THE CLIMATE IN OUR HANDS

EXTREME WEATHER EVENTS

Teacher's guide book for secondary school

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THE CLIMATE IN OUR HANDS

Extreme Weather Events

A teacher's handbook

This document should be cited as follows: **'The Climate in Our Hands – Extreme Weather Events, a teacher's handbook, Office for Climate Education (OCE), Paris, 2025'.**

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A full list of the many people who contributed to this book, through their critical reviews, proposals, classroom tests, etc., is provided in the 'Acknowledgements', page 81.

Classroom tests
Many thanks to the teachers and students who tested the activities and gave us their feedback!

Date of publication
December 2025

Information
English, French and Spanish versions are already available. Information on the work of the Office for Climate Education, as well as extra copies of this document can be obtained at the following address:

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GRANT AGREEMENT
N° 101003469

ARTIFICIAL INTELLIGENCE TO DETECT AND ATTRIBUTE EXTREME EVENTS TO CLIMATE CHANGE

Climate is changing fast, with losses and damages experienced in every region and every sector. However the awareness of this fact remains limited. Of particular relevance is how climate change modifies and enhances extreme weather events.

During the last 5-10 years, a large number of extreme weather and climate events have occurred, causing damage to infrastructure and casualties. This has raised the question about the role of climate change in altering the odds or the magnitude of a number of such events.

XAIDA, an EU-funded project started in September 2021, brings together the interdisciplinary expertise of a research consortium of 16 universities and research organisations. Our consortium unites experts in machine learning, statistics and climate modeling.

Together we are designing new methods and apply them to recent high-impact events to understand the role of climate change. Further, we are studying if such events, or even more-intense ones, will occur in the future. We are collaborating with concerned stakeholders from different sectors to prepare risk assessment and adaptation strategies for extreme weather.

Together with teachers, we are developing new educational material to improve the education of younger generations.

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THE OFFICE FOR CLIMATE EDUCATION

Created in 2018 on the initiative of the educational and scientific community, the Office for Climate Education (OCE) aims to organise strong international cooperation between scientific bodies, NGOs and educational institutions. This cooperation is essential to educate present and future generations about climate change.

The mission of OCE and its partners is to promote climate change education worldwide through high-quality teaching resources, professional development courses and design and implementation of national and international operational projects.

In 2020, the Office for Climate Education became a category 2 centre under the auspices of UNESCO to promote climate change education internationally, focusing in particular on emerging countries.

CONTENTS

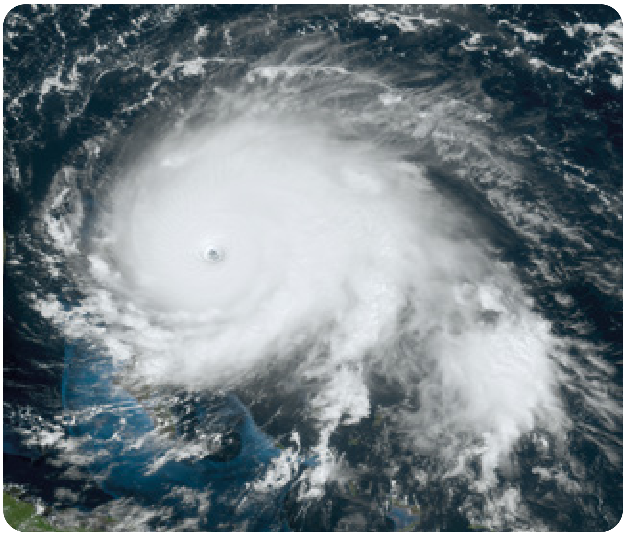
INTRODUCTION

Content of this Guide

LEARNING OUTCOMES OF THE SET OF ACTIVITIES

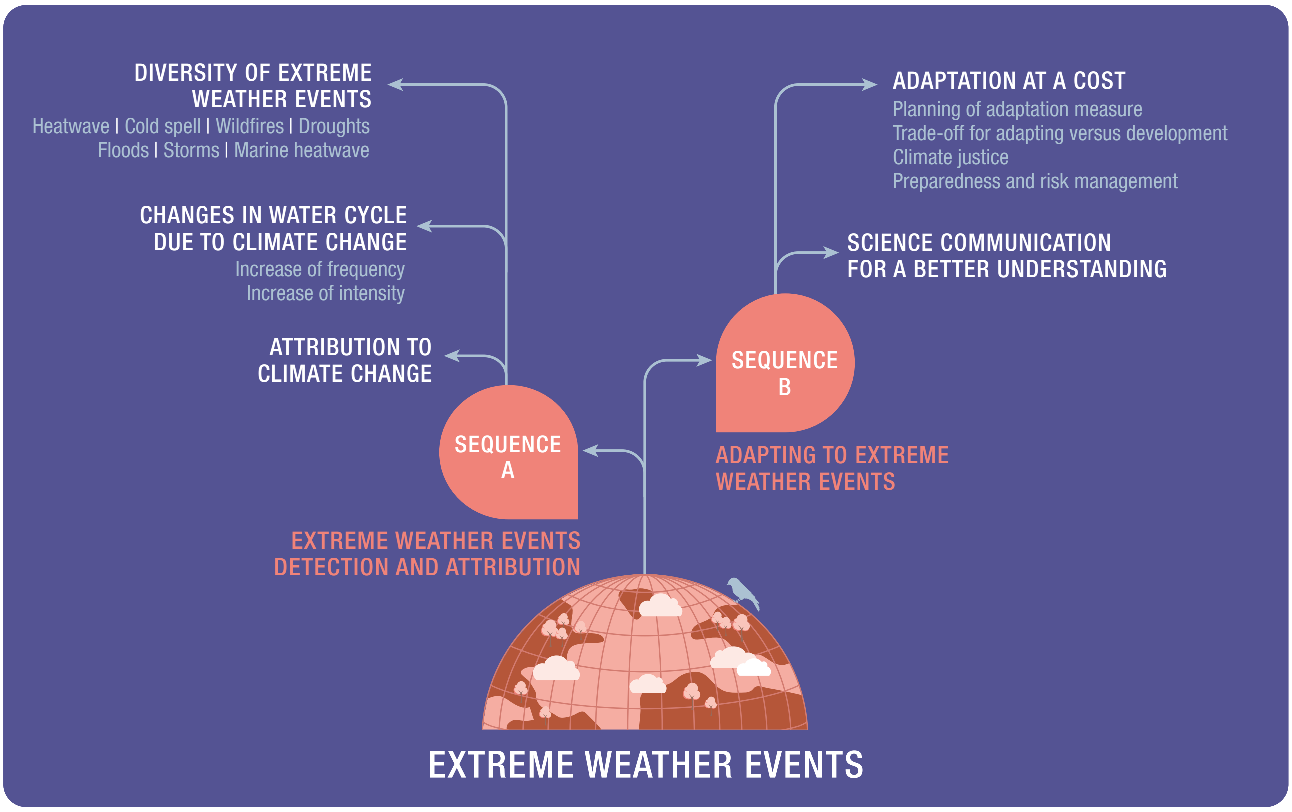
Learners will be able to:

- Identify the different types of extreme weather events.
- Understand the notion of attributing an extreme weather event to climate change.
- Understand solutions for adapting to extreme weather events.
- Understand the link between the water cycle, extreme weather events and climate change.
- Using probabilities to understand the likelihood of occurrence of extreme weather events under climate change.
- Experiment with collective decision-making on climate risk management.
- Understand the elements of scientific communication needed to make informed decisions.



View of hurricane Dorian from space, Abaco Islands, September 2019.

CONCEPTS COVERED IN THIS HANDBOOK



LESSON PLAN: TWO PROGRESSIVE AND COMPLEMENTARY TEACHING UNITS

INTRODUCTORY ACTIVITY

1 Exploring Extreme Weather Events

In this lesson, students explore extreme weather events through an online interactive map and learn how scientists study them using meteorological data and climate models. They discover how climate change can influence the likelihood or severity of such events through attribution studies. The concept of adaptation is also introduced as a key response to reduce the impacts of extreme weather.

SEQUENCE A EXTREME WEATHER EVENTS DETECTION AND ATTRIBUTION

2 The Frequency of Extreme Weather Events

In this two-part activity, students explore how the frequency and distribution of weather events define local climate. Using dice, they simulate temperatures to understand probability and what makes an event ‘extreme’. They then model how climate change affects the frequency of extreme events today and in the future.

3 The Physics of Extreme Weather Events

In this lesson, students explore how global warming has increased the frequency and intensity of most extreme weather events since pre-industrial times. Using IPCC data, they examine regional variations and future projections, especially for heatwaves, heavy rainfall, and droughts. They also learn that mitigation can reduce the severity and occurrence of such events.

4 The Water Cycle in a Changing Climate

This lesson introduces the water cycle, made up of reservoirs (like oceans, rivers, and the atmosphere) and the fluxes between them. Students learn that water changes state as it moves, and that its total quantity stays constant. Climate change, however, alters both flows and storage, impacting the frequency and intensity of extreme weather events.

SEQUENCE B ADAPTING TO EXTREME WEATHER EVENTS

5 Adaptation for the Decade

In this lesson, students take part in a serious game where they plan adaptation strategies for a fictional community facing climate hazards. Over three rounds, they choose between development and protection against drought or floods, with evolving risks simulated by dice rolls. The activity ends with a discussion on adaptation, development, and climate justice.

6 (Un)natural Disasters

In this lesson, students participate in a serious game simulating disaster management on a fictional island. Through role-play and group decisions, they explore concepts like risk, vulnerability, and intersectionality. The activity helps them understand why climate change impacts some communities more than others.

7 How to Communicate about Extreme Weather Events?

In this lesson, students watch video clips of experts explaining how global warming has increased the frequency and intensity of certain extreme events. They deepen their understanding of these phenomena and the scientific tools used to attribute them to climate change. Students also create their own video clips and explore how societies prepare for and respond to such events, from early warnings to recovery efforts.

TABLE OF COMPETENCES USED IN THIS MANUAL (BASED ON THE GREENCOMP [1])

DOMAIN 2 EMBRACING COMPLEXITY IN SUSTAINABILITY

GREENCOMP	DESCRIPTION	LESSONS
2.1 Systems Thinking	To approach a sustainability problem from all sides; to consider time, space and context in order to understand how elements interact within and between systems. *E.g.:* Biofuel production and increased competition for land.	1 - 2 - 3 4 - 7
2.2 Critical thinking	To assess information and arguments, identify assumptions, challenge the status quo, and reflect on how personal, social and cultural backgrounds influence thinking and conclusions. *E.g.:* Critical understanding of the issues involved in mass sales of electric cars.	7
2.3 Problem Framing	To formulate current or potential challenges as a sustainability problem in terms of difficulty, people involved, time and geographical scope, in order to identify suitable approaches to anticipating and preventing problems, and to mitigating and adapting to already existing problems. *E.g.:* Controversy mapping-type activity.	6

DOMAIN 3 ENVISIONING SUSTAINABLE FUTURES

GREENCOMP	DESCRIPTION	LESSONS
3.2 Adaptability	To manage transitions and challenges in complex sustainability situations and make decisions related to the future in the face of uncertainty, ambiguity and risk. *E.g.:* Proposals for energy-saving measures in buildings.	5 - 6
3.3 Exploratory Thinking	To adopt a relational way of thinking by exploring and linking different disciplines, using creativity and experimentation with novel ideas or methods. *E.g.:* Imagining circular consumption patterns on a school scale.	7

DOMAIN 4 ACTING FOR SUSTAINABILITY

GREENCOMP	DESCRIPTION	LESSONS
4.1 Political Agency	To navigate the political system, identify political responsibility and accountability for unsustainable behaviour, and demand effective policies for sustainability. *E.g.:* Students engagement.	6
4.2 Collective Action	To act for change in collaboration with others. *E.g.:* Take part in a participatory science project, *e.g.* 'Who protects the oaks?' project [2].	5

1 European Commission, Joint Research Centre, GreenComp, the European sustainability competence framework, Publications Office of the European Union, 2022, https://data.europa.eu/doi/10.2760/13286

2 https://www.oce.global/en/resource/tree-bodyguards/

VIDEO ASSOCIATED WITH EACH LESSON

In relation to this teachers' handbook, a set of 8 video clips featuring scientists from the XAIDA project has been developed. These videos are part of the CLIM series, available on the OCE website and YouTube channel. Each video presents a topic related to the work of the scientists that can be associated with some activities of the handbook in particular. In this table you will find all the videos, accessible online, and their associated lessons. Note that lesson 7 is entirely based on the exploitation of every video by the learners, and one learning objective of this activity is the production by the students of a science communication video.

CLIM VIDEO	SCIENTIST	DESCRIPTION	LESSONS	ACCESS
#1 Extreme Events	**Dr. Dim Coumou** Professor in Climate Extremes and societal risk, Vrije Universiteit Amsterdam, Netherlands.	In this video, Dim Coumou explains the causes and impacts of extreme weather events on both the environment and society. He highlights the key role of climate change in intensifying these events and offers insights to help better understand our impact.	1 - 2 - 3 5 - 6 - 7	VIDEO #1 ↗
#2 AI to Study Extreme Events	**Dr. Miguel Ángel Fernández Torres** Senior researcher in Machine Learning, Universitat de Valencia, Spain.	Miguel Ángel Fernández Torres presents how artificial intelligence is transforming the way we predict and understand extreme weather events, with new tools to better anticipate their impacts.	1 - 7	VIDEO #2 ↗
#3 Heatwaves and Droughts	**Dr. Raed Hamed** Researcher in water and climate risk, Vrije Universiteit Amsterdam, Netherlands.	Raed Hamed explains the links between heatwaves and droughts, their impacts on ecosystems and society, and the strategies needed to adapt to a warming climate.	3 - 5 - 7	VIDEO #3 ↗
#4 Ecosystem Impacts	**Dr. Nora Linscheid** Researcher in Ecosystem-Climate Interaction,Max Planck Institute for Biogeochemistry Jena and University of Leipzig, Germany.	Nora Leinscheid explains how extreme weather events impact biodiversity and ecosystems, highlighting their crucial role in climate regulation.	4 - 7	VIDEO #4 ↗
#5 Severe Convective Storms	**Dr. Chen Lu** Researcher in Earth System Physics, ICTP, Italy.	Chen Lu explains how severe convective storms form, their destructive impacts, and how climate change may intensify them.	3 - 5 - 6 - 7	VIDEO #5 ↗
#6 Cold Extreme Events	**Dr. Xiaocen Shen** Researcher in cold extreme events, University of Reading, UK.	Xiaocen Shen explains how cold extremes form, their potential impacts, and how scientists study these risks in the context of climate change.	3 - 7	VIDEO #6 ↗
#7 Compound Events	**Dr. Emanuele Bevacqua** Researcher in compound weather and climate extreme events, Helmholtz Center for Environmental Research, Germany.	Emanuele Bevacqua explains compound events – when multiple extreme weather events occur together or in sequence – and how they threaten ecosystems and communities in a changing climate.	3 - 6 - 7	VIDEO #7 ↗
#8 Management of Extreme Events	**Dr. Clair Barnes** Researcher in Climate Change and Extreme Weather, Imperial College of London, UK.	Clair Barnes explores key strategies to anticipate, respond to, and adapt to extreme weather events intensified by climate change, helping to reduce their impact on communities and the environment.	1 - 5 - 6 - 7	VIDEO #8 ↗

HOW TO USE THIS GUIDE

HOW ARE ACTIVITIES ORGANISED?

The **DURATION** includes:
- Preparation time (for you)
- Activity time (with your students)

Rough estimate

The **AGE GROUP** is given as a rough guideline

PEDAGOGICAL METHOD(S) proposed in this lesson

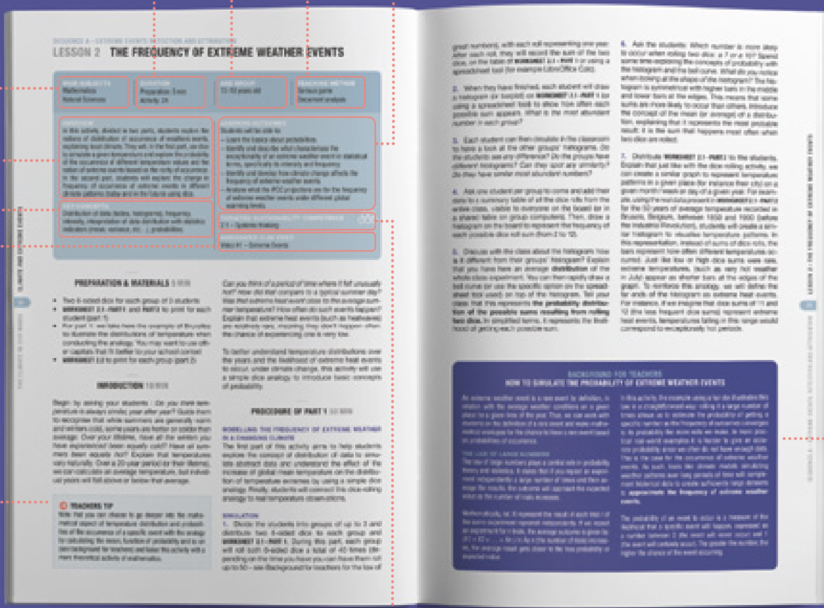
The main **LEARNING OUTCOMES** (knowledge and skills) your students will acquire during this lesson

MAIN SUBJECTS that can include the topics of this activity

An **OVERVIEW** of the activity: what your learners will do

List of the **CONCEPTS** related to this lesson

List of **CLIM VIDEOS** related to the notions covered in this activity



The **TEACHER TIP** section gives you some advice on the methodology, or some specific points on which to focus

The main sustainability competence your students will acquire through this lesson **(GREENCOMP)**

Some of the lessons have a **BACKGROUND FOR TEACHERS'** box, with information about the specific topic of the lesson

LEVELS

The targeted age group is 11+ year-old students (middle-school and high-school). Note that each lesson has been tested in the classroom of this specific age group during the calibration phase of the lesson plan. Of course, this does not mean that you cannot conduct the lesson plan with another age group, but it gives you an idea of the ability level of the activities involved.

EVALUATION: ASSESS YOUR STUDENTS

In order to implement assessments for learners on the activities proposed in *Extreme Weather Events,* we propose a set of assessment tools you can have access to online.

ASSESS YOUR STUDENTS ↗

How to Teach Climate Change?

In high-quality climate change education, as outlined in UNESCO's *Greening Curriculum Guidance*[3], it is essential to foster cognitive, socio-emotional, and behavioural learning in concert. Cognitively, students require robust scientific understanding – such as grasping carbon cycles and climate modelling – to situate local phenomena within global systems. For instance, linking greenhouse gas dynamics to rising heat island effects in their own community deepens relevance. Socio-emotionally, learners build empathy and resilience by reflecting on their emotional responses – grief, anxiety, hope – and developing coping strategies, thereby avoiding helplessness. Behaviourally, the curriculum promotes actionable competencies, such as designing a school-yard greening project or initiating energy audits, which translate knowledge and emotion into community-oriented interventions. Together, these dimensions equip students to understand, internalize, and act on climate change, thus preparing them to become informed and engaged agents of transformation.

The purpose of this teacher's handbook is to help teachers propose activities that allow students to actively participate through questioning, experimentation, observation, trial and error, debate and the implementation of local, concrete solutions to address climate change issues. This 'active learning' can take different forms. **The two approaches that we strongly promote throughout this handbook are inquiry-based learning and serious game-based learning.**

WHAT IS INQUIRY-BASED LEARNING?

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

1. **Questioning:** initiated by the teacher or students to help formulate hypotheses.
2. **Formulating a hypothesis and conducting research:** carrying out experiments or investigations, making observations, using models, analysing documents.
3. **Structuring and constructing knowledge** (discussion on information/data collected or produced): the purpose of this phase is to draw some broad conclusions, which in turn can lead to more questioning, more research, etc.

WHAT IS SERIOUS GAME-BASED LEARNING?

Integrating **role-play simulations** and **serious games** into climate education offers a dynamic form of active pedagogy that significantly enhances students' cognitive understanding, emotional engagement, and behavioural agency. Role-play simulations – such as the World Climate Game, where learners act as delegates negotiating climate policies using real-time feedback – have been shown to improve knowledge of climate impacts while also boosting participants' urgency and intent to act[4]. Similarly, serious games focusing on climate adaptation or urban planning foster systems thinking and localised decision-making skills, increasing both awareness and preparedness[5]. Both lessons 5 and 6 (Sequence B) are based on role-play games. These methodologies offer a powerful pathway to translate abstract climate concepts into lived experience – cultivating not only understanding but also the capacity and willingness to take meaningful action.

WHY USE AN INTERDISCIPLINARY APPROACH IN CLIMATE EDUCATION?

While 'traditional' scientific disciplines are essential to understanding the physical and biogeochemical mechanisms of climate change and its consequences, the humanities and social sciences allow students to understand the social, political and economic issues of sustainable development and climate justice. The arts and language disciplines are also valuable for encouraging students to express their feelings and engage with certain forms of action (such as public

Example of inquiry-based learning through experimental analogies.

3 UNESCO. (2024). *Greening curriculum guidance: Teaching and learning for climate action*. Paris: UNESCO. https://unesdoc.unesco.org/ark:/48223/pf0000388872

4 Juliette N. Rooney-Varga et al., 'Combining Role-Play with Interactive Simulation to Motivate Informed Climate Action: Evidence from the World Climate Simulation', *PLOS ONE 13,* no. 8 (2018): e0202877.

5 Flood, Stephen, et al. 'Adaptive and Interactive Climate Futures: Systematic Review of 'Serious Games' for Engagement and Decision-Making.' *Environmental Research Letters,* vol. 13, no. 6, 2018, 063005.

awareness). Disciplines such as engineering, agriculture and technology are of use in developing practical solutions. **Teaching climate change means taking into consideration all its dimensions, and this requires an interdisciplinary approach.**

WHY USE POSITIVE THINKING IN CLIMATE EDUCATION ?

Worldwide, climate change issues and future projections have led to a strong mobilisation of young people, often marked by strong emotions and reactions, especially amongst the youngest, who talk of ‘civilisation collapse’ or the ‘end of our planet’. The term ‘eco-anxiety’ has been coined to describe this climate anguish.

We propose here to take account of and mitigate this anxiety by:

- **Raising awareness on climate change:** not denying its seriousness and challenging aspects, but focusing on scientific facts instead of on catastrophic narratives. This approach is important, but not sufficient, considering the high emotional charge of climate change consequences.

- Encouraging students to **acknowledge their emotions and feelings** and to connect with others rather than remain in isolation (see lesson ‘How do you feel about climate change? Working on emotions’ in the handbook ‘Climate Change and Land’).

- Realising that it is necessary, and still possible, **to act at different levels** – individual, school, community, etc. (see Sequence C in the ‘The Climate in Our Hands’ series ‘Climate Models’).

- Encouraging students to take part in **a concrete plan of action,** through projects (see the ‘We act’ section in the ‘The Climate in Our Hands’ series ‘Ocean and Cryosphere’ and ‘Climate Change and Land’) that will lead to mitigation or adaptation.

Example of a concrete project about local adaptation against drought due to climate change.

INTRODUCTORY ACTIVITY

LESSON 1 EXPLORING EXTREME WEATHER EVENTS

MAIN SUBJECTS
Physics
Natural Sciences
Geography

DURATION
Preparation: 5 min
Activity: 2h

AGE GROUP
11 years and up

TEACHING METHOD
Documentary Analysis
Multimedia Animation

OVERVIEW
In this lesson, students explore extreme weather events using an online interactive map showing their global distribution. They learn how scientists use observations and climate models to study these events through attribution studies. These studies assess whether climate change made an event more / less likely or severe, had no effect, or if evidence is insufficient. The lesson also introduces adaptation actions to reduce extreme weather impacts.

