration-management, fishing and recreational sector, environmental groups, researchers) of the protected areas in which they operate.

To this end, existing information was analysed and updated, a study was carried out on the perception of the services provided by these habitats and training workshops were implemented in order to draw up a map of services and conflicts. Based on these results, a participatory forum and working groups were organised with the actors involved to jointly develop a diagnostic and participatory management report for the mitigation of impacts and conflicts.

Image 50: *Research in Testal, Noia.*

An educational innovation programme on interaction and identified conflicts was also carried out. This programme involved students from IES Virxe do Mar who investigated the distribution of *Zostera* in the ecosystem service of Testal beach, continuing the work in the laboratory to present the results in the context of citizen science in the project.

Image 51: *Laboratory work at IES Virxe do Mar (Noia).*

3.6. E-INNOEDUCO2

This is an Erasmus+ funded project for the 2021-2023 biennium under the KA226 extraordinary modality to overcome pedagogical barriers arising from the COVID-19 pandemic.

Image 52: *Students carrying out a field practice during the return to face-to-face classes after the pandemic.*

The pandemic demonstrated that most education systems were not prepared for the world of digital learning opportunities, and that there is also an urgent need to foster a culture of innovation throughout society and at all levels, starting at school age. STE(A)M (science, technology, engineering, arts and mathematics) education enables students to develop skills and competences related to innovation. It allowed us to see that the social distance required for the prevention of contagion required visualisation formulas for experimental details that can only be perceived with straight visualisation. This led to the development of audiovisual visualisation systems that made it possible to project school science towards citizen science.

The pandemic was also a call for renewed commitment to the SDGs: to ensure that all young people have the opportunity to succeed in school and develop the knowledge, skills, actions and values that will enable them to contribute to society in terms of ecological recovery, especially with regard to the urgency of mitigating and adapting to climate change. The UN has designated 2021-2030 as the Decade of Ocean Science for Sustainable Development. Engaging school students in this in an experiential way can initiate them to act as agents of the ecological transition, marking Ecology and ICT as cross-cutting themes for creative science outreach.

The design of this project was inspired by the good citizen science practices developed by students in the school science projects Oceántica, Edu-CO_2cean and Zosteco. The students were trained to understand the relationship between the *Zostera* grasslands and the ecosystem services they provide in relation to climate change mitigation and the effects on human health, especially those linked to the consumption of molluscs and fish whose biological cycle is related to these grasslands. The guarantees of this type of grassland for the prevention of zoonoses due to its role in water filtration were also addressed. Within this framework, the students were trained to communicate the importance of the conservation of this type of ecosystem through the production of short films.

In the Atlantic, work was carried out in the intertidal seagrass beds of the Testal bivalve shellfish beds. There, using an application developed within the framework of the project by CESGA, they uploaded data on the density and coverage of this marine plant.

Image 53: *Testal, Noia.*

In the laboratory they then measured the dry biomass, organic matter and biodiversity of samples taken from different grasslands: one with minimal fragmentation, one with medium fragmentation and one with isolated plants.

After the field and laboratory work was completed, the influence of seagrass fragmentation on organic matter removal from water and biodiversity was discussed and conclusions were drawn on the importance of seagrasses for climate change mitigation as relevant carbon sinks.

The experience was repeated in the coastal lagoon of Aveiro in order to compare two distinct Atlantic intertidal meadow ecosystems.

Image 54: *Laboratory work.*

Image 55: *Aveiro.*

In the Black Sea they worked with a case study on the influence of public works on seagrass meadows. The case study focuses on the differences between a seagrass meadow affected by public works and a seagrass meadow not affected by public works.

The Baltic Sea included an analysis of the relationship between seagrass meadows and eutrophication, a problem that according to the latest IPCC report on oceans and the cryosphere already affects more than 900 coastal areas and semi-enclosed seas worldwide.

The students thus make these ecology studies available to the public through short films in which they present their results, their analysis, their justifications backed by science and their conclusions.

3.7. FOUR CLIMATES

Image 56: *Navigation in the Ría de Noia.*

In order to adapt the methodologies and approaches of e-InnoEduCO$_2$ to different autonomous communities, the Agrupación escolar Cuatro Climas candidacy was articulated, which was financed under the grants for the promotion of school clusters from the Subdirección General de Cooperación Territorial e Innovación Educativa of the Ministry of Education.