KEY CONCEPTS
Adaptation, Attribution, Climate Projections, Droughts, Extreme Weather Event, Floods, Frequency, Heatwaves (on land), Hurricanes, Intensity, Maladaptation, Marine Heatwaves, Meteorological Parameters, Storms, Wildfires.

LEARNING OUTCOMES
Students will be able to:
~ Identify different types of extreme weather events using a world map and describe the meteorological parameters (temperature, humidity, precipitation...) and tools (observations, climate model outputs) used to study them.
~ Explain the purpose of extreme weather attribution studies.
~ Recognise that most attribution studies show events have become more intense and/or frequent due to climate change.
~ Evaluate examples of adaptation strategies to reduce extreme weather impacts.

TARGETED SUSTAINABILITY COMPETENCE
2.1 – Systems Thinking

ASSOCIATED CLIM VIDEOS
Video #1 – Extreme Events
Video #2 – AI to Study Extreme Events
Video #8 – Management of Extreme Events

TEACHER TIP
This activity (and this handbook in general) assumes that students are already familiar with the concept of climate change and understand its origin. If the students are not, we recommend doing one of the activities on the subject from our manual 'The Climate in Our Hands – Ocean and Cryosphere' before this activity. For example, Lessons A2 and B2.

PREPARATION & MATERIALS 5 MIN

- A computer per group (or a tablet) with internet access to use the online interactive map. For class tests: access to the online interactive map.
- **WORKSHEET 1.1** to print for each group of students.
- **WORKSHEET 1.2** to print for each group of students with the cards cut out.

INTRODUCTION 15 MIN

Ask students what they think an extreme weather event is. Ask them to name the types of extreme weather events they have experienced in their country or in a country they visited, or have read / heard about in the news or from family members.

Write all answers on the board in the form of a 'word cloud', without correcting them. *Can they think of examples from other parts of the world? Are all extreme weather events the same? What differences do they notice? How would they classify them?* Listen to their responses and then group the extreme weather events by circling them in the same colour according to the following categories: **land heatwaves** (extremely high temperatures) **and cold spells** (extremely low temperatures), **droughts, floods, marine heatwaves, storms and hurricanes, wildfires.**

If some students mentioned events that are not linked to weather (e.g. earthquakes or tsunamis), explain that extreme weather events are specifically tied to weather and can be measured using meteorological parameters, like temperature, precipitation, humidity, and wind.

By discussing with your students, building together a definition of extreme weather event, it is important to come up with the notions of rarity, and the fact that these events have negative impacts on societies and that they are not the same everywhere on the planet.

Here is a definition you can reach during the class discussion: **an extreme weather event is an event that is rare at a particular place on Earth and time of year. The severity of these events has a strong negative impact on human society and ecosystems locally.**

PROCEDURE 1 H 30

PART 1 (45 MIN) – EXPLORING EXTREME WEATHER EVENTS

1. Divide the class into 6 groups based on the categories below, and distribute **WORKSHEET 1.1** to each group (you may have more than 6 groups, thus several groups working on the same category).

CATEGORY 1: **Land Heatwaves and Cold Spells**
CATEGORY 2: **Droughts**
CATEGORY 3: **Floods**
CATEGORY 4: **Marine Heatwaves**
CATEGORY 5: **Storms and Hurricanes**
CATEGORY 6: **Wildfires**

2. Each group will explore their assigned type of extreme event and answer the questions in **WORKSHEET 1.1** using the online interactive map, focusing only on the 'Description', 'Physics' and 'Projections' sections. When all groups have completed **WORKSHEET 1.1**, they take turns presenting their findings to the class.

3. Ask students: *Can scientists say that extreme weather events are caused or influenced by climate change?* Some might say the former by referring to events for which the attribution is 'more severe or more likely', it is the moment to clarify that scientists **do not frame it in terms of direct causation** (see *Background for teachers* for more details). Instead, they can quantify **how climate change modifies an extreme weather event's likelihood, intensity and mechanisms.** In this activity, we focus on attribution studies that assess **the influence of climate change in altering the frequency and intensity of specific extreme weather events.**

The examples featured in the online interactive map illustrate each of the four possible conclusions: human-induced climate change made the event **more likely and/or severe; less likely and/or severe; had no influence; or there is insufficient data to draw conclusions.**

4. Draw a table on the whiteboard with four lines, each representing the four types of attribution conclusions, and ask each group to give the number of extreme weather events for each conclusion. Once all the groups have passed, the table for all the events of the online interactive map should look like this:

IMPACT OF CLIMATE CHANGE	COUNT	%
More severe or more likely to occur	13	65
Less severe or less likely to occur	2	10
No discernible human induced-climate change influence	3	15
Insufficient data/inconclusive	2	10
Total number of events	20	100

The conclusion should be that the majority of attribution studies conducted by climate scientists **show a tendency of extreme weather events to be more likely to occur as a consequence of climate change.**

Note: these proportions reflect findings from scientific literature on extreme weather attribution and are sourced from Carbon Brief in 2025, and may change over time. These proportions and additional event information are available in a detailed sheet.

PART 2 (45 MIN) – IMPACTS AND SOLUTIONS

At this stage, students should have understood the concept of extreme weather event attribution and that scientists can answer the question: ***To what extent did climate change make this extreme event more likely to happen and/or as intense?***

To which there are four conclusions:
- some have been made **more frequent** and/or severe because of climate change;
- some have been made **less frequent** and/or severe because of climate change;
- some had their frequency and/or intensity **unchanged** by climate change;
- some events **cannot be attributed due to knowledge gaps or insufficient data.**

Students will now discover potential **adaptation solutions** and try to link them to the extreme weather events they described and discussed in part 1. In this part, they will use cards and then use the online interactive map only to have more event-specific information.

5. Ask students : *What do you think people, communities, or governments might do to keep themselves safe or better prepared for these extreme weather events? Can anyone try to describe what adaptation to climate change might mean in your own words?*

Adaptation to climate change means making changes to cope with the effects of a changing climate. It means taking actions **to reduce the severity of impacts of future extreme weather events.** This could include constructing more storm-resistant buildings, building dams, having more vegetation in cities, for example.

6. Form new groups by including at least one representative from each of the previous groups and invite the groups of students to propose solutions on how they could adapt to the effects of extreme weather events. They can write their own suggestions of solutions on paper.

7. Distribute the 'Adaptation to extreme weather events cards' (**WORKSHEET 1.2**), which contain only the name of the adaptation measure and ask them to link the cards to the different types of extreme weather events featured in the animation. To engage the discussion ask them to think about: *What are the relevant sectors (such as agriculture, urban planning, etc.) that will be affected by the extreme weather event? How can different sectors adapt to these changes? Based on what you learnt about projections of different extreme weather events in the previous part of the activity, what do you think are more relevant solutions? Do you think these adaptation solutions are suitable for all the regions shown in the online interactive map?*

The online animation features a world map with localisation of recent extreme weather events.

8. Among the cards, tell the students that there is an example of a false 'good solution': *Which one is it and why?*

The card 'More air conditioning and/or fans' is an example of maladaptation.

Maladaptation refers to a solution that seems effective in the short term but worsens now or in the long term. Although air conditioning provides immediate comfort, it can increase energy consumption and greenhouse gas emissions if the energy comes from fossil fuels. This exacerbates climate change and can lead to more intense heatwaves.

WRAP-UP 15 MIN

To wrap-up, ask the different groups to share with the rest of the class the links they made between the adaptation cards and extreme weather events.

Then, they can go to the online interactive map and check whether they linked each card to the correct corresponding extreme weather event. They can also look at more information on the different adaptation measures by checking the details of event-specific adaptation measures implemented or suggested.

BACKGROUND FOR TEACHERS
WHAT IS THE AIM OF CLIMATE ATTRIBUTION STUDIES?

Extreme weather attribution studies consist in studying how climate change modifies extreme weather events compared to the past. For this, scientists use observations of climate variables as well as climate model outputs.

It is important to clarify that attribution studies are not answering the question: *Did climate change cause this extreme event?* In fact, scientists cannot answer directly whether all the damages due to extreme weather events can be explained by climate change, since such impacts result from a mix of human vulnerability and natural factors. Instead, using climate models, they can evaluate the relative contributions of human and natural influences in altering the intensity and probability of the extreme weather event.

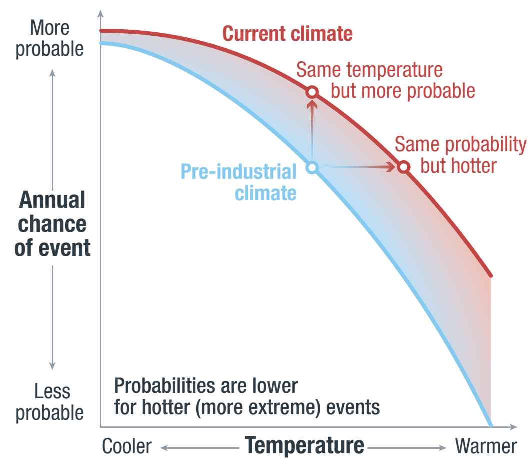
In other words, **they can answer the question: *How different is this extreme event because of climate change?*** This is done by comparing the probability of occurrence and magnitude of similar events in two different climate scenarios: the current world, with increased greenhouse gas concentrations, to a hypothetical world where greenhouse gas levels remained at pre-industrial levels.

To make this comparison, climate scientists use climate models to simulate thousands of possible outcomes for both scenarios. By running these simulations with and without changes in greenhouse gases concentration, scientists can estimate how much more likely or severe a particular extreme event has become due to climate change.

There can be four conclusions to an attribution study focusing on the frequency and/or intensity of extreme events:

- The event was made more likely and/or intense due to climate change.
- The event was made less likely and/or intense due to climate change.
- Climate change did not alter the frequency of occurrence and/or intensity of the event.
- With our current understanding and tools we cannot assess whether and how the event was influenced by climate change.

In the multimedia interactive map, there are 20 extreme weather events covering these four conclusions: it includes attribution studies of heat and cold extremes, rainfall extremes, wildfires, storms, droughts and marine heatwaves. As an example, as seen below, with a figure from the IPCC report on Extreme Weather Events, temperature extremes do not have the same intensity and frequency under a simulated world with no climate change and a world with climate change: hotter extremes are more likely to happen in a warmer world, this concept of frequency of extreme weather events is detailed in the lesson 2 of this handbook.



Changes in climate result in changes in the magnitude and probability of extremes. Example of how temperature extremes differ between a climate with pre-industrial greenhouse gases (shown in blue) and the current climate (shown in red) for a representative region. The horizontal axis shows the range of extreme temperatures, while the vertical axis shows the annual chance of each temperature event's occurrence. Moving towards the right indicates increasingly hotter extremes that are more rare (less probable). For hot extremes, an extreme event of a particular temperature in the pre-industrial climate would be more probable (vertical arrow) in the current climate. An event of a certain probability in the pre-industrial climate would be warmer (horizontal arrow) in the current climate. While a climate with pre-industrial greenhouse gas levels experiences a range of hot extremes, such events are hotter and more frequent in the current climate.

Source: 2021, IPCC AR6. Adapted from the FAQ11.3 Fig11.3. Available on the IPCC website. (https://www.ipcc.ch/report/ar6/wg1/downloads/faqs/IPCC_AR6_WGI_FAQ_Chapter_11.pdf).

Attributable increases have also been found for some extreme precipitation events, including hurricane rainfall events, but these results can vary between events. It is more complicated to assess attribution for other types of events such as wildfires, tornadoes or droughts, because of the uncertainties of climate models in simulating such events. In addition, since the comparison between both worlds (the world with climate change and without) is dependent on past observations, it can be difficult to make attribution studies in regions with poor past data records. This also explains the regional disparities in the projections section of the online interactive map. Overall, we have more information on temperature extremes because of the more consistent and robust data of past temperature records. For rain, wildfires or storms, it is more complicated to address projections with a similar level of confidence due to the lack of observations, and theoretical knowledge gaps (for instance in clouds modelling).

EXPLORING EXTREME WEATHER EVENTS

Group name ....

Assigned extreme weather event ....

1. How to characterise extreme weather events?

Question 1. Define the extreme weather event you have been assigned.

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....

Now, open the online interactive map on your computer. For the following questions, focus only on the 'Description', 'Physics' and 'Projections' sections.

Question 2. Compare your definition of the extreme weather event with the one in the online interactive map. What similarities and differences do you notice?

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Question 3. What meteorological parameters are used to measure this event? (e.g. temperature, precipitation)

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....

....

Group name ....

Assigned extreme weather event ....

2. Are extreme weather events affected by climate change?

Question 4. Watch the Video #2 – *AI to Study Extreme Events.* Write down a definition of extreme weather attribution.

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Question 5. Read the section on weather / climate attribution in the online interactive map. For each extreme weather event, there is a scientific statement indicating whether the event can be attributed to climate change or not. For your type of extreme event, fill in the table below.

ATTRIBUTION CONCLUSION	NUMBER OF EVENTS
Event more likely and/or more severe because of climate change	
Event less likely and/or less severe because of climate change	
Climate change has no influence on the event	
Scientists did not have enough data or knowledge to understand the effect of climate change on the event	

Question 6. What type of data was used to reach this conclusion? Was it only observational data? Model output data? Other data?

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The ‘Projections’ section shows results from the Intergovernmental Panel on Climate Change (IPCC), which publishes reports compiling the current state of scientific knowledge on the causes and impacts of climate change.

A climate projection shows what the climate might be like in the future. It uses powerful climate models to estimate how meteorological parameters such as temperature, precipitation etc. could change, depending on how much greenhouse gases we emit into the atmosphere. Climate models are based on physical equations that quantify global and regional climate change and its impacts, such as extreme weather events.

Question 7. What do the projections show for the different examples of your assigned extreme weather events ? Assuming that global temperatures will further rise, how will the number of your assigned extreme weather events evolve? Explain.

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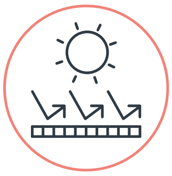
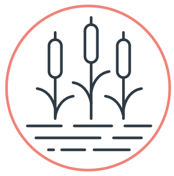
WORKSHEET 1.2 PAGE 1/2

EXTREME WEATHER EVENTS ADAPTATION CARDS

IMPLEMENTING
EARLY WARNING SYSTEMS



IMPLEMENTING
COOL ROOFS AND WALLS



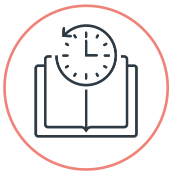
RESTORATING WETLAND

IMPLEMENTING
EVACUATION PLANS

OPENING COOLING CENTRES

MODIFYING CULTIVATED
CROPS TYPES

INSURING FARMERS

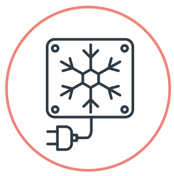


INCLUDING
TRADITIONAL KNOWLEDGE

BUILDING ELEVATED
INFRASTRUCTURES

DEVELOPING
GREEN SPACES IN CITIES

ADAPTING WORKING HOURS



IMPLEMENTING
MORE AIR CONDITIONING
AND / OR FANS

EXTREME WEATHER EVENTS ADAPTATION CARDS

LAND HEATWAVE AND COLD SPELL

DROUGHT

FLOOD

MARINE HEATWAVE

STORM AND HURRICANE

WILDFIRE

LESSON 2 THE FREQUENCY OF EXTREME WEATHER EVENTS

MAIN SUBJECTS
Mathematics
Natural Sciences

DURATION
Preparation: 10 min
Activity: 2h

AGE GROUP
11 years and up

TEACHING METHOD
Serious Game
Document Analysis

OVERVIEW
In this activity, divided into two parts, students explore the notions of distribution of the occurrence of weather events, explaining local climate. They will, in the first part, use dice to simulate a given temperature and explore the probability of the occurrence of different temperature values and the notion of extreme events based on the rarity of occurrence. In the second part, students will explore how the frequency of extreme events changes under different climate patterns (today and in the future) using dice.

KEY CONCEPTS
Distribution of Data, Frequency, Intensity, Interpretation of Data Distribution with Statistical Indicators (mean, variance, etc.), Probabilities.

LEARNING OUTCOMES
Students will be able to:
~ Learn the basics of probability.
~ Identify and describe what characterises the exceptionality of an extreme weather event in statistical terms, specifically its intensity and frequency.
~ Identify and explain how climate change affects the frequency of extreme weather events.
~ Analyse what the IPCC projections show about the frequency of extreme weather events under different global warming levels.

TARGETED SUSTAINABILITY COMPETENCE
2.1 – Systems Thinking

ASSOCIATED CLIM VIDEO
Video #1 – Extreme Events

PREPARATION & MATERIALS 10 MIN

- Two six-sided dice for each group of 3 students.
- **WORKSHEET 2.1 - PART 1** and **PART 2** to print for each student (part 1).
  For part 1: we use here the example of Brussels to illustrate the distribution of temperatures when conducting the analogy. You may want to use other cities that fit better with your school context.
- **WORKSHEET 2.2** to print for each group (part 2).

INTRODUCTION 10 MIN

Begin by asking your students: *Do you think temperature is always similar, year after year?* Guide them to recognise that while summers are generally warm and winters cold, some years are hotter or colder than average: *Over your lifetime, have all the winters you have experienced been equally cold? Have all summers been equally hot?* Explain that temperatures vary naturally – some years are warmer or cooler than the long-term average. Over a 20-year period (or their lifetime), we can calculate an average temperature, but individual years will fall above or below that average.

Can you think of a period of time where it felt unusually hot? How did it differ from a typical summer day? Was that extreme heat event close to the average summer temperature? How often do such events happen? Explain that extreme heat events (such as heatwaves) are relatively rare: the chance of experiencing one is very low.

To better understand temperature distributions over the years and the likelihood of extreme heat events to occur, under climate change, this activity uses a simple dice analogy to introduce basic concepts of probability.

PROCEDURE OF PART 1 50 MIN

MODELLING THE FREQUENCY OF EXTREME WEATHER IN A CHANGING CLIMATE

The first part of this activity aims to help students explore the distribution of data to simulate abstract data and understand the effect of increasing global mean temperature on the distribution of temperature extremes by using a simple dice analogy. Finally, students will connect this dice-rolling analogy to real temperature observations.

SIMULATION

1. Divide the students into groups of up to 3 and distribute two six-sided dice to each group along with **WORKSHEET 2.1 - PART 1**. During this part, each group will roll both dice a total of 40 times (depending on the time you have, they can roll up to 50 – see *Background for teachers* for the law of large numbers), with each roll representing one year. After each roll, they record the sum of the two dice on the table in the **WORKSHEET 2.1 - PART 1** or using a spreadsheet tool (e.g. LibreOffice Calc).

2. When they have finished, each student will draw a histogram (or bar plot) on **WORKSHEET 2.1 - PART 1** (or using a spreadsheet tool) to show how often each possible sum appears. *What is the most abundant number in each group?*

3. Each student can then circulate in the classroom to have a look at the other groups' histograms. *Do the groups have different histograms? Can they spot any similarity? Do they have similar most abundant numbers?*

4. Ask one student per group to come and add their data to a summary table of all the dice rolls from the entire class, visible to everyone on the board (or in a shared table on group computers). Then, draw a histogram on the board to represent the frequency of each dice roll sum of the classroom (from 2 to 12).

5. Discuss the histogram with the class: how is it different from their groups' histogram? Explain that you have here an average **distribution** of the whole-class experiment. You can then rapidly draw a bell curve (or use the specific option on the spreadsheet tool used) on top of the histogram. Tell your class that this curve represents **the probability distribution of the possible sums resulting from rolling two dice.** In simplified terms, it represents the likelihood of getting each possible sum.

6. Ask the students: *Which number is more likely to occur when rolling two dice: a 7 or a 10?* Spend some time exploring the concepts of probability with the histogram and the bell curve. *What do you notice when looking at the shape of the histogram?* The histogram is symmetrical, with higher bars in the middle and lower bars at the edges. This means that some sums are more likely to occur than others. Introduce the concept of the mean (or average) of a distribution, explaining that it represents the most probable result: it is the sum that happens most often when two dice are rolled.

7. Distribute **WORKSHEET 2.1 - PART 2** to the students. Explain that just like with the dice-rolling activity, we can create a similar graph to represent temperature patterns in a given place (for instance their city) in a given month, week or day of a given year. For example, using the real data presented in **WORKSHEET 2.1 - PART 2** for the 50 years of average temperature recorded in Brussels between 1850 and 1900 (before the Industrial Revolution), students will create a similar histogram to visualise temperature patterns. In this representation, instead of sums of dice rolls, the bars represent how often different temperatures occurred. Just like low or high dice sums were rare, extreme temperatures (such as very hot weather in July) appear as shorter bars at the edges of the graph. To reinforce this analogy, we will define the far ends of the histogram as extreme heat events. For instance, if we imagine that dice sums of 11 and 12 represent extreme heat events, temperatures falling in this range would correspond to exceptionally hot periods.

8. As your students should already know, climate change since the end of the 19th century has increased the global average temperature. The combined land and ocean surface temperature has increased by 1.35°C on average. On land, where the warming is more pronounced, there has been a temperature increase of 2°C on average.

Ask your students: *Do you think Brussels' temperature distribution today looks different from what it did at the end of the 19th century? If we want to continue the analogy with the dice, how can we do this? How can we mimic an additional 2°C on average?* Take some time discussing this, hearing ideas and hypotheses, to end with the idea of adding 2 to the sum of each roll.

9. Back in groups, students will now repeat the dice-rolling game but this time with a scenario representing a global warming of +2°C. Each group rolls the dice 20 times (or more) and records the results and add +2 to each sum in the second table of **WORKSHEET 2.1 - PART 1**. Next, they draw the histogram, and eventually a new bell-curve associated, with a different colour. Then, they follow the same steps as before and share their data with the class to create a collective summary table of frequency of occurrence for each sum. Draw the new histogram on the board on the same graph as that of the one without the global warming scenario. Ask the students: *What is different? What can you see?* **The mean changes and becomes higher. There is a shift in the distribution towards higher, hotter values.**

10. Remind students that every sum above 11 is considered as an extreme heat event: *How has the probability of getting a 11 or a 12 changed?* The probability of having a 11 or a 12 has increased. *What does this mean in relation to extreme heat events?* The global mean temperature increased, and as a consequence there is an increase in extreme heat events. *Were there any new possible results now? What do these represent?* New possible sums (13,14) now exist, representing even higher temperatures: as a result of global warming, unprecedented temperatures for a given time and place are recorded.

11. Now students can plot the actual observations of July temperature data for Brussels (over the past 50 years) using **WORKSHEET 2.1 - PART 2**. *What is the new mean of the distribution? Are there any new record highs or lows? Do extreme events occur more frequently?*

> **TEACHERS TIP**
> Note that you can choose to go deeper into the mathematical aspect of temperature distribution and probabilities of the occurrence of a specific event with the analogy by calculating the mean probability function, and so on (see the *Background for teachers*) and link this activity with a more theoretical mathematics activity.

WRAP-UP OF PART 1 10 MIN

Explain to your students that the game they played serves as an analogy for the shift in the average global temperature towards higher global temperatures – which is due to climate change. They have been exploring some notions of probabilities and have linked the analogy with real observed data for a given place. They have seen that higher temperatures are more likely to occur due to climate change, creating a shift in the temperature distribution. Higher global temperatures can lead to an increase in the frequency of extreme weather events, not only heatwaves, but also extreme precipitations, droughts, hurricanes, and violent storms. This is because rising temperatures cause significant changes in the water cycle (see lessons 3 and 4 on this topic).

In **WORKSHEET 2.1 - PART 2** students will place the following words on the graph where they have been drawing their histograms: **'Shift towards a hotter climate', 'New climate distribution', and 'Old climate distribution'.** Ask them to identify the old and new means in both distributions.

BACKGROUND FOR TEACHERS
HOW TO SIMULATE THE PROBABILITY OF EXTREME WEATHER EVENTS

An extreme weather event is a rare event by definition, in relation to the average weather conditions in a given place for a given time of year. Thus, we can work with students on the definition of a rare event and make mathematical analogies for the chance of having a rare event based on probabilities of occurrence.

THE LAW OF LARGE NUMBERS

The law of large numbers plays a central role in probability theory and statistics. It states that if you repeat an experiment independently a large number of times and then average the results, the outcome will approach the expected value as the number of trials increases.

Mathematically, let X_i represent the result of each trial i of the same experiment repeated independently. If we repeat an experiment for n trials, the average outcome is given by: $(X1 + X2 + \ldots + Xn)/n$. As n (the number of trials) increases, the average result gets closer to the true probability or expected value.

In this activity, the example using a fair die illustrates this law in a straightforward way: rolling it a large number of times allows us to estimate the probability of getting a specific number as the frequency of outcomes converges to its probability the more rolls we make. In more practical real-world examples it is harder to give an accurate probability since we often do not have enough data. This is the case for the occurrence of extreme weather events. As such, tools like climate models simulating weather patterns over long periods of time will complement historical data to create sufficiently large datasets to **approximate the frequency of extreme weather events.**

The probability of an event occurring is a measure of the likelihood that a specific event will happen, expressed as a number between 0 (the event will never occur) and 1 (the event will certainly occur). The greater the number, the higher the chance of the event occurring.

For example, let's take a fair six-sided die. We can define an event as E = 'rolling a 3'. What is the probability of this event occurring? In other words, what is the chance of rolling a 3? The probability P of an event E to occur is: $P(E) = 1/6 \approx 0.1667$ (or 16.7%). This indicates that there is a 1/6 (or 16.7%) chance of rolling a 3 on a single roll of a fair six-sided die.

PROCEDURE OF PART 2 40 MIN

MODELLING CHANGES IN FREQUENCY AND INTENSITY OF 10-YEAR EXTREME WEATHER EVENTS DUE TO CLIMATE CHANGE

In part 2, yet through another dice game and with additional data from the IPCC, students will learn how climate change affects 10-year extreme weather events—events that were statistically expected to occur once every 10 years in the past (during the pre-industrial period: 1850-1900), such as significant heatwaves or storms (see *Background for teachers* below for more context). This activity highlights the urgency of keeping global warming below 1.5°C, as outlined in the Paris Agreement, to reduce the likelihood of such extreme weather events.

SIMULATION

1. Divide your class into several small groups (2 to 4 students), each group being one of the following team:

TEAM 1: Today's climate
TEAM 2: 1.5°C global warming
TEAM 3: 2°C global warming
TEAM 4: 4°C global warming

2. Distribute one six-sided die to each team. They will repeat at least two rounds of 10 dice rolls for each global warming level to gather a reasonable amount of data.

3. Each round represents a decade, with each individual roll representing a different year.

The occurrence of an extreme heat event is defined as follows – it is different for each team:

- **Team 1 (today's climate):** an extreme heat event occurs when rolling a **5 or 6.**
  Note: While an extreme heat event occurred once in a decade in pre-industrial times, it occurs three times in a decade today. This means that the probability that such an event occurred/occurs in a decade increased from 10% to 30%.

- **Team 2 (+1.5°C):** an extreme heat event occurs when rolling a **4, 5, or 6.**
  Note: In reality, an extreme heat event that occurred only once during a 10-year period in the pre-industrial era will likely occur 4 times (40% probability) during a 10-year period under a global warming of 1.5°C. However, this has been adjusted to a 50% probability in this activity to account for the limitations of using a single die.

- **Team 3 (+2°C):** an extreme heat event occurs when rolling a **3, 4, 5 or 6.**
  Note: While an extreme heat event occurred once in a decade in pre-industrial times, it occurs six times in a decade in a +2°C scenario. This means that the probability that such an event occurred/occurs in a decade increased from 10% to 60%.

- **Team 4 (+4°C):** an extreme heat event occurs when rolling a **2, 3, 4, 5, or 6.**
  Note: In reality, an extreme heat event occurring only once during a 10-year period in the pre-industrial period, will likely occur 9 times (90% probability) during a 10-year period under a global warming of 4°C. However, this has been adjusted to an 83% probability in this activity to account for the limitations of using a single die.

4. Now, each group calculates the frequencies of the occurrence of an extreme heat event for each global warming level (today's climate, +1.5°C, +2°C, and +4°C) using the results from each team. Dividing the total number of extreme heat events in a decade by the total number of dice rolls yields the probability that such an event occurs in a decade. They will present the result in a table with three columns (see the example in the table below for your reference).

The students then compare the results with the figure on **WORKSHEET 2.2**, which presents the IPCC's results on how the frequency of 10-year heat extreme weather events changes for these three global warming levels.

TEAM	N° OF EXTREME WEATHER EVENTS		PROBABILITY OF OCCURRENCE
	1ST ROUND	2ND ROUND	
Present	3	3	0.3
1.5°C	4	5	0.45
2°C	7	8	0.75
4°C	9	9	0.9

5. Ask students to add a column to the table from step 4 for the intensity of a 10-year extreme heat event for the different global warming levels using the information from **WORKSHEET 2.2**.

WRAP-UP OF PART 2 10 MIN

To conclude, ask the students to interpret their results: *How does the probability of occurrence of heat extremes evolve as global warming increases? What does this mean?* The expected answer is that heat extremes are becoming more frequent with increasing global warming levels. *Do you find it surprising that hot extremes are more likely to occur with higher temperatures? Why or why not? What do you notice about how the intensity of extreme weather events changes as global temperatures increase?*

Now that they've explored how global warming affects the frequency and intensity of extreme weather events, encourage them to think of the bigger picture by asking: *In what ways do you think the increased intensity and frequency of extreme weather events could affect ecosystems and communities? How might these changes influence our daily lives?*

Finally, end on a positive note by asking what actions we can take to reduce the frequency and intensity of extreme weather events in our communities. You can present them with local examples or encourage them to search on their own (this can be done by looking at the solutions part of the animation on extreme weather events, which can be found on the OCE website).

For instance, for 10-year agricultural and ecological droughts in drying regions only, the sides of a fair six-sided die roll should be attributed as follows (again, the numbers have been adjusted for simplicity):

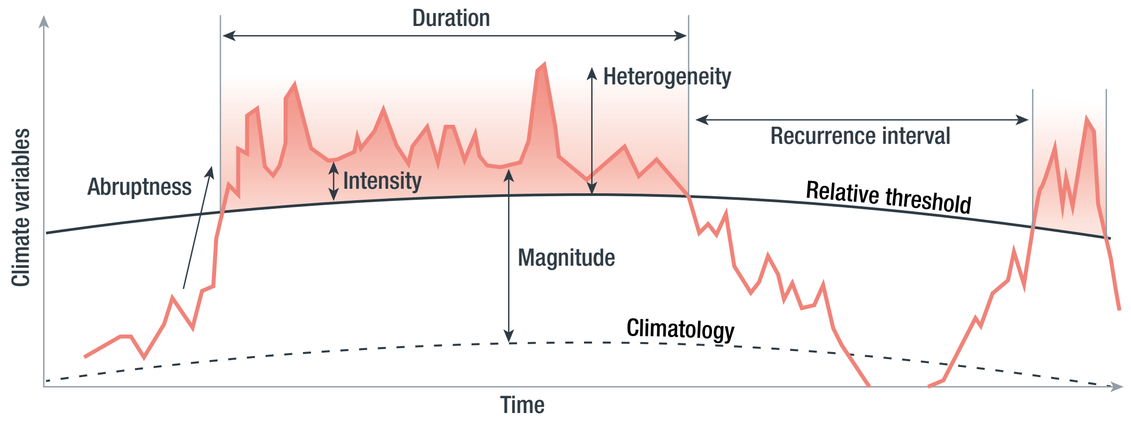
- Today's climate: The IPCC states that a drought event that occurred once per decade between 1850 and 1900 occurs 1.7 times more often today. This means that a drought occurs if the dice roll yields a 6 (1/6 ≈ 0.167).

- At a global warming of 1.5°C, the IPCC states that a drought event that occurred once per decade between 1850 and 1900 will occur 2 times more often. This means that a drought occurs on rolls of 5 or 6 (2/6 ≈ 0.3).

- At a global warming of 2°C, the IPCC states that a drought event that occurred once per decade between 1850 and 1900 will occur 2.4 times more often. This means that a drought occurs on rolls of 4, 5, or 6 (3/6 ≈ 0.5).

- At a global warming of 4°C, the IPCC states that a drought event that occurred once per decade between 1850 and 1900 will occur 4.1 times more often. This means that a drought occurs on rolls of 3, 4, 5, or 6 (4/6 ≈ 0.6).

BACKGROUND FOR TEACHERS
NUMERICAL CHARACTERISTICS OF EXTREME EVENTS



Different metrics to describe extreme weather events

Source: Adapted from: Gruber, N., Frölicher, T. L., Lachkar, Z., Long, M. C., Vogt, M., & Paynter, D. (2021). Marine heatwaves under global warming. Nature.

In this activity, we saw how climate change impacts extreme weather events in two key ways: through changes in their frequency and their intensity, both of which are increasing as a result of climate change. Although not tackled in this activity, the duration is also affected by climate change, with evidence showing that certain extreme weather events – such as heatwaves and droughts – are lasting longer due to climate change (IPCC, 2021).

A FREQUENCY PERSPECTIVE: 10-YEAR EXTREME WEATHER EVENTS

The IPCC defines a 10-year extreme weather event as an event that is so exceptional that, on average, in pre-industrial times (1850-1900), it occurred only once per decade. For instance, a 10-year extreme heat event is characterised by daily maximum temperatures over land that were exceeded, on average, once a decade during the pre-industrial period (1850-1900), as illustrated in the figure of the **WORKSHEET 2.2**. As demonstrated in the second part of this activity, the recurring interval between extreme weather events decreases, which means that their frequency increases. For example, while an extreme heat event only occurred once per decade between 1850 and 1900, it occurs three times as often today – the probability of an extreme heat event thus increased from 10% to 30%. In a 1.5°C scenario, the probability increases to 40%.

Alongside this increase in frequency, relative thresholds are changing, with events that were previously regarded as extreme becoming more common due to shifting climatologies (or climate baselines, i.e long-term averages of climate variables).

AN INTENSITY PERSPECTIVE: DIFFERENT DEFINITIONS OF THRESHOLDS

Various approaches are used to define extreme weather events, typically based on the determination of relative thresholds. This can be done in two main ways (as seen in Figure 2. below):

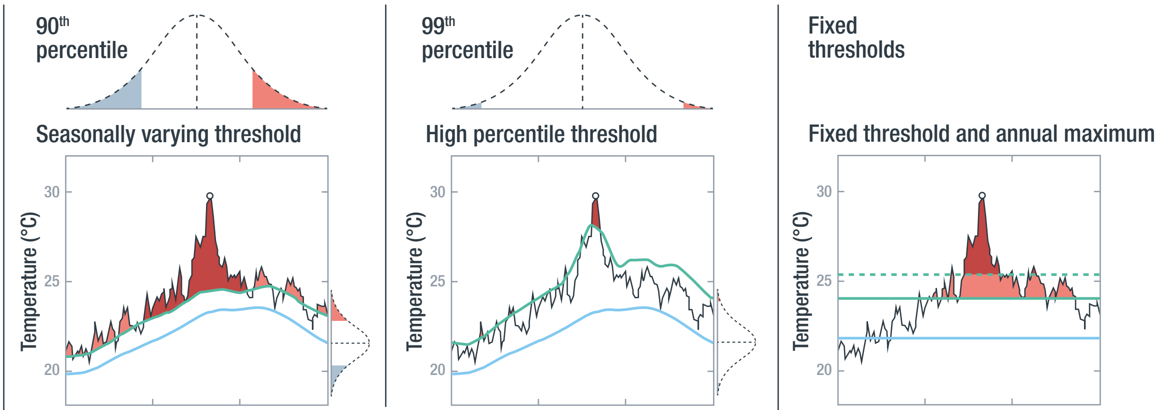
Percentile-based thresholds: for example, conditions exceeding the 90th or 99th percentiles are considered extreme (as shown in the left and middle plots below) .

Fixed absolute thresholds: for instance, a temperature of 35°C is classified as a hot day (as seen in the right plot below). Such thresholds are usually based on metabolic processes, but the amplitude of such thresholds can vary slightly by region depending on factors such as health conditions, better body adaptation to heat events, etc. This is why considering percentile-based thresholds can be more appropriate to take into consideration regional differences. In the percentile approach, the 90th percentile is computed regionally for the reference period, which means that the threshold is regionally adapted. In some other cases, however, absolute thresholds are 'globally uniform', this is the case for heat stress thresholds, for example, which take into consideration the compounding effects of humidity and heat: the maximum of 35°C of a heat stress index known as wet-bulb temperature has a fixed thermodynamic limit above which the body can no longer cool itself.

In both cases, conditions above these thresholds are considered extremes.

[...]

[...]



Assessments of the impacts at the ecosystem level have often taken a **relative threshold approach** because it is considered to cope with the **normal range of variability.**

Assessments of the impacts at **organism level** have often used **absolute thresholds** that reflect specific **limits of metabolic processes.**

Different ways to describe extreme weather events

Source: Adapted from: Oliver, E. C. J., Donat, M. G., Burrows, M. T., Moore, P. J., Smale, D. A., Alexander, L. V., Benthuysen, J. A., Feng, M., Sen Gupta, A., Hobday, A. J., Holbrook, N. J., Perkins-Kirkpatrick, S. E., Scannell, H. A., Straub, S. C., & Wernberg, T. (2020). Projected changes in marine heatwaves and their impacts on ecosystems. Nature Climate Change.

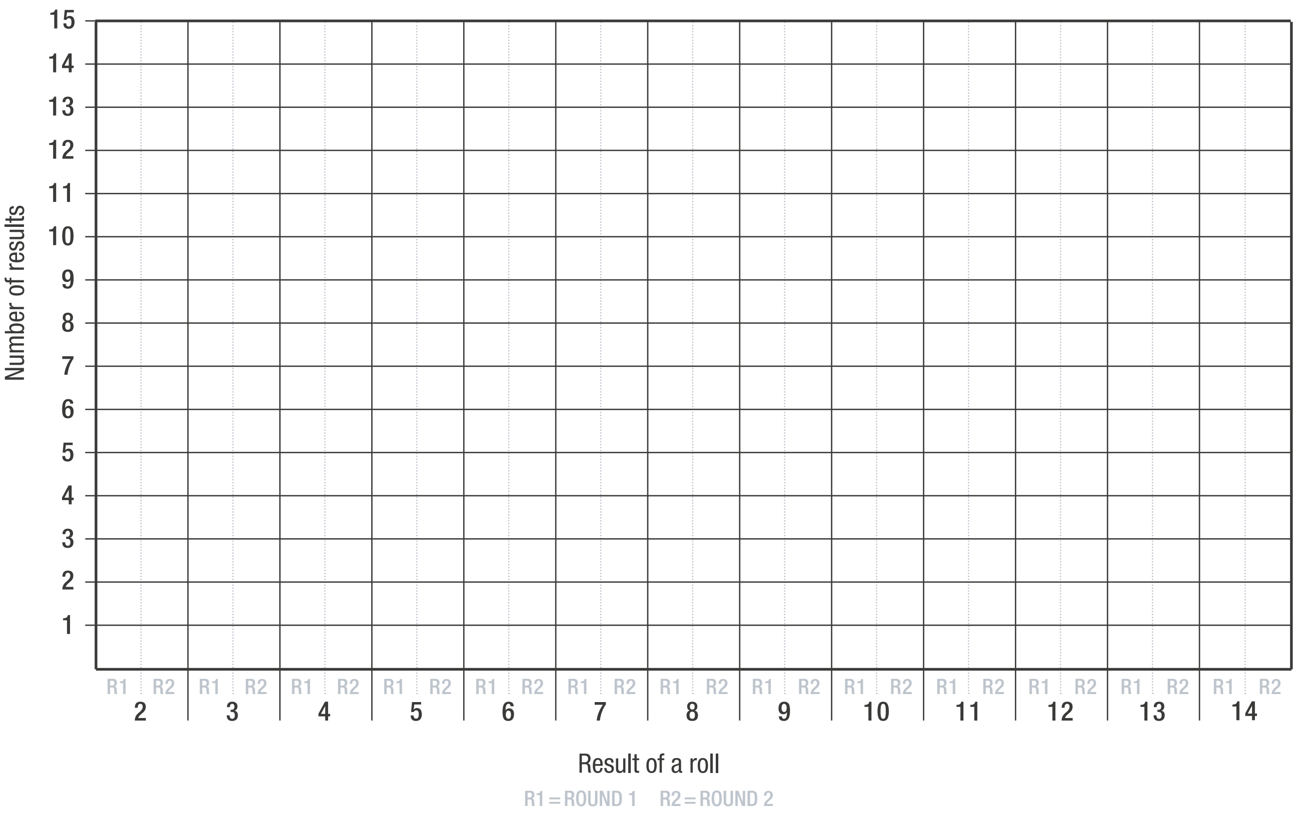
WORKSHEET 2.1 PART 1
DICE ROLLS SIMULATION

ROUND 1: TWO 6-SIDED DICE

Roll	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20
Result																				
Roll	21	22	23	24	25	26	27	28	29	30	31	32	33	34	35	36	37	38	39	40
Result																				

ROUND 2: TWO 6-SIDED DICE ADDING 2 TO THE RESULT

Roll	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20
Result																				
Roll	21	22	23	24	25	26	27	28	29	30	31	32	33	34	35	36	37	38	39	40
Result																				



WORKSHEET 2.1 PART 2

DISTRIBUTION OF TEMPERATURE OBSERVATIONS IN BRUSSELS (BELGIUM)

Here are reported observed average temperatures for the month of July in Brussels (Belgium) for 50 years at the end of the 19th century, before the Industrial Revolution with little human influence on climate (pre-industrial climate) and for 50 years from now with human-induced climate change (present climate).

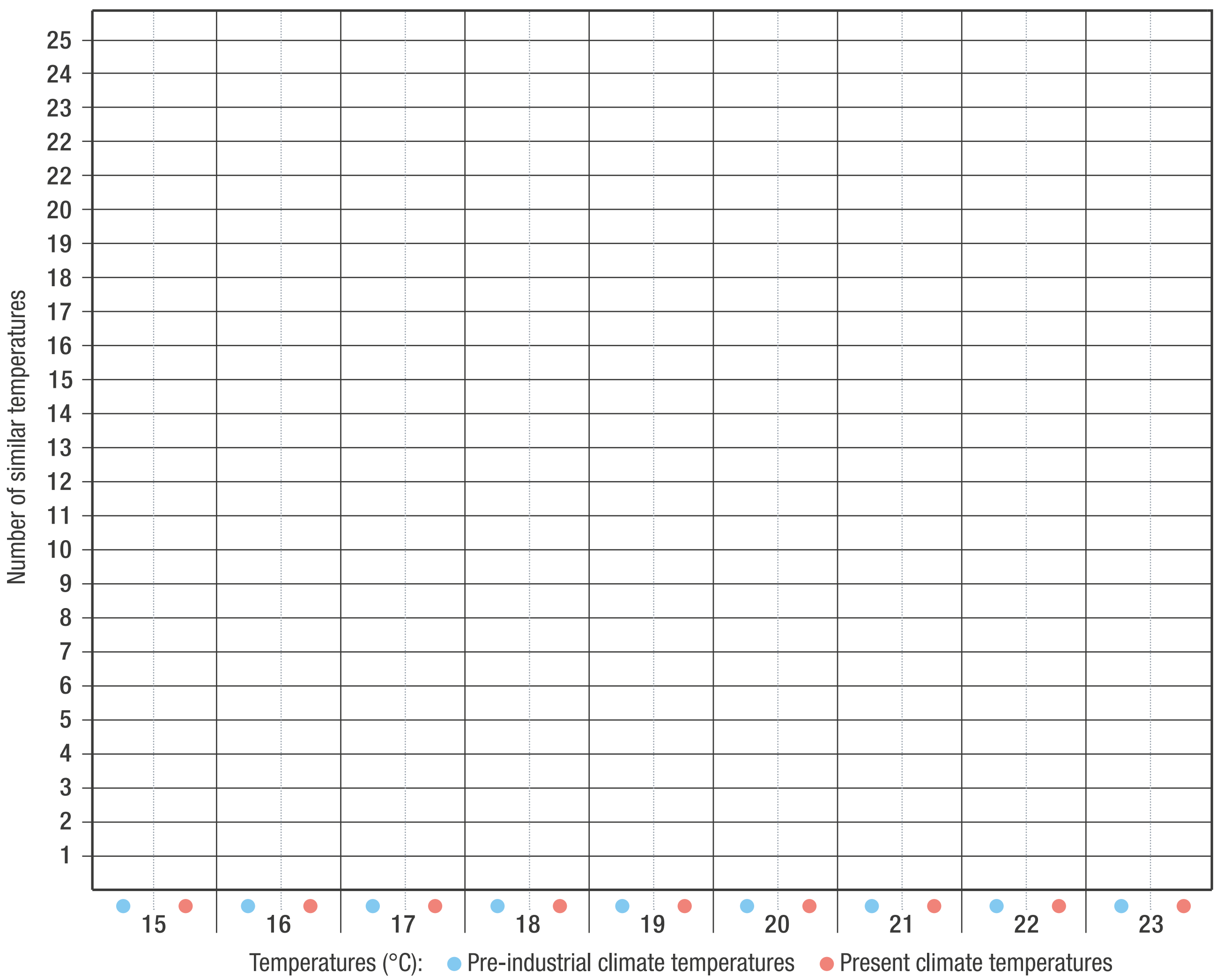
PRE-INDUSTRIAL CLIMATE

From 1850 to 1875	Year	1850	1851	1852	1853	1854	1855	1856	1857	1858	1859	1860	1861	1862	1863	1864	1865	1866	1867	1868	1869	1870	1871	1872	1873	1874	1875
	Temperature (°C) 🔵	17	17	18	19	17	17	19	18	17	18	17	17	17	15	15	16	16	17	16	16	18	17	17	16	16	17
From 1876 to 1900	Year	1876	1877	1878	1879	1880	1881	1882	1883	1884	1885	1886	1887	1888	1889	1890	1891	1892	1893	1894	1895	1896	1897	1898	1899	1900	
	Temperature (°C) 🔵	16	17	16	17	16	19	17	16	18	16	17	15	16	17	18	17	17	17	16	16	17	18	17	15	17	

PRESENT CLIMATE

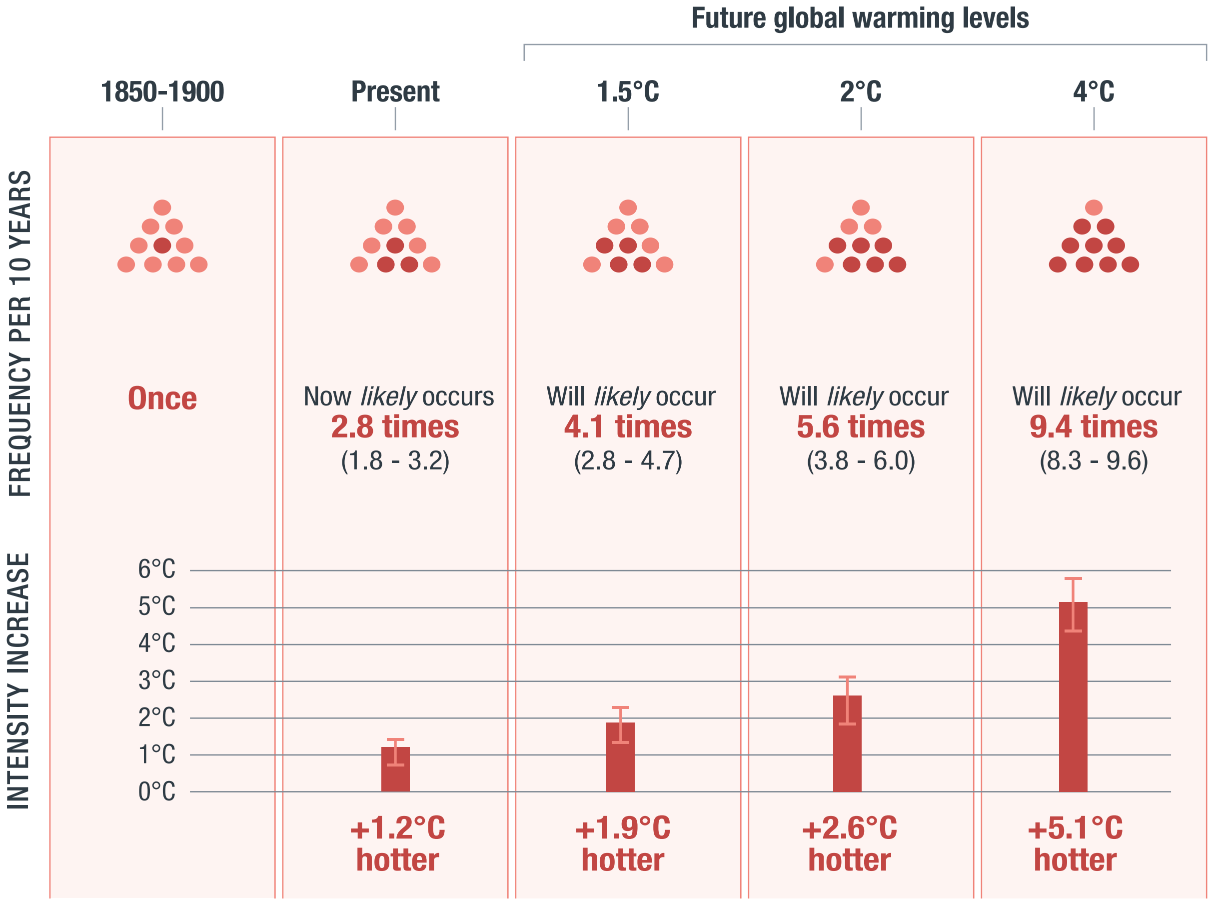
From 1975 to 2000	Year	1975	1976	1977	1978	1979	1980	1981	1982	1983	1984	1985	1986	1987	1988	1989	1990	1991	1992	1993	1994	1995	1996	1997	1998	1999	2000
	Temperature (°C) 🔴	19	18	20	20	20	18	19	19	20	18	19	18	18	20	21	19	20	19	18	19	21	19	21	16	20	19
From 2001 to 2025	Year	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019	2020	2021	2022	2023	2024	2025	
	Temperature (°C) 🔴	19	19	17	19	19	21	18	18	18	20	19	18	20	19	20	18	19	19	17	19	19	19	19	17	18	

Source: Data extracted from Meteostat database (https://meteostat.net/fr/).