For its development, 4 mobilities were planned, one in each of the autonomous communities that are members of the consortium to comparatively study the intertidal seagrass meadows of the Rías Baixas, the Santoña Marshes in Cantabria, those of Doñana in Andalusia and those of Tabarca Island in the Valencian Community. Short films by school producers, scientific-artistic performances under the SostenArte project and photo-reportages of the different activities will be shown during the event.

The first stay of the group took place in the last week of March 2023 in Galicia, coordinated by the IES Virxe do Mar de Noia under the theme "*Las Rías Baixas vistas desde Cuatro Climas*" (*The Rías Baixas seen from Four Climates*). The centres of Cantabria and Andalusia took part in it, with the centre of the Valencian Community being connected telematically.

During this stay, the relationships of seagrass meadows with water purification, sediment fixation and the improvement of species reproduction were discussed, as well as short films made by school products. In addition, the NW Atlantic climatic dimension was introduced from the care of the protected area of the Dunes de Corrubedo Natural Park. There was also a meeting

with scientists who lead schoolchildren in research on Ecology and Conservation of Genetic Biodiversity to organise research activities in the intertidal area of Testal, with shellfish gatherers and scientists. The ecosystems of the Rías Baixas were interpreted at the Finisterrae Aquarium in A Coruña and the Biodiversity Museum of the University of Santiago de Compostela, where species were illustrated in order to conceptualise the ecological relationships in these communities and transfer the knowledge to the public through short films produced by students and musical performances.

Image 57: *Biodiversity Museum.*

Image 58: *Tambre I.*

In order to locate the silty sedimentology where the intertidal shellfish meadows of Testal develop and the nature of the estuaries, the arrival of the Tambre mountain river crossing in the area of tidal influence was visualised. We also visualised the classic dam turbine that runs along the mountainside of the Tambre I hydroelectric power station with the modern Tambre II turbine, which is fed with water from the bottom of the Barrié de la Maza reservoir, with water channelled through a tunnel, and with a high content of silty sediment, part of which filters the Zostera.

The second stay of the project was coordinated by the IES Bernardino de Escalante de Laredo under the STEAM theme of the project "*SostenArte*" which has led to a musical video performance whose purpose is to integrate art to communicate to the public the urgency of caring for the seagrasses. It took place in the first week of April 2023.

Image 59: *Source of the Ebro.*

There, the source of the rivers was analysed in limestone mountains, visualising the colour due to the dissolution of limestone from the Ebro, in order to identify the limestone nature of the silty sedimentology of the Santoña Marshes, at the mouth of the river Ansón, where the sea meadows develop.

The Zostera ecosystem in the Natural Park of the Santoña Marshes was analysed in order to study the seagrass meadows of *Zostera noltii* during low tide. To express this, the musical preformance *SostenArte* was developed through workshops aimed at preparing the artistic action where ecosystems, sustainability and art will come together in the piece "*SostenArte*" which was visualised on the last day at the Casa de Cultura in Laredo. In this mobility, the centres of Galicia and Valencia will participate in person and the Andalusian centre will be connected telematically.

Image 60: *Santoña and Laredo.*

Image 61: *Sostenarte in the workshop.*

It is planned for the academic year 2023-2024, the stay coordinated by the IES Sixto Marco of Elx under the theme "*Coastal morphology and Posidonia oceanica. The coastline of Santa Pola and the island of Nueva Tabarca. The Posidonia oceanica meadows*". The centres of Cantabria and Andalusia will take part in it, and the centre of Galicia will be connected telematically. A visit will be made to get to know the environment of the Marine Reserve of the Island of New Tabarca and the coastal morphology of Santa Pola, and a coastal wetland in the south of the province of Alicante will also be analysed: the Santa Pola Salt Flats. Diving activities will be carried out in order to record the key images for the documentary in the Tabarca meadows.

Andalusia mobility will also take place in the 2023-2024 academic year, coordinated by IES Averroes in Cordoba. The centres of Galicia and the Valencian Community will participate in it, with the Cantabrian centre joining in on a thematic basis. The youth documentary will end with a study of the Natural Monument of the Sotos de la Albolafia, in the urban section of the Guadalquivir river to reflect on the importance of the conservation of the fluvial environment for the good condition of the meadows, ending this analysis with a visit to the Doñana National Park with a study of the coastal area, the marshes of El Rocío and Arroyo de La Rocina in the northern area of the park; including a visit to the Hornachuelos Natural Park, which forms part of the Dehesas de Sierra Morena Biosphere Reserve.

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