10-YEAR EVENT

Frequency and increase in intensity of extreme temperature events that occurred **once in 10 years** on average **in a climate without human influence.**



Source: Adapted from: Figure SPM.6 in IPCC, 2021: Summary for Policymakers. In: Climate Change 2021: The Physical Science Basis. Contribution of Working Group I to the Sixth Assessment Report of the Intergovernmental Panel on Climate Change [Masson-Delmotte, V., P. Zhai, A. Pirani, S.L. Connors, C. Péan, S. Berger, N. Caud, Y. Chen, L. Goldfarb, M.I. Gomis, M. Huang, K. Leitzell, E. Lonnoy, J.B.R. Matthews, T.K. Maycock, T. Waterfield, O. Yelekçi, R. Yu, and B. Zhou (eds.)]. Cambridge University Press.

LESSON 3 THE PHYSICS OF EXTREME WEATHER EVENTS

MAIN SUBJECTS
Physics
Chemistry
Natural Sciences
Geography

DURATION
Preparation: 2h
Activity: 2h

AGE GROUP
11 years and up

TEACHING METHOD
Inquiry-based
Document Analysis

OVERVIEW
Through experiments, students will understand that global warming has led to an increased frequency and / or intensity of most extreme weather events since pre-industrial times. Using documents taken from the IPCC, they will understand that this will in all likelihood continue in the future. Regional changes in the intensity and frequency of extreme events generally correlate with global warming. This is particularly evident for temperature extremes, heavy precipitation and droughts in certain regions. However, the intensity and frequency of extreme cold events are expected to decrease. Mitigating climate change would limit the frequency of extreme weather events and their intensity.

KEY CONCEPTS
Clausius–Clapeyron Relation, Compound Events, Confidence Level, Evaporation, Evapotranspiration, Extreme Weather Events (heavy precipitation, floods, droughts, extreme cold events, storm surges, severe storms), IPCC, Model, Scientific Experiment.

LEARNING OUTCOMES
Students will be able to:
~ Use models as analogies of reality, helping them to make projections on how the future climate will look like.
~ Establish a link between global warming and the increase in certain extreme weather events since pre-industrial times.
~ Understand that as the atmosphere warms, the maximum amount of moisture it can hold increases: this is one of the main causes of the increase in certain extreme events, such as heavy precipitations and storms.
~ Discover how mitigating climate change may reduce the intensity of extreme weather events.

TARGETED SUSTAINABILITY COMPETENCE
2.1 – Systems Thinking

ASSOCIATED CLIM VIDEOS
Video #1 – Extreme Events
Video #3 – Heatwaves and Droughts
Video #5 – Severe Convective Storms
Video #6 – Cold Events
Video #7 – Compound Events

PREPARATION & MATERIALS 2 HOURS

- **WORKSHEET 3.1** to print for each team of four students.
- **WORKSHEETS 3.2** to **3.6** to print. Each team will be assigned a different worksheet (up to five teams in total).
- For each experiment, the required materials are listed in **WORKSHEETS 3.2** to **3.6**. Take time to prepare and test materials and experiments.

TEACHER TIP
In this lesson, we propose a variety of document difficulties that you may use in order to address diverse student needs through differentiated instruction. Some documents are easier to understand, others are designed for more advanced students.

The different levels are:

TRAINEE CURIOUS EXPERT

INTRODUCTION 15 MIN

1. Students learnt in Lesson 1 that there are different types of extreme weather events. Ask them to choose one type of extreme event; it could be extreme temperatures, forest fires, heavy precipitation, severe storms, floods, and so on. Have them explain how they think climate change has affected that event. They should write down all their hypotheses, such as:

- Severe storms could become more devastating due to climate change.
- Severe storms could become less devastating due to climate change.
- Severe storms could become more (or less) frequent due to climate change.
- Severe storms could become more (or less) intense due to climate change.

2. To validate the hypotheses related to severe storms, you can watch Video #5 on severe convective storms. Afterward, ask your students whether they think climate models can help verify their hypotheses. According to the researcher, models predict an increase in the intensity of severe storms due to climate change.

BACKGROUND FOR TEACHERS
WHAT IS A MODEL?

Depending on the level and the competences of your students, it could be very useful to remind them what a model is. Show pictures (or scale models) of three to five items: for instance, a plastic dinosaur, a diagram of the life cycle, a weather forecast, a GPS device... *What do these items have in common?* Guide them towards the word 'model'. *What is a model? More specifically, what is it used for?*

Many possible answers:

FACILITATING AN OBSERVATION

- Model as a representation of a living being (e.g. dinosaur, flower, etc.)
- Scale model (solar system, lithospheric plates)
- Grouping information in a diagram (flowchart, graph, pie chart)
- Substitute for a standard living organism (Drosophila in biology, swine in surgery)
- Statistical analysis (poll, probabilities)

PRESENTING CLEARLY

- Theoretical model (Mendel's laws of inheritance)
- Diagram (water cycle)

APPLYING THEORY FOR PREDICTIONS

- Mathematical model (Malthusian population growth, consumer rational behaviour)
- Heuristic model (GPS)
- Computational model (weather forecast, flight simulator)

Collectively, the class comes up with a definition of a 'model': a simplified representation of reality that can be used to understand complex problems. It can also be used for making projections (of future climate, for example). To verify their hypotheses, and more generally to study the climate and its evolution, one can use models.

Using models has many advantages, but it also has its limitations. A model cannot represent the full complexity of reality. Climate scientists develop models and compare them with real-world data to assess their accuracy.

For more information on models and how they can be used in the classroom, please refer to Lesson 'Models to represent reality' of the Climate Models teacher's handbook.

3. During this activity, students will focus on one extreme event and take on the role of an expert in that event:

TEAM 1 – **WORKSHEET 3.2: ATMOSPHERIC SCIENTISTS**
HEAVY RAIN

TEAM 2 – **WORKSHEET 3.3: HYDROLOGISTS**
LAND FLOODS

TEAM 3 – **WORKSHEET 3.4: ECOLOGISTS**
DROUGHTS

TEAM 4 – **WORKSHEET 3.5: METEOROLOGISTS**
EXTREME COLD EVENTS

TEAM 5 – **WORKSHEET 3.6: OCEANOGRAPHERS**
STORM SURGES

Each team will have three tasks:
i. Design a model of an extreme weather event and carry out an experiment related to this event.
ii. Use this model to explore how climate will change when temperatures will increase further.
iii. Compare the results with the findings compiled in the latest IPCC report.

PROCEDURE 1 H 30

4. Students can use any material to design their model and let their creativity run wild! To assist them in building a scientifically sound model, you may distribute **WORKSHEET 3.1,** which can also be used to assess their work.

TEACHER TIP

If the models they design are too complex, if the necessary materials are not readily available, or if students are struggling to come up with ideas, you can download the teacher's sheets to visualise the expected experimental set ups.

5. Distribute one of the **WORKSHEETS 3.2** to **3.6** to each team. The materials in the worksheets should be easily accessible and cheap. Students will begin working on the three tasks outlined in step 3.

TEACHER TIP

During the various stages of inquiry-based learning, it's important to give regular feedback to encourage learning and progress. To help you, you may use the 'Suggested Responses for Each Expert Team'.

WRAP-UP 15 MIN

Once the experiments have been designed and carried out and the questions answered, it's time to move on to the necessary phase of structuring knowledge. This can be done with the whole class. The scientific concepts that were studied in this lesson should be clearly formulated (see 'Key Concepts', on the first page of this lesson and the 'Glossary', page 78 for definitions).

TEACHER TIP

The knowledge structuring phase of the inquiry-based approach: a fundamental step in inquiry-based learning is structuring the knowledge that the students have acquired. They establish links between the different concepts and give a common answer to the initial question.
The teacher should help the students formulate clear and simple concepts.
At the end of the lesson, the teacher evaluates the activities done in this lesson together with the students: *what was the knowledge and the skills they built?*

As of today's state of research, it is an established fact that global warming has led to an **increased frequency and/or intensity of some weather extremes since pre-industrial times.** This will very likely **continue in the future.**

Regional changes in the intensity and frequency of extreme events generally **correlate with global warming.** This is particularly evident for temperature extremes, heavy precipitation and droughts in certain regions. On the other hand, the intensity and frequency of **extreme cold events are expected to decrease** with global warming.

Since the **IPCC is a very reliable source on the state and evolution of the climate,** it is essential to take this information into account. **Models serve as analogies for reality, allowing us to make projections.** Mitigating climate change would **limit the frequency of extreme events and their intensity.** Take the opportunity to introduce the concept of mitigation: human intervention to reduce global warming by reducing greenhouse gas emissions or by enhancing greenhouse gas sinks. **Mitigation is one of the solutions to tackle each extreme event.**

WORKSHEET 3.1

USING A MODEL IN THE CLASSROOM

An analog model uses an object, a system, or a process to represent another, more complicated, object, system, or process. **A digital model,** on the other hand, models the real world (an object, a system, or a process) using measured data and the laws of physics, mathematics, etc. Models can be useful **tools to understand** the evolution of the Earth's climate, for example, but they also **have limitations.** Models **cannot represent the full complexity of reality.**

Climate models are digital models and allow us to make projections about future trends (e.g. projections of how high the global temperature will be at the end of the century). Climate models are also used to **understand today's climate and its impacts on societies, the environment, etc.** With increasing computer performance, the models are continually evolving, integrating additional parameters, and increasing the resolution (which allows scientists to make better projections for regional climates).

Question For each skill, draw the appropriate smiley in the self-assessment column depending on whether you feel confident with one or several elements of a correct model construction and communication.

3 validated elements = 2 validated elements = 1 validated element = No complete element =

ELEMENT FOR AN ANALOG MODEL USED TO SIMULATE AN EXTREME WEATHER EVENT

SKILL	ELEMENTS	SELF-ASSESSMENT
Use tools and methods to learn	**1.** The model represents reality, i.e. a natural phenomenon or object. **2.** The model can be used to carry out an experiment by changing a single parameter. **3.** The model can predict events.	
Scientific communication	**1.** The communication is clear and comprehensible, the vocabulary and grammar are precise and correct. **2.** The communication is complete. **3.** The title, as well as figure and diagram captions, mention the studied extreme weather event.	
Understand consequences of climate change	**1.** The model can be used to make predictions/projections for the future. **2.** The model can be used to conduct experiments to understand how climate change affects extreme weather events. **3.** The experiment can be used to demonstrate that mitigating climate change can reduce its impacts.	

STEP 1 **Set up a model to simulate an extreme weather event (heavy rain) and carry out an experiment**

- Use some of the materials listed below to build your model of heavy precipitation.
- Underline in green the equipment needed to measure a physical quantity related to the event.
- Set up the experiment and take measurements: for example, measure the water level in the glass every five minutes.
- Draw a diagram of your experiment.

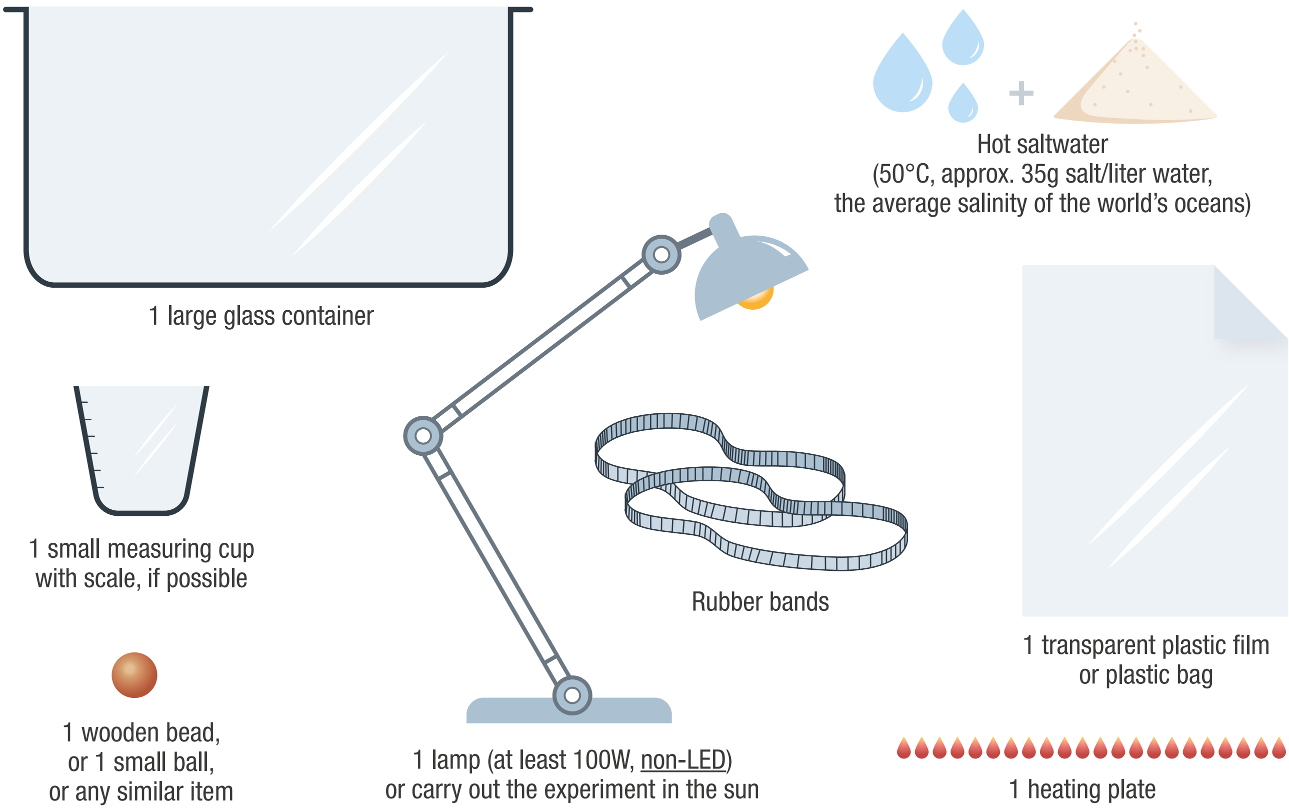
STEP 2 **Use your model to carry out an experiment simulating a changing climate**

- Empty the graduated glass. Simulate an increase in ocean temperature by turning on the heating plate.
- What parameter did you change between step 1 and step 2?
- Underline in red the equipment needed to simulate global warming.
- Which step represents the test? The control?
- What are the results? Did your experiment allow you to verify your hypothesis? If so, has your hypothesis been confirmed? What can you conclude?
- Complete the diagram of your experiment.

STEP 3 **Compare and explain how your experimental results differ from / match with scientific results compiled by the IPCC** (see **DOCUMENTS 1** and **2**)

SETTING UP A MODEL OF HEAVY RAIN

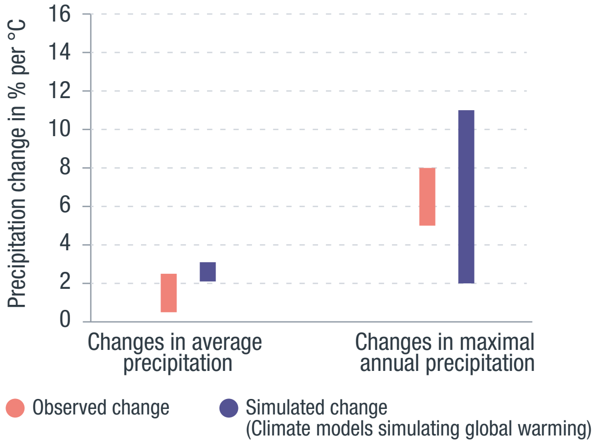
EQUIPMENT THAT CAN BE USED



DOCUMENT 1. ESTIMATES OF INCREASED PRECIPITATION WITH GLOBAL WARMING

In the graph on the right, precipitation change is presented as a percentage per degree Celsius of global warming. Observed changes are based on measured historical data of precipitation change from 1988 to 2014, while simulated changes are based on climate models. For example, the diagram reads: if global warming increases by 1°C, the average precipitation increases by between 0.5 and 2.5°C (real data) and between 2 and 3°C (simulated data).

Studies show that the maximum amount of moisture the atmosphere can hold increases by approximately 7% for every 1°C of global warming, following a scientific law called the Clausius–Clapeyron relation, which states that warmer air can hold more water vapor.
However, the increased rainfall is not only due to the increased amount of water vapour in the atmosphere, it is also due to dynamic effects, meaning that the rain falls onto a smaller surface area.



Source: Adapted from IPCC, 2021, Assessment Report 6, WG1 (The Physical Science Basis), ch8 Water Cycle Changes, Figure 8.4. Published on the IPCC website (https://www.ipcc.ch/report/ar6/wg1/figures/chapter-8/figure-8-4).

DOCUMENT 2. INFORMATION COMPILED BY THE IPCC ON HEAVY RAIN

The frequency and intensity of heavy rain events have likely increased at the global scale over a majority of land regions with good observational coverage.

Heavy rain is expected to become more frequent and intense with increasing global warming. At a global warming level of 4°C relative to pre-industrial levels, very rare heavy rain events (e.g. those occurring once in 10 years or more) are projected to become more frequent and intense than in the recent past, a change that is virtually certain to occur on a global scale and across all continents.

Source: Adapted from IPCC, 2021, Assessment Report 6, WG1 (The Physical Science Basis), ch11, Executive Summary.
Published on the IPCC website (https://www.ipcc.ch/report/ar6/wg1/chapter/chapter-11/)

WORKSHEET 3.3 PAGE 1/2

TEAM 2: HYDROLOGISTS

CURIOUS

STEP 1 Set up a model to simulate an extreme weather event (floods) and carry out an experiment

→ Use some of the materials listed below to build your model of floods.
→ Underline in green the equipment needed to measure a physical quantity related to the event.
→ Set up the experiment and take measurements for 10 minutes.
→ Draw a diagram of your experiment.

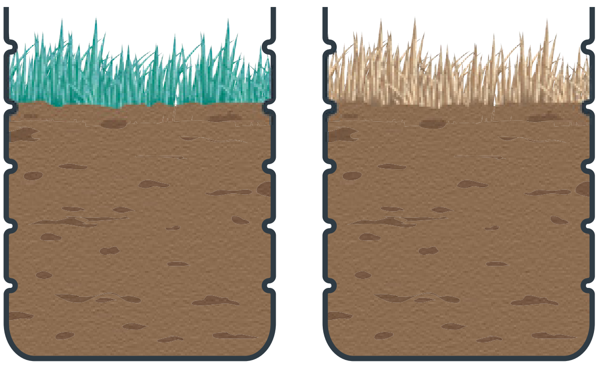
STEP 2 Use your model to carry out an experiment simulating a changing climate

→ Use dry grass or hay to simulate a drought caused by climate change.
→ What parameter did you change between step 1 and step 2?
→ Underline in red the equipment needed to simulate global warming.
→ Which step represents the test? The control?
→ What are the results? Did your experiment allow you to verify your hypothesis? If so, has your hypothesis been confirmed? What can you conclude?
→ Complete the diagram of your experiment.

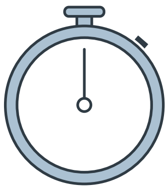
STEP 3 Compare and explain how your experimental results differ from / match with scientific results compiled by the IPCC (see **DOCUMENTS 3** and **4**)

SETTING UP A MODEL OF LAND FLOODS

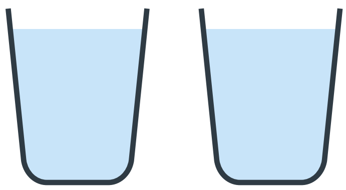
EQUIPMENT THAT CAN BE USED



2 plastic bottles cut in half horizontally
and filled with grass-covered soil:
~ One bottle with freshly cut grass (well-watered)
~ One bottle with dry grass or hay



1 stopwatch



2 glasses filled with water,
to be turned over quickly

DOCUMENT 3. FLOODS CAN BE COMPOUND EVENTS

Floods especially affect arid land. There are different types of floods: pluvial, flash, fluvial, storm surge, coastal floods etc. – depending on where they occur and how long they last, on the main causes (rainfall intensity, duration and land use) and on the processes involved (runoff, soils being saturated with water, etc.).

Sometimes, several extreme weather events can occur simultaneously shortly one after the other: a heatwave, followed by a drought and wildfires; or heavy rain followed by floods. **A combination of such extreme weather events is called a compound event.** A compound event can have impacts that are much stronger and more destructive than the impacts of each extreme event alone.
Compound events can be:
~ extremes occurring simultaneously or **one after another;**
~ extremes occurring **in the same place;**
~ **combinations of events** that are not themselves extreme but **that lead to an extreme event.**

Source: Adapted from IPCC, 2021, Assessment Report 6, WG1 (The Physical Science Basis), Ch. 11.
Published on the IPCC website (https://www.ipcc.ch/report/ar6/wg1/chapter/chapter-11/)

DOCUMENT 4. NUMBER OF EXTREME FLOODS MODELLED FOR DIFFERENT LEVELS OF GLOBAL WARMING

The floods considered here are simulated to take place in various basins in India. A basin is an area of land drained by watercourses that converge into a common watercourse.

RATE OF GLOBAL WARMING	+1°C (PRESENT-DAY)	+1.5°C	+2°C	+3°C AND HIGHER
Number of extreme floods for each basin over the period considered (2020-2060)	More than 3 floods per basin in 40 years	More than 5 floods per basin in 40 years	Between 2 and 6 floods per basin in 40 years	More than 12 floods per basin in 40 years

Source: Adapted from IPCC, 2021, Assessment Report 6, WG1 (The Physical Science Basis), Ch. 11.2, Table 1 | Examples of changes in low-likelihood, high-impact extreme conditions (single extremes, compound events) at different global warming levels.
Published on the IPCC website (https://www.ipcc.ch/report/ar6/wg1/chapter/chapter-11/).

WORKSHEET 3.4 PAGE 1/2

TEAM 3: ECOLOGISTS

EXPERT

STEP 1 Set up a model to simulate an extreme weather event (agricultural and ecological droughts) and carry out an experiment

- → Use the materials listed here to build your model of agricultural and ecological droughts.
- → Underline in green the equipment needed to measure a physical quantity related to the event.
- → Set up the experiment and take measurements.
- → Draw a diagram of your experiment.

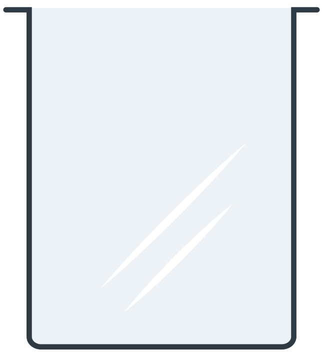
STEP 2 Use your model to carry out an experiment simulating a changing climate

- → Place your model directly under a powerful lamp or direct sunlight.
- → What parameter did you change between step 1 and step 2?
- → Underline in red the equipment needed to simulate global warming.
- → Which step represents the test? The control?
- → Complete the diagram of your experiment.
- → Did your experiment allow you to verify your hypothesis? If so, has your hypothesis been confirmed? What can you conclude?
- → Optional: You can continue running your experiment for several hours in direct sunlight and observe changes in the appearance of the soil.

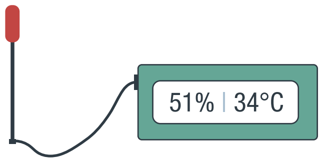
STEP 3 Compare and explain how your experimental results differ from / match with scientific results compiled by the IPCC (see **DOCUMENTS 5** and **6**)

SETTING UP A MODEL OF AGRICULTURAL AND ECOLOGICAL DROUGHTS

EQUIPMENT THAT CAN BE USED

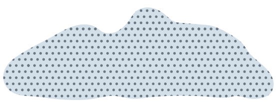


1 container (500mL or 1L)



2 detectors:
one for humidity, one for temperature

Direct sunlight or 2 lamps (<u>no LED</u>):
one of 50W, one of 100W



Modeling clay

A plant in a small pot (to trace the evapotranspiration from the plant and evaporation from the soil)
or a sample of moist clay in a Petri dish or a saucer
(to trace the evaporation of water contained in the clay)

DOCUMENT 5. MAIN CHARACTERISTICS AND IMPACTS OF DROUGHTS

An example of agricultural and ecological drought: visible desiccation cracks in the soil, caused by an abnormal soil moisture deficit from a shortage of precipitation and excess evapotranspiration.

A **drought** is an exceptional period of water shortage affecting ecosystems as well as humans and their livelihoods.
There are three types of droughts:
~ An **agricultural and ecological drought** is characterised by an abnormal soil moisture deficit due to a combined shortage of precipitation and excess evapotranspiration.
~ A **hydrological drought** describes significant runoff and water deficits.
~ A **meteorological drought** is defined as a period with abnormal precipitation; and a socioeconomic drought relates the supply and demand of various commodities to drought.

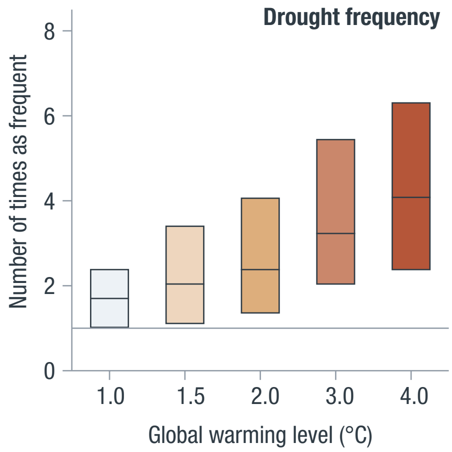
*'Human-induced climate change has contributed to increases in agricultural and ecological droughts in some regions due to evapotranspiration increases (medium confidence). This has been induced by increased temperature. There is an increase in the maximum amount of moisture that the atmosphere can hold as it warms (high confidence), of about **7% per 1°C** of global warming (following the Clausius–Clapeyron relation).'*

Droughts can be part of **compound events,** exacerbating their impacts. Compound events of heatwaves and droughts have become more frequent. All in all, the land surface affected by compound extreme events involving extreme temperatures, droughts, wildfires, storms or floods has increased (high degree of confidence). This has consequences for the agricultural sector and, thus, for our food supply chains.

Source: Adapted from IPCC, 2021, Assessment Report 6, WG1 (The Physical Science Basis), Ch. 11, Executive Summary. Published on the IPCC website (https://www.ipcc.ch/report/ar6/wg1/chapter/chapter-11/)

DOCUMENT 6. PROJECTED CHANGES IN AGRICULTURAL AND ECOLOGICAL DROUGHT UNDER VARYING LEVELS OF GLOBAL WARMING (RELATIVE TO PRE-INDUSTRIAL TIMES)

The diagram assesses the changes in soil moisture during agricultural and ecological droughts. The numbers plotted on the y-axis are 'per decade' and only regions that are becoming increasingly arid were considered. The values were obtained using climate models. The trend is the same if we consider the intensity of droughts.



Source: Adapted from IPCC, 2021, Assessment Report 6, WG1 (The Physical Science Basis), Ch. 11, Figure 11.18 | Projected changes in (a) the intensity and (b) the frequency of drought under 1°C, 1.5°C, 2°C, 3°C, and 4°C global warming levels relative to the 1850–1900 baseline. Published on the IPCC website (https://www.ipcc.ch/report/ar6/wg1/figures/chapter-11/figure-11-18).

WORKSHEET 3.5 PAGE 1/2

TEAM 4: METEOROLOGISTS

EXPERT

FORECASTING MODEL TO MAKE WEATHER PREDICTIONS

STEP 1 See how models forecast extreme cold events

- Use the database from The Weather Prediction Center, available on the NOAA website (https://www.wpc.ncep.noaa.gov/noaa/noaa_archive.php), to view weather forecasts for the United States.
- Compare and note the weather forecast for the morning of 6 February 2021, with the forecast for the morning of 6 February 2024.
- The forecasts proved to be very accurate: a very rare episode of extreme cold occurred throughout North America in February 2021, with temperatures reaching -30°C in Havre, Montana, in the USA.
- In **DOCUMENT 7,** mark the weather event that occurred in Montana on the morning of 6 February 2021 – just like the heat wave event that struck Europe in July 2023 and caused a temperature maximum on 23 July.

CLIMATE MODELS AND EXTREME COLD EVENTS

STEP 2 Extreme cold events in 2100 as projected with a climate model

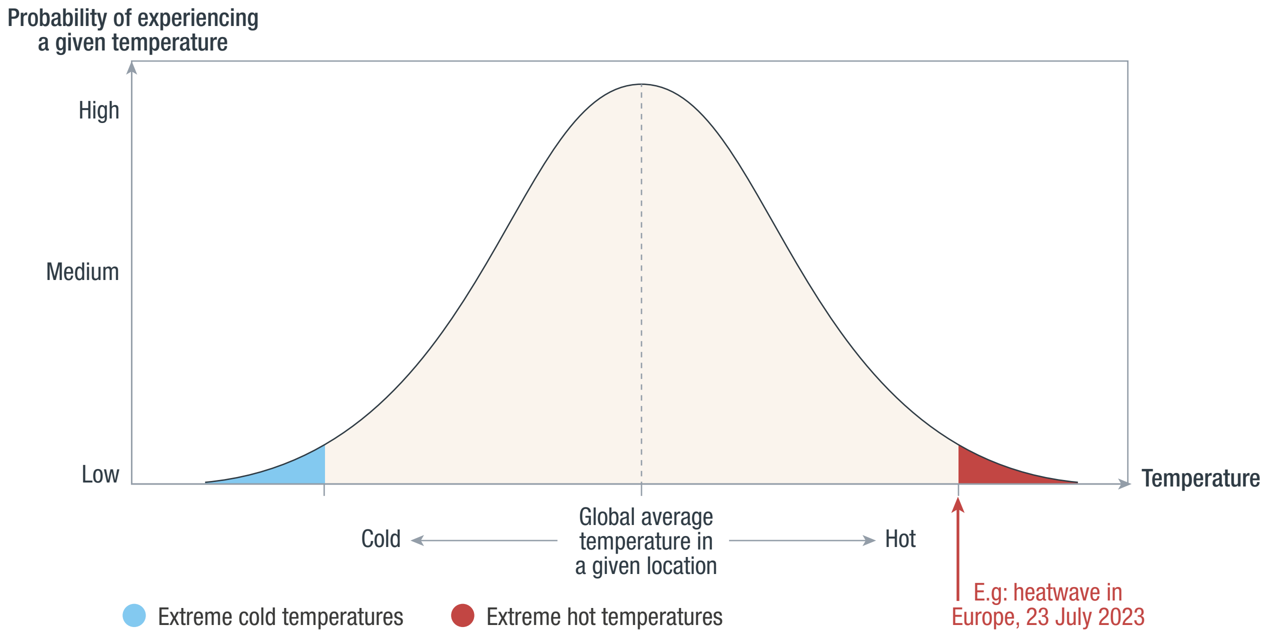
- Open the Urban Heat Islands multimedia animation (available on the OCE website).

- Click on Havre, Montana, USA. Describe what the climate was like in 2020.
- According to **DOCUMENT 7**, what is the probability of experiencing an extreme cold event in Havre (high, medium, low)?
- Use the multimedia animation to view the projected climate for Havre at the end of the century.
- According to scientific results compiled by the IPCC **(DOCUMENT 8),** do you think the probability of experiencing an extreme cold event will be the same in Havre in 2100?

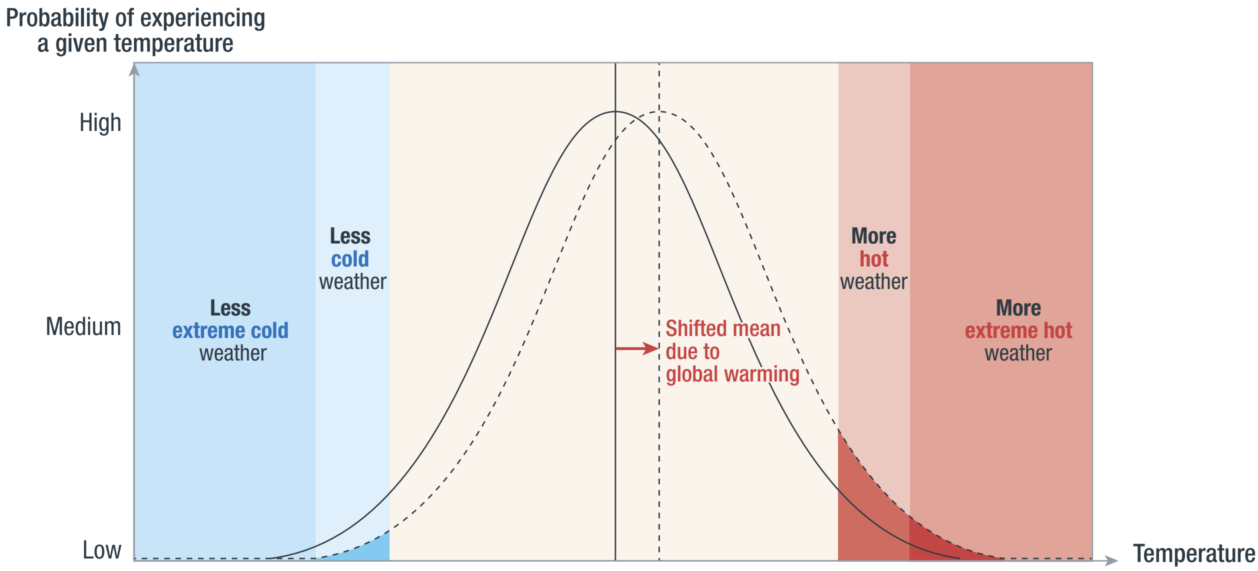
STEP 3 Use this climate model to carry out an experiment

- Stay in Havre in the year 2100: click on ‘Energy’, ‘Electricity mix’, and ‘Renewable energies’ (all countries shift their energy mix away from fossil fuels towards renewable energies).
- Which step represents the test? The control?
- What are the results?
- If effective solutions are implemented to mitigate global warming, do you think the probability of experiencing an extreme cold event will be the same as if no measures are taken?

DOCUMENT 7. PROBABILITY OF AN EXTREME EVENT OCCURRING IN A GIVEN LOCATION



DOCUMENT 8. PROBABILITY OF AN EXTREME EVENT OCCURRING IN A GIVEN LOCATION WITH CLIMATE CHANGE (SCIENTIFIC RESULTS COMPILED BY THE IPCC)



Source: Adapted from IPCC, 2012, Special Report on Extreme Events. Figure SPM.3. Published on the IPCC website (https://www.ipcc.ch/report/managing-the-risks-of-extreme-events-and-disasters-to-advance-climate-change-adaptation/).

WORKSHEET 3.6 PAGE 1/2

TEAM 5: OCEANOGRAPHERS

CURIOUS

STEP 1 Set up a model to simulate an extreme weather event (storm surges) and carry out an experiment

- You can see the analog model used by scientists to study storm surges: https://planet-terre.ens-lyon.fr/objets/Images/CSP-tsunami/tsunami-cuve.jpg
- Use the materials listed below to build your own model of storm surges.
- Underline in green the equipment needed to characterize the impact of the event.
- Set up the experiment.

STEP 2 Use your model to carry out an experiment simulating a changing climate

Part 1 – Change in storm surges

- Simulate a larger storm surge and observe the impacts.
- What parameter did you change between step 1 and step 2?
- Underline in red the equipment needed to simulate climate change.
- Which step represents the test? The control?
- Draw a diagram of your experiment. Did your experiment allow you to verify your hypothesis? If so, has your hypothesis been confirmed? What can you conclude?

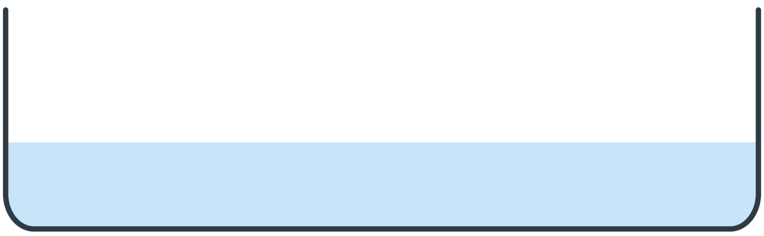
Part 2 – Adding sea level rise

- Why is sea level rise a result of climate change? How can we model this rise in sea level?
- Use a measuring cup or a beaker to add 1L of water to the aquarium. Release the balloon into the water at the same height as step 2 to simulate high storm surges. Observe the impact. What parameter did you change between step 2 and step 3?
- Underline in black the equipment needed to simulate climate change. Which step represents the test? Which step represents the control?
- Draw a diagram of this experiment.
- Did your experiment allow you to verify your hypothesis? If so, has your hypothesis been confirmed? What can you conclude?

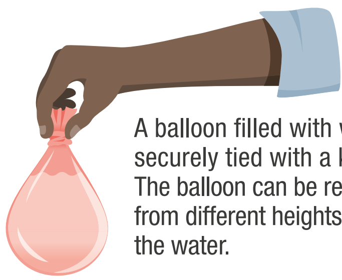
STEP 3 Compare and explain how your experimental results differ from / match with scientific results compiled by the IPCC (see **DOCUMENTS 9** and **10**)

SETTING UP A MODEL OF STORM SURGE

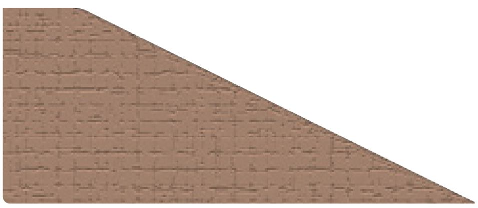
EQUIPMENT THAT CAN BE USED



1 aquarium or large container filled with water to simulate the ocean

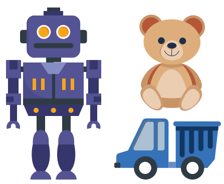


A balloon filled with water, securely tied with a knot. The balloon can be released from different heights above the water.



An inclined plane board to simulate a continental shelf

1 measuring cup or a beaker for adding water to the aquarium



Small toys to be placed on the inclined plane

1 ruler

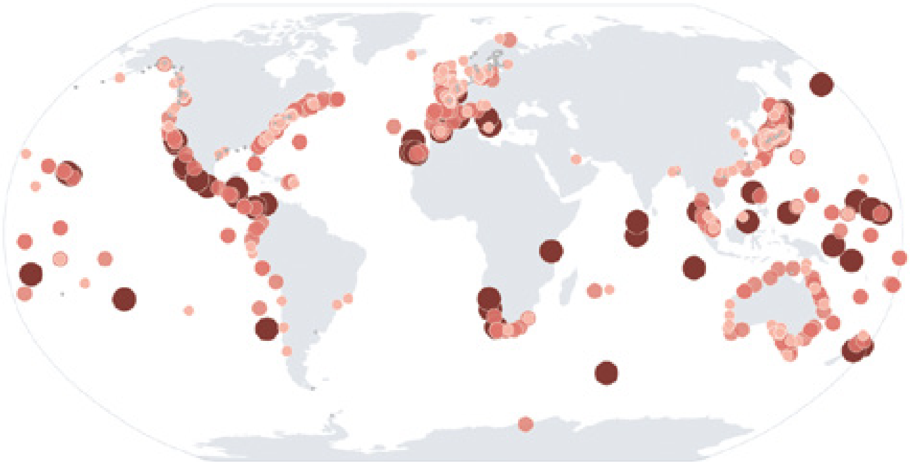
DOCUMENT 9. IPCC INFORMATION ABOUT EXTREME STORM SURGES, INCLUDING TROPICAL CYCLONES

Projected increases in sea level, average intensity, and rainfall rates of cyclones generally contribute to further elevating future storm surges. Among various factors influencing storm surges, there is high confidence that sea level rise will make coastal floods more likely to occur in most regions.

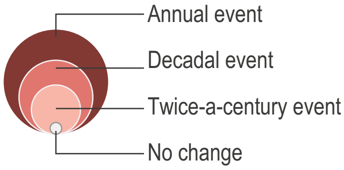
Coasts and estuaries are prone to various meteorological extreme events, which can occur concurrently. Floods with multiple drivers are often referred to as **'compound floods'**. The occurrence of floods may be influenced by the interdependence of storm surges, extreme rainfall, and river flow, as well as sea level rise, waves, tides, and groundwater in estuaries.

Source: Adapted from IPCC, 2021, Assessment Report 6, WG1 (The Physical Science Basis), Ch. 11.
Published on the IPCC website (https://www.ipcc.ch/report/ar6/wg1/chapter/chapter-11/)

DOCUMENT 10. INCREASED FREQUENCY OF EXTREME SEA LEVEL EVENTS BY 2040



Frequency of events that currently occur on average once every 100 years



Source: Adapted from IPCC, Assessment Report 6, Synthesis Report, Figure 4.3 (b).
Published on the IPCC website via CIESIN/SEDAC (DOI: 10.7927/5s2t-2j81)

LESSON 4 THE WATER CYCLE IN A CHANGING CLIMATE [1]

MAIN SUBJECTS
Physics
Chemistry
Natural Sciences
Geography

DURATION
Preparation: 10 min
Activity: 1h30

AGE GROUP
11 years and up

TEACHING METHOD
Document Analysis

OVERVIEW
The Earth has immense quantities of water. Almost all of this water (97%) is salty, and is found in seas and oceans. Water is stored in different reservoirs like the ocean, the rivers, the atmosphere, ice caps, etc. and is constantly moving from one reservoir to another (i.e. fluxes). Reservoirs and fluxes make up the water cycle. When changing reservoirs, water may change its state of matter between solid, liquid, and gaseous. The amount of water remains constant. However, the amount stored in the different reservoirs changes both on geological timescales and with climate change. Climate change affects both flows and reservoirs – leading, among other things, to an increase in the frequency and intensity of extreme weather events.

KEY CONCEPTS
Evaporation, Evapotranspiration, Extreme Weather Events, Fluxes, IPCC, Level of Confidence, Precipitation, Reservoirs, Runoff, Water Cycle, Water States.

LEARNING OUTCOMES
Students will be able to:
~ Calculate that the quantity of water on Earth remains constant.
~ Differentiate between fluxes and reservoirs, which are the building blocks of the water cycle.
~ Discover how climate change impacts the water cycle. It depletes some reservoirs (e.g. sea ice, mountain glaciers), increases others (e.g. the amount of water in the ocean) and modifies the fluxes (e.g. the ice melts faster, there is more water evaporation into the atmosphere etc.).
~ Make projections on how climate change will affect the water cycle in the future.

TARGETED SUSTAINABILITY COMPETENCE
2.1 – Systems Thinking

ASSOCIATED CLIM VIDEO
Video #7 – Compound Events

PREPARATION & MATERIALS 10 MIN

- **WORKSHEETS 4.1** and **4.2** to print for each student.
- Computer and audio equipment to show a video in class.
- Ice cubes, cold water and hot water to demonstrate the three states of water.
- A globe.

INTRODUCTION 15 MIN

1. Students learnt in Lesson 1 that there are different types of extreme weather events. Ask them to name a few examples, such as extreme temperatures or forest fires. Then, ask them if they can identify which events involve water. They might mention heavy precipitation, tropical cyclones, river floods, pluvial floods, and droughts.

2. *Is the water on Earth always liquid? In what states can water be found? Where can the different states of water be observed?* You can use a globe to help them visualize the ocean, polar ice caps, lakes, and major rivers. Use ice cubes, cold water, and hot water to demonstrate the different states:
Water exists in three different states of matter:

- **Solid state (ice):** Polar ice caps (ice floes and continental ice in Antarctica and Greenland), continental glaciers (in mountains, volcanoes, permafrost).
- **Liquid state:** This is usually referred to as 'water'. It can be saltwater (in seas and oceans) or freshwater (in lakes, rivers, groundwater, clouds, fog, etc.).
- **Gaseous state (water vapour):** This includes moisture in the air, the condensation of which can be seen on the rim of a glass filled with hot water.

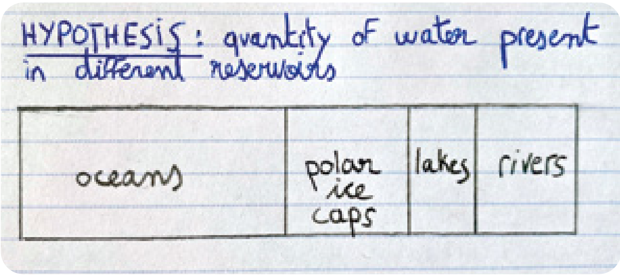
TEACHER TIP
For this lesson, we will not consider the water stored in biomass (living cells).
Clouds, fog, and condensation are not made up of water vapour; instead, they consist of tiny droplets of liquid water suspended in the air. When you put hot water into a glass, you can observe the condensation of water vapour: droplets are formed on the rim of the glass.

1 This lesson is inspired by two lessons in the handbook 'The Ocean, my Planet... and Me!', by Mathieu Hirtzig, David Wilgenbus and Gabrielle Zimmermann. Éditions Le Pommier, 2015.

3. Next, introduce the concept of 'reservoir' to refer to the distribution of water on Earth, which includes:

- Seas and oceans (liquid saltwater)
- Glaciers and ice caps (solid freshwater)
- Groundwater (liquid freshwater)
- Surface water (liquid freshwater)
- Atmosphere (liquid freshwater and water vapour)

Ask the students to individually represent the proportions of water they think each reservoir holds. For example, you could instruct them to distribute 100 litres of water between the different reservoirs. You can encourage them to be creative with their representations; some students may feel more comfortable with writing, while others may prefer to draw graphs.



A student's representation of the different amounts of water stored in the Earth's water reservoirs often shows an overestimation of the amount of freshwater.

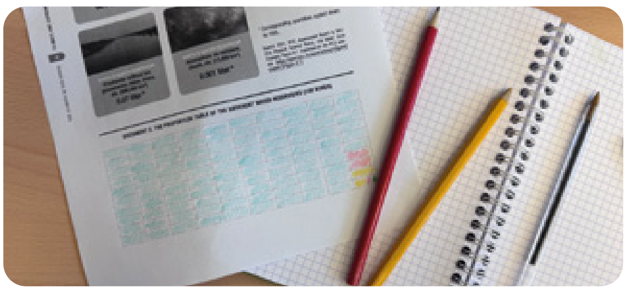
PROCEDURE 1 HOUR

1. Hand out **WORKSHEET 4.1**, which presents Earth's major reservoirs, with the corresponding quantities scaled down to 100 litres of water (roughly the capacity of a bathtub). Ask them to revise their original representations with the updated information given in Document 1.

2. Ask them to represent the correct proportions in the table provided, too.

TEACHER TIP

Note that the volumes (in litres) on **WORKSHEET 4.1** correspond to the percentage distribution among the different reservoirs (e.g. 0.001% of the water on Earth is found in the atmosphere).
Providing the same colour code to the entire class can make it easier to assess their responses.



An example of a student's completed worksheet. This activity allows students to understand that most of the water on Earth (97%) is salty and is found in the oceans.

BACKGROUND FOR TEACHERS
THE THREE STATES OF WATER

Water can be in three states of matter: **gas** (water vapour in the air), **liquid** (oceans, rivers, groundwater, rain, clouds, etc.), and **solid** (glaciers, snow crystals, hail, and ice). It constantly moves between the oceans, the atmosphere, and land. The **reservoirs** and the **fluxes** are the building blocks of the water cycle:

~ Surface water of oceans, lakes and soil **evaporates** – the warmer it is, the more it evaporates. The water stored in plants also evaporates in a process known as **evapotranspiration**. For children, the concept of evaporation often stops at the simple observation of puddles that disappear. To illustrate evapotranspiration and evaporation from land, encourage them to collect a few plant samples and a shovelful of soil (ideally after recent rainfall). When they place these samples in plastic bags and keep them in a warm place, moisture from the soil will evaporate and condense on the surface of the bags as little droplets.

~ Similarly, water vapour in the air **condenses** into fine droplets that form clouds before falling as rain onto oceans and land.

~ Some of the rain **infiltrates** the soil and replenishes the water tables (groundwater). When the soil is saturated with water, some of it **runs off** into the rivers and lakes.

The calculations made by the students on **WORKSHEET 4.2** show that the amount of water on Earth remains constant, as does the amount of water in each reservoir. But this does not apply on geological timescales: **past glacial and interglacial periods** have considerably modified these amounts (and fluxes) in each reservoir. Similarly, **climate change** over the last century has had a **profound effect on the natural water cycle.** For example, the increase in average temperatures and the melting of glaciers are leading to a gradual reduction in the amount of water stored in the form of ice, as shown in **WORKSHEET 4.2.** Similarly, the amount of water vapour in the atmosphere increases as its temperature increases.

If the question comes up whether humans disrupt the water cycle by drinking water, you can explain that the water absorbed by the body is released back into the environment through feces, urine, and sweat. From this perspective, humans do not disrupt the water cycle any more than other living species. On the other hand, how humans use land strongly modifies the water cycle (see **WORKSHEET 4.2**, or refer to the next *Background for Teachers*), especially in the context of climate change.

3. *Does the amount of water in a reservoir remain the same?* This question is an opportunity to discuss how water can change states and move between different reservoirs. For example, scientists often talk about the melting of glaciers due to climate change, illustrating how the amount of freshwater can decrease over time. You can now distribute **WORKSHEET 4.2** and ask the students to follow the instructions provided.

WRAP-UP 15 MIN

The total amount of water that evaporates is 470 + 74 = 544 thousand km^3 per year. The total water that falls on Earth as rain, snow, hail, etc. each year is 424 + 120 = 544 thousand km^3 per year. These two quantities are the same, meaning that the atmosphere gains as much water as it loses; thus, the total amount of water on Earth remains constant.

Similarly, the amount of water in the oceans is stable. Each year, the oceans lose 470 thousand km^3 of water through evaporation but gain 424 + 46 = 470 thousand km^3 per year by precipitation falling directly into the oceans and runoff from continental waters (see **WORKSHEET 4.2,** Document 3).

Group discussions will help lead to the conclusion that water moves from one reservoir to another while each reservoir gains as much water as it loses; at the end of the day, the amount of water in each reservoir remains constant. However, the fact that each reservoir retains the same amount of water is only true when considering the natural water cycle.

Ask the students to write in their science notebooks the conclusion: 'Almost all water on Earth (97%) is saltwater and is located in seas and oceans. The amount of water in each reservoir is constant, which means that the total amount of water on Earth also remains constant. It's called the **water cycle**.'

Depending on the time available and your students' understanding, you can expand on this, for example by explaining that the quantity of water in each reservoir is not constant over geological time (glacial/interglacial periods, or during the formation of the Earth, etc.).

The IPCC highlights the **various changes observed in the water cycle as a result of human activities.** Global warming is **intensifying the water cycle,** which – seen globally – leads to increased precipitation and evaporation, both over land and over the ocean. However, global warming doesn't have the same effects in all the regions of the world – it modifies precipitation patterns: while in some areas, especially at high latitudes, precipitation is increasing; it decreases in large parts of the subtropics. **Melting ice** from glaciers and ice caps is increasing **runoff** into the ocean, profoundly affecting the water cycle. This has **significant consequences for both flows** (e.g. more runoff leads to increased flooding) **and reservoirs** (e.g. more freshwater reaching the oceans reduces the volume available on land). This intensification of the water cycle is closely linked to an **increase in the frequency and intensity of certain extreme events,** such as floods and heavy rain. The IPCC estimates that these changes will continue and worsen in the future.

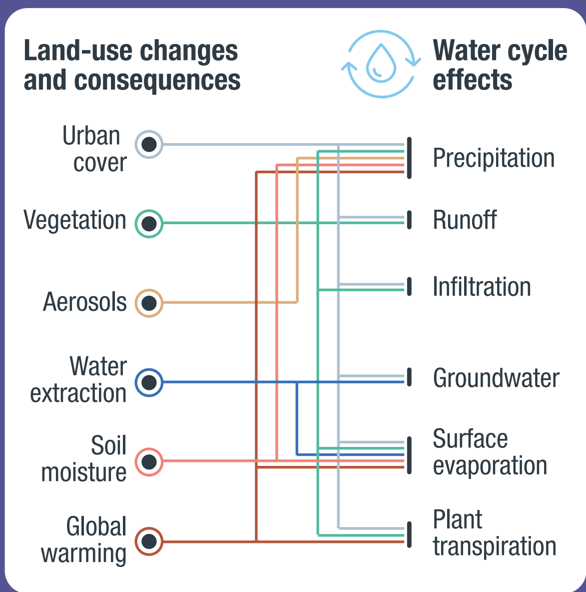
Depending on the available time and the level of your students, you can take a few minutes to discuss how climate change impacts water resources. This can be facilitated by watching the Video #7 'Compound Events'.

You can also explain that reliable scientific information is always accompanied by a level of confidence, as seen in the IPCC reports (see **WORKSHEET 4.2,** Document 5), and that the IPCC is one of the most reliable sources of information on climate change.

BACKGROUND FOR TEACHERS
THE IMPACTS OF LAND USE CHANGES ON THE WATER CYCLE

The ways in which humans use and change land cover – such as converting fields into urban areas or clearing forests – can affect every aspect of the water cycle. As we can see in the figure, global warming modifies precipitation, surface evaporation, and evapotranspiration. Changes in land use and land cover alter the water cycle on global, regional, and local scales. Since all components of the water cycle are interconnected, changes in land use can influence many other elements of the water cycle and the climate system.

You can summarise this lesson by showing this figure, as most of the elements presented have been covered.

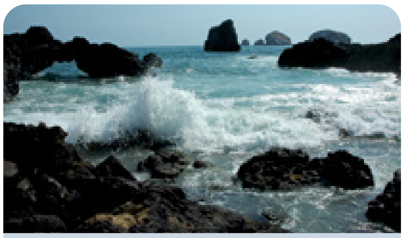


Source: Adapted from IPCC, 2021, Assessment Report 6, WG1 (The Physical Science Basis), Ch. 8 Water Cycle Changes, Figure FAQ 8.1, Figure 1 | Land-use changes and their consequences on the water cycle. Published on the IPCC website (https://www.ipcc.ch/report/ar6/wg1/figures/chapter-8/faq-8-1-figure-1).

WORKSHEET 4.1
EARTH'S MAJOR WATER RESERVOIRS

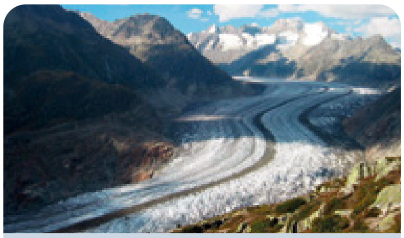
Question Using the information below, colour the boxes in the table at the bottom to represent the distribution of water in the Earth's major reservoirs. What do you notice?

DOCUMENT 1. PROPORTION OF WATER STORED ON EARTH IN DIFFERENT RESERVOIRS
(The total slightly exceeds 100% because of rounding)



EARTH'S WATER RESERVOIR
Ocean, inland seas and saline lakes (1,335,000,000 km^3)

96.7 litres*

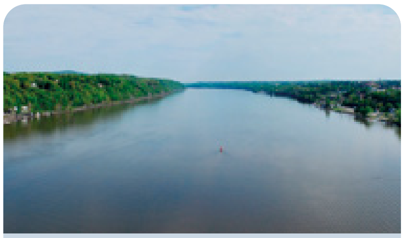


EARTH'S WATER RESERVOIR
Ice caps, glaciers, ice floes, etc. (26,213,000 km^3)

1.9 litres*

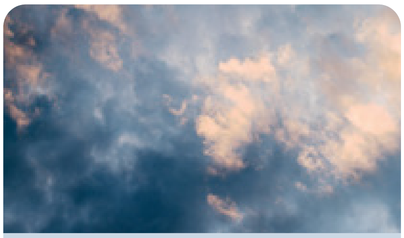
EARTH'S WATER RESERVOIR
Saline groundwater (22,000,000 km^3)

1.6 litres*



EARTH'S WATER RESERVOIR
Freshwater without ice: groundwater, lakes, rivers, etc. (986,000 km^3)

0.07 litres*



EARTH'S WATER RESERVOIR
Atmosphere: air moisture, clouds, etc. (13,000 km^3)

0.001 litres*

* Corresponding quantities scaled down to 100L.

Source: IPCC, 2021, Assessment Report 6, WG1 (The Physical Science Basis), Ch. 8 Water Cycle Changes, Figure 8.1. Published on the IPCC website (https://www.ipcc.ch/report/ar6/wg1/figures/chapter-8/figure-8-1).

DOCUMENT 2. THE PROPORTION TABLE OF THE DIFFERENT WATER RESERVOIRS (100 BOXES)

Question 1 Draw arrows to represent the type of flows listed in **DOCUMENT 4** (e.g. ocean evaporation, land precipitation), indicating the correct direction on the diagram of the water cycle below.

Question 2 Write the figures for annual flows from **DOCUMENT 4** on the water cycle diagram, to better understand the magnitude of these flows.

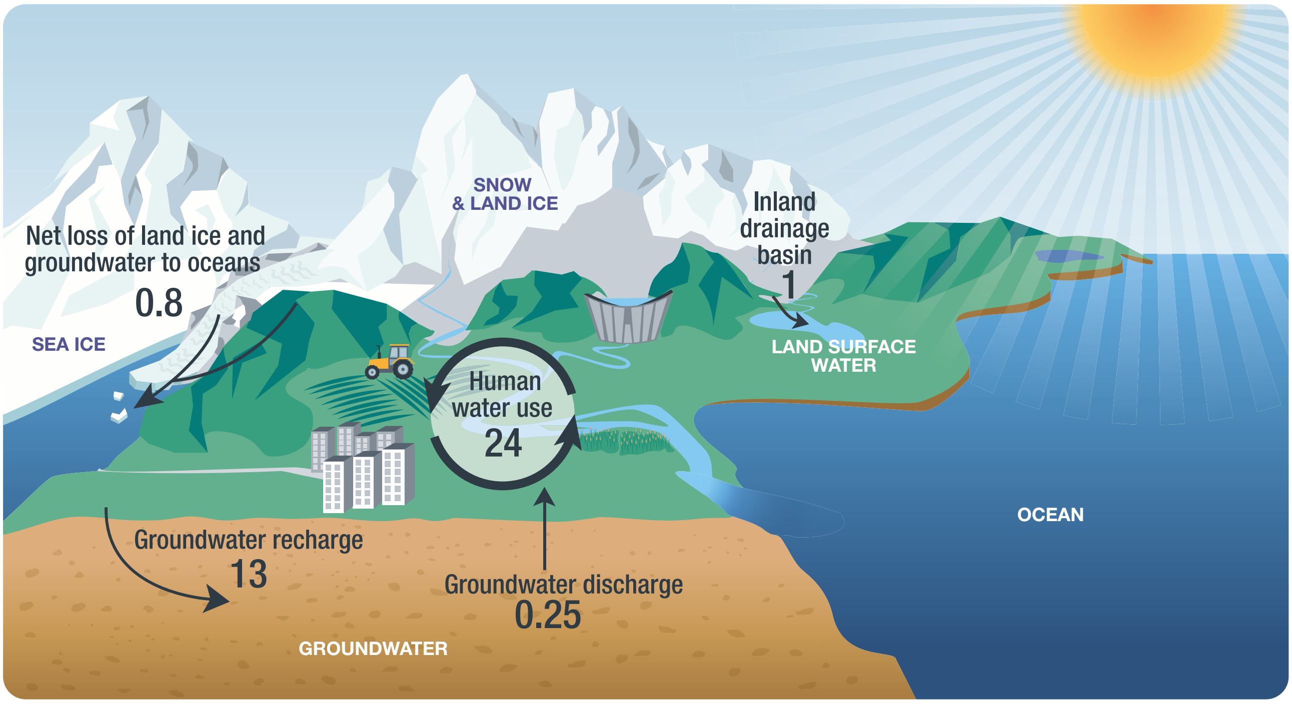
Question 3 Calculate the total volume of water that evaporates each year from both land and ocean, and the total volume of water that falls each year. Then, compare the two. What is the total amount of water in the atmosphere?

Question 4 Perform the same calculations for the oceans only: determine how much water the oceans lose each year and how much they gain, then compare the two. How does this affect the total amount of water in the oceans?

Question 5 Read **DOCUMENT 5** and explain how climate change currently affects the water cycle and how it is expected to change in the future.

DOCUMENT 3. THE WATER CYCLE AND THE WATER FLUXES

(in thousands km^3 per year)



Sources: Adapted from IPCC, 2021, Assessment Report 6, WG1 (The Physical Science Basis), Ch. 8 Water Cycle Changes, Figure 8.1b. Published on the IPCC website (https://www.ipcc.ch/report/ar6/wg1/figures/chapter-8/figure-8-1).

DOCUMENT 4. ANNUAL WATER FLOWS ON EARTH

(in thousands km^3 per year)

Ocean Evaporation	470
Land Evaporation	74
Ocean Precipitation	424
Land Precipitation	120
Contribution to Ocean from Watercourses	46

Sources: 2021, IPCC, Assessment Report 6, WG1 (The Physical Science Basis), ch8 Water Cycle Changes, Figure 8.1b. Published on the IPCC website (https://www.ipcc.ch/report/ar6/wg1/figures/chapter-8/figure-8-1).

DOCUMENT 5. THE IMPACT OF CLIMATE CHANGE ON THE WATER CYCLE

Observed Changes in the Water Cycle: The IPCC reports widespread but uneven human-caused changes to the water cycle. There is high confidence that global mean precipitation and evaporation rates increase with global warming, rising by 1–3% per +1°C of warming. Global warming has also contributed to an overall increase in atmospheric moisture and precipitation intensity (high confidence), and increased terrestrial evapotranspiration (medium confidence). A warmer climate increases moisture transport into weather systems, intensifying heavy precipitation events and worsening flood risks. Both very wet and very dry events are becoming more severe in a warming climate (high confidence).

Future Changes to the Water Cycle: Without reductions in greenhouse gas emissions, global warming is projected to cause substantial changes to the water cycle (high confidence). Global annual precipitation over land is expected to rise. It is virtually certain that ocean evaporation will increase, and land evapotranspiration is also likely to rise. Higher precipitation intensity will lead to greater runoff in some regions. Regional changes in the strength and frequency of climate extremes usually match the rate of global warming. The occurrence of unprecedented extreme events is expected to increase with continued global warming.

There is high confidence that mountain glaciers and ice caps will shrink in all regions. Runoff from small glaciers will typically decrease due to the loss of ice mass, while runoff from large glaciers is likely to increase with global warming until their mass becomes depleted (high confidence).

Source: Adapted from IPCC, 2021, Assessment Report 6, WG1 (The Physical Science Basis), Ch. 8 and Ch.11.

LESSON 5 ADAPTATION FOR THE DECADE [1]

MAIN SUBJECTS
Natural Sciences
Geography
Social Sciences
Mathematics
Physics

DURATION
Preparation: 30 min
Activity: 2h

AGE GROUP
11 years and up

TEACHING METHOD
Role-Playing Game

OVERVIEW
In this lesson, students will play a serious game consisting in planning adaptation strategies for future climate hazards. During 3 rounds, in groups, they will choose to invest in protecting their fictional community against drought, flood, or invest in development. The occurrence of extreme events is mimicked by dice rolls that will change round after round. Finally, they will discuss the notions of development, adaptation, and climate justice.

KEY CONCEPTS
Adaptation, Climate Justice, Collective Choices, Development, Drought, Frequency, Floods, Hazard, Investment, Probability, Risk, Vulnerability.

LEARNING OUTCOMES
Students will be able to:
~ Lead group discussions and reach a consensus for a group decision.
~ Evaluate the trade-offs between adaptation and development goals.
~ Compare the probability of occurrence of extreme events for a decade in a present climate and in a future climate.
~ Understand that climate change induces an increase in the probability of extreme events.
~ Experience various degrees of vulnerability to climate change.
~ Elaborate the concept of climate justice based on climate hazard and community vulnerability.

TARGETED SUSTAINABILITY COMPETENCES
3.2 – Adaptability
4.2 – Collective Action

ASSOCIATED CLIM VIDEOS
Video #1 – Extreme Events
Video #3 – Heatwaves and Droughts
Video #5 – Severe Convective Storms
Video #7 – Compound Events
Video #8 – Management of Extreme Events

PREPARATION & MATERIALS 30 MIN

- A six-sided die (large or normal size)
- An eight-sided die (large or normal size)
- A 'robust option shield' (see **WORKSHEET 5.1**)
- A stopwatch
- For small groups (< 10 students): a set of 10 tokens and **WORKSHEET 5.2** to print per group

Read through the game rules in advance and try out the game briefly, to adapt it if necessary to your class context.

INTRODUCTION 10 MIN

Start a discussion with your students by asking if they have themselves or their relatives ever experienced an extreme weather event. Then, ask them to name other extreme weather events they know of and whether they can think of ways to protect against or adapt to them. Collect the answers and write down adaptation solutions to face extremes, and explain to the students that they will then play as if they, as a community, were to face extreme weather events and adapt to them.

PROCEDURE 1H30

Explain to the class that they will be playing a game in which they must develop plans to invest in their community and protect it from future extreme weather events.

RULES

1. Arrange the class into groups of 10, each standing in a circle of chairs. If you have smaller groups,

1 This lesson is adapted from a game developed by the Red Cross Climate Center called 'Decision for the decade' (https://www.climatecentre.org/games/2520/decisions-for-the-decade/).

distribute 10 tokens and **WORKSHEET 5.2** to each group. These groups will represent a community — invite them to name themselves as a community like a village or a district of a city!

2. The game consists of three to four rounds, each representing a new decade. At the beginning of each round, groups will have 2 minutes to decide how to allocate their investments based on their estimate of the number of floods or droughts coming in the next decade. They can choose from three investment options: **development** (thumbs up), **flood adaptation** (umbrella), or **drought adaptation** (bucket).

For groups of 10: In groups, students decide on the proportion of each investment option, then each student stands up and represents one of these options, using hand gestures to indicate their choice.

Thumbs-up for development.
Arms in the shape of a bucket, around the head, for adaptation to drought.
Hands up as an umbrella for adaptation against flood.

For smaller groups: They will collectively decide how to allocate their 10 tokens across the three investment options. For example, they may choose to invest 5 coins in development, 2 coins in flood adaptation, and 3 coins in drought adaptation, and place their coins accordingly on **WORKSHEET 5.2**.

After 2 minutes, anyone who has not made a choice is out for the round and must sit down, which results in fewer investments for the group (indecisiveness is not rewarded in this game!). For smaller groups, the number of students who sit down should correspond to the number of coins that have not been allocated.

Advise them to choose wisely, as their decision at the beginning of the round represents their investment plan for the community for the next 10 years, and they will not be able to change their choices during that round.

At the end of each round, each group's development points are totaled, reflecting the number of investments allocated to developments (the number of tokens in development or thumbs-up for groups of 10).

Announce to the class that the group with the most development points at the end of the game will be declared the winner.

Note that you will engage in a global discussion with students at the end of the game about what can be seen as 'development' for a community.

3. When the 2 minutes are up, you will roll the die 10 times (one roll for each 'year' in the decade).

For Round 1 (no climate change, six-sided die): If you roll a 1, it means an extreme drought occurred this year. If you roll a 6, it means that an extreme flood occurred. Any number from 2 to 5 reflects a year without any extreme event. Write down the number accordingly on the whiteboard.

For Round 2 (with climate change, eight-sided die): Rolling a 1 or 2 indicates an extreme drought, while rolling a 7 or 8 indicates an extreme flood, and any number from 3 to 6 reflects a year without extreme events. Write down the number accordingly on the whiteboard.

4. During each round, whenever an extreme drought occurs, one drought protection investment will protect the whole community until the next roll of the dice.

For groups of 10: One student who chose protection (bucket) will 'use it' by shouting *'We're saved!'* and then sitting down. If no one in the group chose drought protection or if they no longer have any drought protection available, their community will be devastated, and they will lose all their development investment points. The entire group must then shout, *'Oh no!'* and sit down for the remainder of the round. The same applies to extreme floods: one student who chose flood protection (umbrella) will 'use it' in the same way. If no flood protection was chosen, or if there is no remaining flood protection, their community will suffer the same fate.

For smaller groups: If they have invested in protection against the extreme event, one member of the group will shout, *We're saved!'* and then sit down, indicating that their protection has been used for that event. They remove one token of this specific protection on the worksheet. If they have not invested in protection or do not have any remaining investments when the event occurs, the entire group must shout, '*Oh no!'* and sit down for the remainder of the round.

PRACTICE ROUND

1. To ensure that the students understand the rules, it is recommended to start with a practice round in which you assign the investment choices for each group.

For example, if you have three groups, you could allocate the investments for each group as follows:
- **Group 1:** Invests everything in development (10 thumbs up).
- **Group 2:** Invests in 4 drought protection (4 buckets), 5 flood protection (5 umbrellas), and 1 development (1 thumbs up).
- **Group 3:** Invests in 8 drought protection (8 buckets), 0 flood protection (0 umbrella), and 2 development (2 thumbs up).

2. Next, start the round by rolling the six-sided die and announcing the result aloud. If you roll a number from 2 to 5, no extreme event has occurred, and you can roll again. If you roll a 1, announce to the class that an extreme drought has occurred. According to the rules:
- **Group 1:** Everyone must shout, *'Oh no!'* and sit down, as all of their investments went into development and they had no drought protection. As a result, they lose all 10 of their development points for the round.
- **Group 2:** One student who chose drought protection will shout, *'We're saved!'* and sit down, while the others remain standing. This group has enough protection for 3 subsequent droughts but only 1 development point for the rest of the round.
- **Group 3:** One student who chose drought protection will shout, *'We're saved!'* and sit down, while the others remain standing. This group has enough protection for 5 subsequent droughts and has 2 development points but is not protected from floods.

You can continue to roll the die 9 more times, ensuring that the groups respond according to the rules. If you feel that the students have a good understanding of the game after a few rolls, you can skip to Round 1.

ROUND 1: A DECADE WITHOUT CLIMATE CHANGE

1. Set the timer to 2 minutes. When you say, *'Go!',* the students must decide how to allocate their investments before time runs out.

2. After 1 minute, pause the timer to introduce a new possibility: the *Robust Option* (**WORKSHEET 5.1**). This option protects the community from any extreme event (drought or flood) for the entire decade (round). However, only one group may purchase it in each round, and it comes at a high cost.

The *Robust Option* is purchased through an auction starting at 10 investment choices, meaning that if a group decides to invest in this option, their community will be fully protected for the duration of the round, but will have 0 development points. If no group is willing to purchase the *Robust Option* for this price, you can continue the auction down from 10 to 7 investment choices. At this price, they would be able to invest in 3 development points while still being fully protected from extreme events.

If no one accepts the offer by this point, or it is sold, restart the timer, and the students can continue making their allocation choices until the remaining time is up.

3. At the end of 2 minutes, shout, *'Stop!'.* Write down the investment strategy of each group for this decade on the whiteboard.

4. Then, roll the six-sided die 10 times, each time writing down the result on the whiteboard. Ensure that the students respond according to the rules after each roll. If the *Robust Option* was purchased, that group can stay seated for the entirety of the round and rest assured that their community will remain safe. At the end of Round 1, tally each group's remaining development points.

ROUND 2: A DECADE WITH CLIMATE CHANGE

1. Start this round by asking the students how they think climate change will affect the frequency (or probability of occurrence) of droughts and floods: *Will it increase, decrease, or stay the same?* Explain that for this round, there will be a slight change: since the frequency of extreme events increases with climate change, the probability of one occurring during the decade is higher. To take into account this new probability, the six-sided die will be replaced with an eight-sided die. Now, an extreme drought will occur any time a 1 or 2 is rolled, and an extreme flood will occur any time a 7 or 8 is rolled.

2. Start another auction for the *Robust Option,* with the bidding ending at 7 investment choices. The auction will likely be more lively this time, given the new information and the results from Round 1.

3. When the auction has closed, set the timer for 2 minutes. When you say, *'Go!',* the students must decide how to allocate their investments before time runs out.

4. When time is up, yell, *'Stop!'*. Then, roll the eight-sided die 10 times, ensuring the students respond according to the rules. Write on the whiteboard the result for each year.

5. At the end of the round, tally each group's remaining development points.

6. Now, start a discussion with your students by asking how they feel after Round 2 compared to Round 1: *Was it harder to decide how to invest in the first round or the second? How did the introduction of the Robust Option affect your investment choices? Were you surprised by the number of extreme events now?*

7. Depending on the time available and the students' motivation, you can replay Round 2 to see if they can be better prepared this time.

ROUNDS 3 AND 4 (OPTIONAL): INTRODUCING THE ASPECTS OF CLIMATE JUSTICE

Now that students have played the game and experienced the importance of planning ahead their investments for the future according to extreme events, you can use this game dynamic to introduce some notions of climate justice via the concepts of differences in climate hazard and climate vulnerability.

ROUND 3: CLIMATE VULNERABILITY

1. Start with some questions based on the previous rules. Ask your students: *In your opinion, are all communities, people, villages, or countries equally wealthy, and thus the same opportunities for investing in development and protection? Can you think of any country that have less or more opportunities than you? How would you represent this with the game you just played?*

2. You can then recall the groups and the rules, and state that some of the groups are wealthier than others: for instance, they will start the game with more than 10 tokens, and other groups will have less resources; they will have less than 10 tokens.

3. Depending on the time you have, let the students play around this concept: you can set up a class competition by randomly assigning for instance 12 tokens, 8 and 4 tokens to the 3 groups, and run Round 2 again.

4. Spend some time asking the students how they feel when they have fewer tokens. *What happened?* Explain that we actually observe some populations that have fewer resources, for instance money, to either develop and, more importantly, protect themselves from drought or flood. It is the case of least developed countries. This is part of the concept of the difference in vulnerability to climate change.

ROUND 4: CLIMATE HAZARD

1. Ask your students: *Are all populations similarly affected by extreme events? Do we have more floods or droughts in some regions than others?*

2. According to their answers, they will come to a conclusion that we have a different spatial distribution of the extreme events on our planet. Thus, some countries are experiencing more extreme weather than others (for instance, Northern Europe experiences less droughts than Spain). Ask your students how they would represent this with the game they played.

3. You can then change the probabilities of the extremes by changing the rules of the dice for the different groups. For example, for 3 groups, you can decide to have each of the groups play with a different distribution: a group can use the same rules as Round 1; another one has the same rules as Round 2, and another group has, for instance, more probabilities of having a drought, or a flood, or both. Then have the group play with a similar number of tokens for each group.

4. Wrap up by asking your students if this was easier or harder than previously. *Did they understand that in some places you need more adaptation plans than in other places?* This is called the difference in climate hazard between different countries, and it also defines climate risk, which helps explain climate injustice worldwide.

5. Thus, in conclusion, you have made your students experience both different types of vulnerability to climate change, due to the group investment options, and different types of hazard, due to the difference in probabilities of extreme events.

The combination of those two aspects defines climate risk, and is a key component of climate justice.

WRAP-UP 20 MIN

Class discussion on the game:

1. Discuss the game with your students. *How did they feel? What would be the best option, in their opinion, to adapt to extreme events, during the first, the second, and potentially the last decade? Do they know about ways to reduce climate change?* Take some time to discuss mitigation solutions. You can also engage in a discussion about what can be the robust option in their opinion and what should we focus on in development, are all developments compatible with climate conditions, and so on?

2. You can then reduce the abstract aspect of the game by proposing the following imaginative exercise:

First step: Ask the students to imagine themselves (for instance, in the group they played) in a fictional community, such as a village. They can draw the village, give everyone a fictional function in the community, and write a story about this community and so on. Then, ask them what activities and services are important for a community, to function well. They may mention aspects of community life related to basic needs (e.g. food production, water supply, healthcare), infrastructure (e.g. transportation, housing, utilities), the economy (e.g. jobs, businesses, trade), social services (e.g. education, community centers), recreation (e.g. parks, sports, cultural activities), or sustainability (e.g. energy sources, waste management). List those aspects on the whiteboard. All of this can be considered as development in the context of the game.

3. Next, explain that the community is vulnerable to extreme weather events, in particular, droughts and floods.

4. Continue the discussion by asking how they think droughts and floods might affect the community, as well as the activities and services they identified. Write their responses on the board. Referring to the list from the first step, ask which adaptation and mitigation methods could be implemented to help the community. For floods, examples include building dams and reservoirs, or constructing barriers and levees. For droughts, examples include planting drought-resistant crops, and building water storage facilities or desalination plants.

5. Then, prompt them to think of any actions or measures that could support the community's activities while also helping them adapt to climate change. Examples could include rainwater harvesting, water conservation, recycling and reuse, constructing wetlands and green roofs, restoring wetlands, using wind and solar energy, and promoting eco-tourism. You can also encourage them to research additional options on their own.

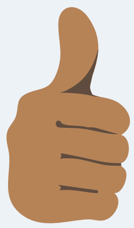
6. Conclude by emphasising that investing in actions and measures that support community life while also enhancing our resilience to climate change (refer back to the list from the imaginary community exercise) will enable us to develop better adaptation plans. However, to address uncertainty, these plans should be iterative, meaning they must be revisited and revised periodically to incorporate new information, allowing for more effective decision-making, with plans to reduce CO_2 emissions.

7. Finally, this is an opportunity to mention an important limitation of this serious game (as with all serious games): while it allows us to understand some of the consequences of climate change, it does not fully capture what happens in the real world. In reality, not all countries have the same capacity to invest in actions and measures to increase their resilience to climate change, including extreme weather events. While wealthy, industrialised countries are largely responsible for historical and current greenhouse gas emissions, it is the least developed and developing countries, including small island states, that do not have the necessary resources to prepare for a rapidly changing and increasingly uncertain world, and are therefore the most vulnerable. This disparity reflects the concept of 'climate justice', which calls for equitable support and responsibility among nations to address the challenges of climate change together.

ROBUST OPTION

WORKSHEET 5.2
BOARDGAME FOR SMALL GROUPS

Question In groups, decide how to allocate the 10 tokens representing the ten years of the decade for each of the three investment options. For each round, the total number must be equal to 10.



INVESTMENT OPTION
DEVELOPMENT
THUMBS UP

NUMBER OF TOKENS

ROUND 1	ROUND 2	ROUND 3	ROUND 4

INVESTMENT OPTION
PROTECTION AGAINST DROUGHT
BUCKET

NUMBER OF TOKENS

ROUND 1	ROUND 2	ROUND 3	ROUND 4

INVESTMENT OPTION
PROTECTION AGAINST FLOOD
UMBRELLA

NUMBER OF TOKENS

ROUND 1	ROUND 2	ROUND 3	ROUND 4

LESSON 6 (UN)NATURAL DISASTERS

MAIN SUBJECTS
Geography
Social Studies
Civic Engagement

DURATION
Preparation: 30 min
Activity: 2h

AGE GROUP
14 years and up

TEACHING METHOD
Serious Game
Case Study
Guided Reflection
Guided Discussion
Role-Play / Simulation

OVERVIEW
Students explore a wicked problem by role-playing different stakeholders in a serious game that simulates disaster management on a fictional island. In this simulation, they negotiate priorities and decide which actions to implement to support the island's recovery and resilience. The activity encourages reflection on the complexity, trade-offs, and interconnected factors involved in disaster response, and on how social and demographic characteristics – such as socioeconomic status, age, gender, ethnicity, and disability – can combine to increase the risk and vulnerability of certain communities.

KEY CONCEPTS
Adaptation, Climate Justice, Disaster, Intersectionality, Preparedness, Risk, Risk Management, Vulnerability.

LEARNING OUTCOMES
Students will be able to:
~ Understand the complexity, challenges, and trade-offs involved in disaster risk management and adaptation planning.
~ Identify and critically evaluate factors – including compounded vulnerability and intersectionality – that increase risks for certain individuals and communities in the context of climate change.
~ Demonstrate empathy and perspective-taking by considering the diverse experiences of people and communities affected by extreme weather events.
~ Apply systems thinking and critical thinking skills as they navigate disaster response, negotiate trade-offs, and engage in group discussions and individual reflections.

TARGETED SUSTAINABILITY COMPETENCES
2.1 – Systems Thinking
2.2 – Critical Thinking
2.3 – Problem Framing
3.2 – Adaptability

ASSOCIATED CLIM VIDEOS
Video #1 – Extreme Events
Video #5 – Severe Convective Storms
Video #7 – Compound Events
Video #8 – Management of Extreme Events

PREPARATION & MATERIALS 30 MIN

- Download and print the game materials, which can be found online. You may want to laminate or print them on cardstock so they last longer and can be reused.

DOWNLOAD THE GAME ↗

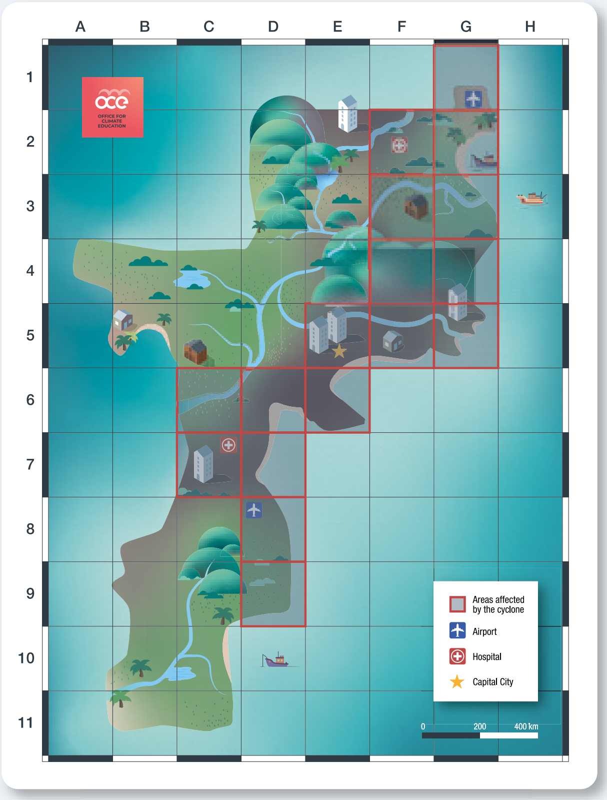
- Cut out the action tokens ahead of time and place one set in a separate envelope for each group.
- Organise the game materials so that each group has a set of the core components (game rules, game board, additional maps, action tokens, action guide, fact sheet, budget tracker) ready to hand out at the start of the activity.
- Prepare the character cards separately by grouping them according to role (e.g. all Farmers cards in one pile, all Flood Engineer cards in another pile). Lay them out on a table so they can be easily distributed or so students can come up and choose their roles.

For each student:
- **WORKSHEET 6.1**

For each group of six students:
- The game rules
- One game board
- A set of action tokens
- An action guide
- A set of character cards
- The fact sheet: Risk & Vulnerability on the Isle of Diega
- Additional maps
- A budget tracker
- Optional: provide name tags so students can write their character role (e.g. Farmer) and create a character name if they choose.

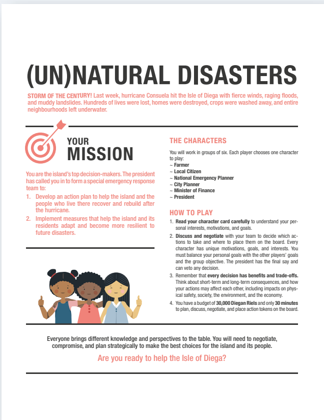
(UN)NATURAL DISASTERS

GAME FEATURES OVERVIEW

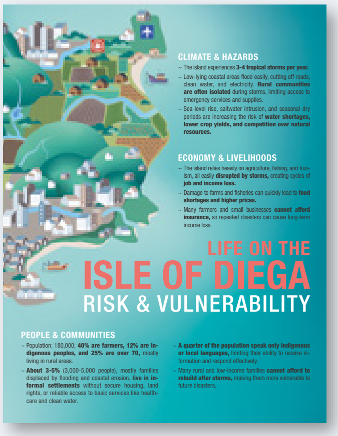


BOARD GAME

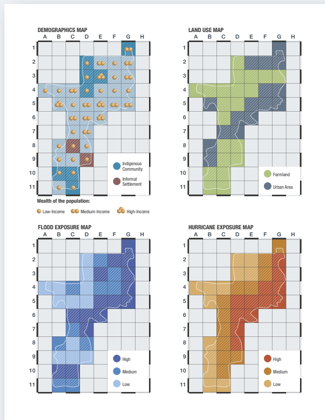
ACTION TOKENS
x13



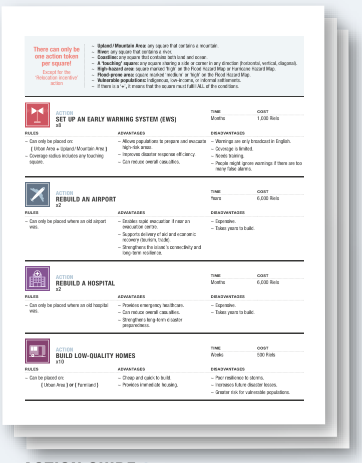
GAME RULES



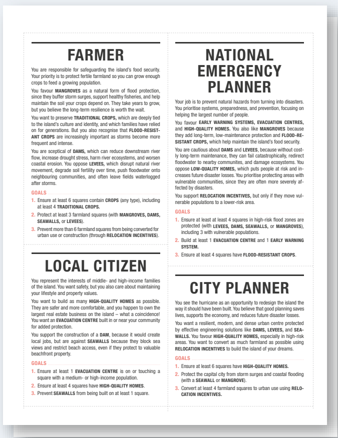
FACT SHEET



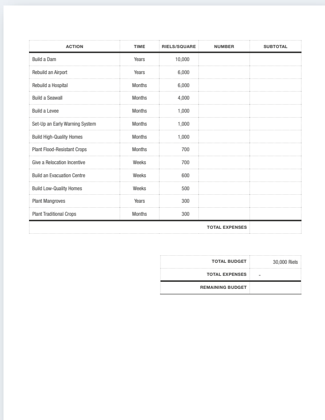
ADDITIONAL MAPS



ACTION GUIDE 3p.



CHARACTER CARDS 2p.



BUDGET TRACKER

This game is an adapted version of Breaking the Silos, a serious game originally developed by researchers at Vrije Universiteit Amsterdam (de Ruiter et al., 2021) for stakeholders, which we have modified for students.
https://gc.copernicus.org/articles/4/383/2021/gc-4-383-2021-discussion.html

INTRODUCTION 10 MIN

(UN)NATURAL DISASTERS: GAME GOALS AND CHALLENGES

The goal of the game is to try to address a so-called 'wicked problem'[1] – a problem that occurs across all or multiple regions and impacts all sectors of our society. These problems are difficult to solve because they involve many interrelated factors, multiple stakeholders, uncertain outcomes, trade-offs, and no single 'correct' solution, and they can change over time and affect different groups in different ways.

During the game, students will need to:

- Balance their character's goals with those of other players (consider ripple effects on other systems).
- Consider local versus national priorities (trade-offs and equity implications).
- Weigh short-term needs against long-term resilience (think about sustainability and adaptation).
- Decide between cheaper, less sustainable options and more costly, sustainable ones.
- Take justice and fairness into account in decision-making (who benefits and who may be disadvantaged).
- Recognise power dynamics, such as who gets to decide and who is excluded.

> **TEACHER TIP**
> The game is based on a fictional case study inspired by real-life examples, providing a neutral space to engage with sensitive topics through role-play. If you have the time and motivation, feel free to adapt the game using a local case to make it more relevant.

SET-UP (10 MIN)

1. Introduce the game by reading the game rules aloud to the students, then allow a few minutes for clarifying questions.

2. Divide students into groups of six, arrange desks into groups, and distribute the following game materials:

- The game rules
- A game board
- A set of action tokens
- An action guide
- The fact sheet
- Additional maps
- A budget tracker

3. Write the six character roles on the board: Farmer, Local Citizen, National Emergency Planner, City Planner, Minister of Finance, President. Give groups 2 minutes to decide who will play each role. No group can have more than one student in the same role. Once players have decided, they can collect their character card.

> **TEACHER TIP**
> This lesson can be streamlined to a one-hour lesson by focusing on a few key discussion questions and assigning **WORKSHEET 6.1** as homework.
> If your students are new to the concept of climate justice, you can refer to Lesson 'Climate Justice' in the Climate Change and Land teacher's manual as a helpful primer.

PROCEDURE 1H35

GAMEPLAY (45 MIN)

4. Give them another 5 minutes to read their character cards and understand their goals, motivations, and interests.

5. Set a timer for 30 minutes. During this time, students must create an action plan by deciding which actions to implement and where to place them on the board, using the information provided and considering the different trade-offs. They must discuss, debate, negotiate, and compromise, to balance their individual character goals with the group's shared objectives, while staying within budget.

6. When the 30 minutes are up, allow groups 10 extra minutes to finalise their action plan. Remind them that the president has the final say and can veto any decision that is made.

DEBRIEF & GROUP DISCUSSION (50 MIN)

7. Bring the class together to reflect on their experience. Invite each group to share their action plan. If time is short, select a few groups to present contrasting approaches.

1 Lazarus RJ (2009) Super wicked problems and climate change: restraining the present to liberate the future. Georgetown University Law Center. [Online] Available at https://scholarship.law.georgetown.edu/cgi/viewcontent.cgi?article=1152&context=facpub

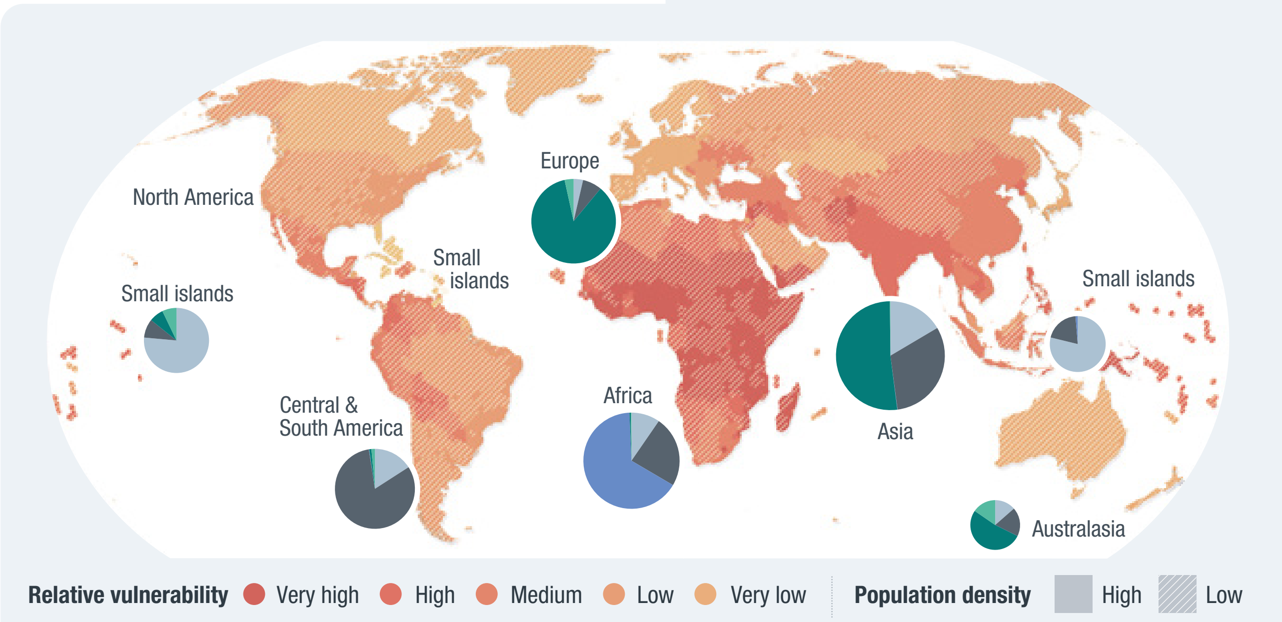
During this time, you can facilitate discussion using the following example questions:

- *Did everyone manage to achieve their individual goals? Which goals were easier or harder to achieve, and why?*
- *What was your biggest challenge as a team? What did you struggle with?*
- *Think about the roles each player had in your group (Farmer, Local Citizen, etc.). How did these roles affect the decisions your group made? Were any perspectives or populations left out, and what impact might that have had on your plan?*
- *What trade-offs did you have to make? Who benefited, and who lost out?*
- *What did your group choose to prioritise (e.g. short-term fixes vs long-term resilience, certain areas or populations), and why?*
- *Were there moments where helping one area increased risks elsewhere? How did you deal with those tensions?*
- *Do you feel like your action plan represented the needs of everyone on the island? Who was included, and who was left out?*

8. Show the students the following figure and ask them to consider:

- *What does this figure tell us about how climate hazards affect people and society in different regions?*
- *Which regions are most vulnerable? Which are least vulnerable? Why do you think this is?*
- *Which regions have the highest death rates from each hazard (heat, drought, floods, storms, wildfires)?*
- *Why do some regions suffer more from certain hazards than others?*
- *Are there regions where multiple risk factors combine to make people more vulnerable?*
- *How does this connect to what you learnt through the game?*

This map shows relative human vulnerability and mortality per hazard event and per region which differ between and within countries, strongly determining how climate hazards impact people and society.



The size of the pie charts shows average mortality per hazard event per region between 2010 and 2020. The slices of pie charts show the distribution of deaths from a particular hazard.

Source: Adapted from IPCC, WG2 TS. https://www.ipcc.ch/report/ar6/wg2/downloads/report/IPCC_AR6_WGII_TechnicalSummary.pdf

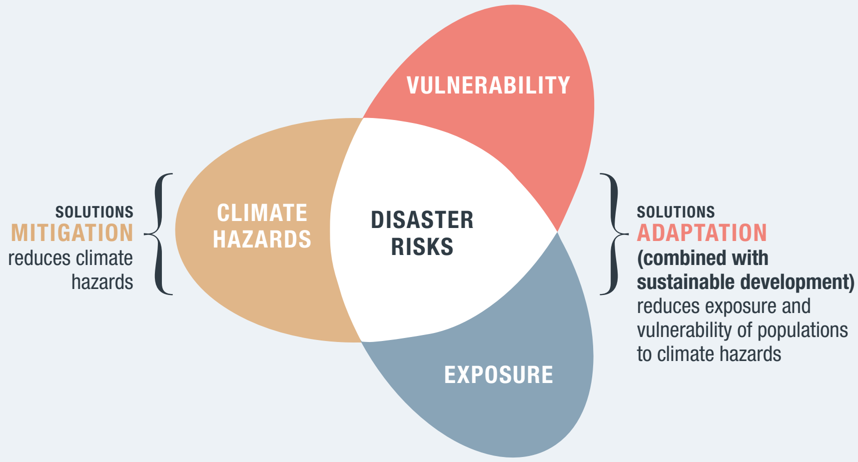
9. Show the students the following figure:

- *What factors determine disaster risk?*
- *Can you think of a real-life example where a weather or climate event (hazard) affected people to a different degree because of where they lived (exposure) or their ability to respond and recover (vulnerability)?*
- *How did these factors change the impacts of the disaster?*

10. Distribute **WORKSHEET 6.1** to each student to work on individually.

Climate change impacts and risks depend on three factors: climate hazards, exposure, and vulnerability. Adaptation helps reduce exposure and vulnerability to climate hazards, while mitigation aims to limit the physical impacts of climate change by addressing its root causes.

- **Climate hazards:** droughts, floods, wildfires, sea level rise, storms, etc.
- **Vulnerability:** women, children, the elderly, people with disabilities, displaced populations, etc.
- **Exposure:** people living in floodplains or coastal areas, hospitals, schools, and roads in hazard-prone zones, etc.



Source: Adapted from IPCC, WG2 TS. https://www.ipcc.ch/report/ar6/wg2/downloads/report/IPCC_AR6_WGII_TechnicalSummary.pdf

WRAP-UP 15 MIN

1. Invite a few volunteers to share their key takeaways with the class.

2. Start a discussion on how often the poorest are the most affected by climate change, and whether they think that this is fair.

3. Ask students if they think disasters are natural. Highlight that while natural hazards like floods or storms occur in nature, disasters happen when those hazards interact with human systems that are vulnerable. Disasters don't affect everyone equally – risk depends not only on where people live, but also on how exposed and vulnerable they are. A person's livelihood, as well as social, economic, and political factors all influence their level of vulnerability.

4. Explain that **compounded vulnerability** happens when multiple hardships (e.g. poverty, poor housing, lack of resources) add up, making it harder for people to prepare for, cope with, or recover from disasters.

5. Discuss how different aspects of a person's identity – such as gender, age, ethnicity, disability, religion, social class, or sexual orientation – can overlap and influence how they experience risk during disasters. These aspects of identity do not automatically make someone vulnerable. Instead, the ways society treats people with these identities can increase or decrease their risk. This concept is called intersectionality.

Both the game and IPCC figures illustrate how these layers of risk overlap, creating complex challenges for disaster planning.

6. Emphasise that disasters are 'wicked problems' because they have no simple or clear solutions, involve the viewpoints of various groups of people affected by a disaster, and require tough choices and trade-offs. In real life, decision-makers often take months or even years to develop a risk management plan. Adaptation planning is an ongoing, evolving process, where plans must be revisited and adapted over time as new information becomes available or circumstances change.

7. Stress that **fair** and inclusive adaptation planning means making sure everyone's needs are considered, especially those of the most vulnerable and those that are not involved in the decision-making process. Encourage students to reflect on how understanding vulnerability, intersectionality, and risk can help society build more fair, effective, and resilient responses to climate change.

TEACHER TIP

Talking about vulnerability can sometimes lead to stereotypical views. It is important to clarify that **vulnerability is determined by systems and conditions or circumstances, not by a person's identity** – for example, being elderly, Indigenous, or a migrant. What makes individuals vulnerable is the way society or the state treats their identity and reinforces unequal access to power, decision-making, resources, and protection.

BACKGROUND FOR TEACHERS
UNDERSTANDING DISASTERS AND COMPOUNDED VULNERABILITY IN ADAPTATION TO CLIMATE CHANGE

BEYOND 'NATURAL' DISASTERS

We often hear of 'natural disasters', but this term can be misleading. While natural hazards like floods, storms, and droughts are indeed natural events, they are called disasters when the hazards have impacts on human societies, causing significant harm. For example, a hurricane hitting an uninhabited island is a natural event but not a disaster, whereas Hurricane Katrina was a disaster because of its devastating consequences (social, economic, and political) for the affected communities.

The extent and severity of disasters depend not only on the hazard itself but also on where people live, how exposed they are, and how vulnerable they are to harm. These vulnerabilities are shaped by human decisions, social systems, and environmental conditions. Factors such as poverty, inequality, marginalisation, and poor infrastructure can amplify the impacts of hazards, turning natural events into disasters. Understanding this helps us see the importance of addressing root causes through better planning, governance, and community resilience.

RISK, VULNERABILITY & COMPOUNDED EFFECTS

Risk is the likelihood that a hazard will cause harm. It depends on three main factors:

~ **Hazard:** the natural event (e.g. flood, storm).
~ **Exposure:** how many people, buildings, or resources are in harm's way.
~ **Vulnerability:** how likely those exposed are to be harmed, based on factors such as poverty, health status, quality of housing, social networks, and access to resources and services.

While **risk** describes the overall probability of harm, **vulnerability** refers specifically to the social, economic, and physical conditions that make some people more susceptible to harm than others. For instance, people living in poverty, those with limited mobility, or those facing social discrimination are often less able to prepare for or recover from disasters. These vulnerabilities can add up and combine, leading to **compounded vulnerability,** where multiple disadvantages overlap and reinforce each other, increasing the overall vulnerability.

For example, a low-income family living in a poorly built home in a flood-prone area may be especially vulnerable because of limited savings, poor infrastructure, and lack of access to emergency support. Their risk is higher not only because they are exposed to the hazard, but because their vulnerability is compounded. If multiple disasters occur within a short time, the situation can worsen. This is an example of compounded risk, where hazards interact with existing vulnerabilities – or where multiple risk factors combine – to increase the overall danger and make recovery more difficult.

Effective climate change adaptation is not only about managing natural hazards; it's also about addressing the social and structural causes of vulnerability. Understanding the interplay of hazards, exposure, compounded risk and vulnerability helps build more resilient and just communities.

WORKSHEET 6.1 PAGE 1/2

FACING THE STORM: WHAT SHAPES RISK AND RECOVERY?

Reflect on what you learned from the game and group discussion, and use your own experiences and observations to answer the following questions.

Question 1. Which populations on the island are more vulnerable to storms? Which populations are less vulnerable?
Think about location, resources, and social factors.

Question 2. What factors make some people more vulnerable than others, and how?
Consider things like age, income, housing quality, language, and access to services.

Question 3. Give one example of an individual or population who faces compounded vulnerabilities – multiple risk factors like age, disability, income, or location that combine to increase risk – either in the game or in real life.
Explain how these factors can make the impacts of disasters worse for them.
Example: an elderly farmer living in a flood-prone area without access to emergency services.

Question 4. Did your group's decisions in the game help or worsen outcomes for these vulnerable populations?
In what ways?

Question 5. Should your group have prioritized short-term solutions or long-term resilience measures?
Explain your reasoning and the potential impacts on the island's people and infrastructure.

FACING THE STORM: WHAT SHAPES RISK AND RECOVERY?

Question 6. Can you think of other factors that might make people more vulnerable during storms, either in the game or in real life?
Examples: language barriers, disability, lack of transportation, limited social support.

Question 7. If you could add one additional person to your response team, who would you include and why?
How might having this additional perspective make planning more complex or create new trade-offs?

Question 8. If you could revise your action plan, what would you do differently to improve resilience and support recovery?

Question 9. What did you notice about the other groups' action plans? Were there strategies you would try or avoid, and why?

Question 10. In your opinion, what would a 'fair' disaster response plan look like?

LESSON 7 HOW TO COMMUNICATE ABOUT EXTREME WEATHER EVENTS?

MAIN SUBJECTS
Media and Information

DURATION
Preparation: 15 min
Activity: 1h30 (classroom)
+ More time for the project (~ 10h)

AGE GROUP
11 years and up

TEACHING METHOD
Video Analysis
Project-Based Learning (Video Production)
Mind-Mapping

OVERVIEW
Students will learn through the voices of experts that global warming has led to an increased frequency and / or intensity of some extreme weather events. They will go deeper into the knowledge of some of these events and the tools scientists use to attribute them to climate change. They will also have the opportunity to learn about how such events are handled – beforehand (warning the population, installing protection measures against the impacts) and afterwards (aid to the affected population, reconstruction).

KEY CONCEPTS
Adaptation, Artificial Intelligence, Attribution, Compound Events, Droughts, Extreme Cold Events, Extreme Weather Events, Heatwaves, Heavy Precipitation, Risk Management.

LEARNING OUTCOMES
Students will be able to:
~ Describe and analyse the characteristics of different types of extreme weather events.
~ Identify how artificial intelligence is used to attribute extreme weather events to climate change.
~ Communicate about extreme weather events through a short video they will produce themselves.

TARGETED SUSTAINABILITY COMPETENCES
2.1 – Systems Thinking
3.3 – Exploratory Thinking

ASSOCIATED CLIM VIDEOS
All 8 CLIM videos

PREPARATION & MATERIALS 15 MIN

- **WORKSHEET 7.1** to print double-sided and distribute one flash card per student.
- **WORKSHEET 7.2** to print double-sided and distribute one flash card per group (one group = one video).
- **WORKSHEET 7.3** to print one-sided and distribute one worksheet per group.
- **WORKSHEET 7.4** to print if required depending on your students' level (one per group).
- **WORKSHEET 7.5** to print (two for each group).
- A camera / a smartphone or any recording material to shoot the video made by the students.
- Computers (or smartphones, or tablets) and an internet connection to watch the 8 short CLIM videos (see Introduction, page 8) and to run the multimedia animation on extreme weather events.

INTRODUCTION 10 MIN

As an introduction to this lesson, a series of eight videos, in which experts talk about one or more aspects of extreme weather events, is provided.

ACCESS THE 8 VIDEOS PLAYLIST ↗

VIDEO #1 **Extreme Events**
VIDEO #2 **AI to Study Extreme Events**
VIDEO #3 **Heatwaves and Droughts**
VIDEO #4 **Ecosystem Impacts**
VIDEO #5 **Severe Convective Storms**
VIDEO #6 **Cold Events**
VIDEO #7 **Compound Events**
VIDEO #8 **Management of Extreme Events**

Each group will become an expert in one specific topic. In order to do so, they will:
1. Watch the general video (Video #1) and the one assigned to their specific topic of expertise.
2. Answer the questions related to the videos (**WORKSHEET 7.1** and **WORKSHEET 7.2**).
3. Briefly present the video related to their expertise to their peers. The other groups have to fill in a question form with the correct information in **WORKSHEET 7.3,** either directly during the presentation or at home.

After this first step in the classroom, present the next step: the students will produce a short video based on the examples of the CLIM videos.

PROCEDURE OF PART 1 1 H20

PART 1: IN THE CLASSROOM
1. The whole class watches the Video #1, which introduces the topic of extreme events. The students answer the questions related to this video, using

WORKSHEET 7.1. This will train them before they do it on their own, in small groups.

> **TEACHER TIP**
> You will be the game master to read the questions to the class. Once the class has answered the questions, you can look at the other side of the card to read the answers.

2. Then, the students split up into small groups of 4 or 5 (depending on the number they are – ideally you have seven groups since there are 7 specific videos) and watch the respective video they are experts on.

3. Each group chooses one of the seven CLIM videos (make sure every video is chosen). The members of each group are now experts in the specific topic of the video – just like the author of the CLIM videos:

- **Video #2:** students become experts on how AI can be used to study the attribution of extreme weather events to climate change;
- **Video #3:** students become experts in heatwaves and droughts extreme events;
- **Video #4:** students become experts on how ecosystems are impacted by extreme weather events in a context of climate change;
- **Video #5:** students become experts in storms' formation in a context of climate change;
- **Video #6:** students become experts in cold extreme events and their formation in a context of climate change;
- **Video #7:** students become experts in compound events and their formation in a context of climate change;
- **Video #8:** students become experts in management strategies related to extreme weather events.

4. Each group has to answer a few questions related to its specific video (**WORKSHEET 7.2**). It is a set of cards with **3 or 4 questions on one side** of the card and the **corresponding answers on the other side.** Students designate a game master to read the questions to their peers (without looking at the answers).

The students might want to **watch the video several times,** especially if they disagree or if they are missing any answer. Once the group has agreed on an answer, the game master checks the answer on the back of the card and reads it to the others.

5. After answering the questions, each group prepares a short three-minute presentation with the main information of the video (free-format presentation).

After a group has given its presentation, the other groups answer the corresponding questions of **WORKSHEET 7.3** – either immediately (giving the students the possibility to ask the 'experts' for clarification or further details) or at home, using notes that they have taken during the presentation.

> **TEACHER TIP**
> All the answers to the **WORKSHEET 7.3** are provided for teachers.

6. After all the groups have given their presentations, you can briefly recap all the information learnt using the multimedia animation from Lesson 1 as a support tool. They can see the different types of extreme weather events on the map, remind them about the physics behind each of them and also the fact that some of them are attributed to climate change and some aren't. This recap is important to integrate everything they have learnt so far and to prepare them for the next part of this activity.

7. If you are doing this lesson at the end of your teaching module on extreme weather events, you may ask your students to **create a mind map summarising and connecting all the concepts** they have addressed during this teaching module on extreme weather events. There are no 'correct' answers, the idea is to use the mind map as a recap or an assesment tool. To make it easier, you might want to write the different concepts on cards, so that the students merely have to connect the different concepts in a logical way (see **WORKSHEET 7.4**). This list is non-exhaustive and students can add any additional words they consider relevant.

> **TEACHER TIP**
> The map can be created in small groups on a big sheet of paper or with the whole class if you are running out of time, on a shared file or directly on the whiteboard. Once they are done, each group presents its mind map. The subsequent discussions with the class allow them to improve their production (you can find a proposed mind map).

PROCEDURE OF PART 2
DEPENDING ON THE TIME AVAILABLE (ABOUT 10 HOURS)

PART 2: VIDEO PROJECT

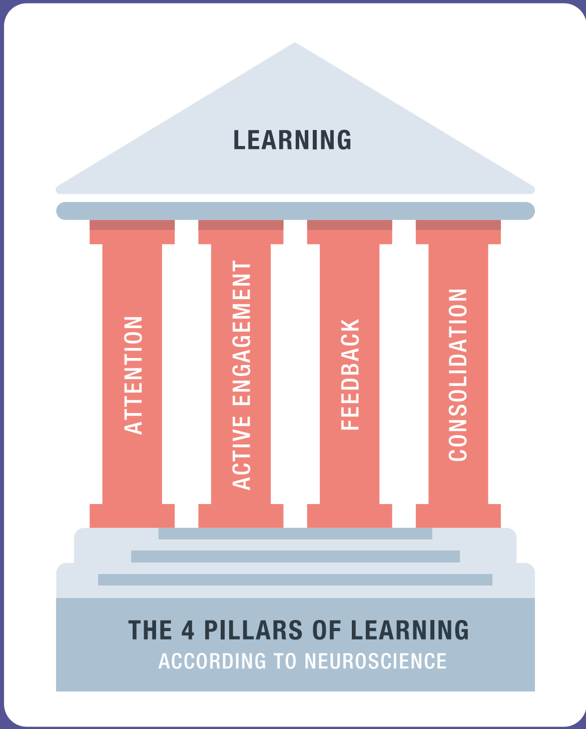
In this second part, students create a short video about extreme weather events based on what they have watched and learnt in the previous section (Part 1). They can either choose to focus on one extreme weather event among those presented in the multimedia animation on extreme weather events or on the extreme weather event(s) of their choice (e.g. depending on where they live, they might have experienced an extreme weather event or they

BACKGROUND FOR TEACHERS
MIND MAPS AND LEARNING OUTCOMES

According to Stanislas Dehaene[1], 'cognitive science has identified four main factors in successful learning: attention, active engagement, feedback and, finally, consolidation'. This can be represented as in the diagram on the right.

The creation of a mind map at the end of a teaching unit is a great opportunity to work on these four pillars, particularly consolidation. The activity itself requires commitment and active participation from the students, particularly during the presentation phase. Feedback is given by the teacher and other students during the presentations to the class, and the consolidation phase takes place during the elaboration of the mind map, which is the most important stage in the process of revisiting all the concepts covered during the teaching unit.

A mind map is a highly-structured creative tool that helps structure the information and share it with others. It can be carried out collectively, in which case it will be a tool that helps to use the same terms to designate the same concepts, and enables communication on the topic. Or it can be carried out individually, promoting creativity, thought organisation, and self-confidence, among other things.



1 'Apprendre! Les talents du cerveau, le défi des machines', Stanislas Dehaene, Odile Jacob 2018

might have relatives who did). This part could involve a literature teacher, for example, to assist with the scriptwriting.

A non-exhaustive list of milestones can be distributed (**WORKSHEET 7.5**) to each group to guide them through this activity.

FIRST STEP: VIDEO ANALYSIS

1. Ask students to form new groups of 4 or 5 or to recreate the groups of the first part (a time-saving strategy).

> **TEACHER TIP**
> If some students are already familiar with writing a script and shooting videos, try to distribute them into the different groups so that each group can have someone comfortable with this type of process.

2. Before starting to work on their own video, ask the groups to analyse the format of the videos they watched in Part 1.

Have them identify:
i. What works well (e.g. the music, the voices, the animations, the length, the illustrations, etc.).
ii. What is missing that they would like to add.

SECOND STEP: VIDEO PRODUCTION

3. Each group of students chooses one extreme weather event to focus on. Their choice can be based on their experience (if they/a relative already experienced an extreme weather event, or if they are interested in a past or a more recent extreme weather event, or if they want to learn more about a specific type of extreme weather event, etc.). The only rule is that each group must work on a different extreme weather event.

4. Once they have identified the topic they want to work on, the students have to do some research to gather information they will include in their video.

> **TEACHER TIP**
> You can help students by providing them with a list of resources.

5. After gathering information on their topic, students will have to learn how to write a script.

6. They start writing their scripts – this step requires help from the teacher to make sure that content and format are correct.

7. The final script should be proofread by the teacher(s). See the evaluation grid on **WORKSHEET 7.5**.

8. Students start filming. Everyone has a different role: speaker, camera operator, sound and light operator, special effects, film editor, etc.

> **TEACHER TIP**
> Some checkpoints are needed along the work to make sure students are on the right track. This can be organised in the form of small weekly meetings with each group, for example. For the evaluation, you can use the evaluation grid on **WORKSHEET 7.5**.

9. The teacher(s) give their feedback on the final version of the videos.

> **TEACHER TIP**
> Short videos (less than 3 minutes) are recommended to encourage students to watch the video to the end. The speech should be captivating and the rate not too fast. Subtitles may help students understand the content.
> Students can choose to incorporate footage, drawings, video clips, animation, etc. to help make some concepts easier to understand and to make the video more entertaining.

10. Videos can then be published either on their own social media accounts, on the school's website, or continuously on a TV screen in the school lobby and/or on the school's social media accounts, to share their work and raise awareness among the rest of the educational community.

> **TEACHER TIP**
> For publication on social media or on the school's website, **the consent of the legal guardians of children appearing in videos** is required.

WRAP-UP 10 MIN

This lesson represents a great opportunity for students to recap what they have learnt about extreme weather events and their attribution to human-induced climate change.

They have seen that extreme weather events are severe and unusual weather conditions that can have significant impacts on human societies and the environment in general. For some of them, frequency, intensity, and duration are changing in response to climate change. Studying extreme weather events is crucial to understanding their mechanisms as well as improving preparedness and adaptation measures. Weather modelling and artificial intelligence help to improve our knowledge and understanding of these extreme weather events, including their occurrence, and their attribution to human-induced climate change. Scientists compare climate models with and without human influence to evaluate the impact of greenhouse gas emissions on the intensity and frequency of extreme events.

Reminders and connections can be made with previous sessions if other lessons from the handbook have been done, as illustrated by the mind map built at the end of Part 1.

The second part of this lesson allows students to develop new skills in the production of videos, working as a team. Once they have produced their videos, students will be able to share their work and communicate about extreme weather events with the rest of the community.

WORKSHEET 7.1 PAGE 1/2 – QUESTIONS

VIDEO #1 – FLASH CARDS ON EXTREME WEATHER EVENTS

Print double-sided and distribute one flash card per student.

VIDEO #1
GENERAL OVERVIEW

QUESTION 1

What are two examples of extreme weather phenomena mentioned in the video?

QUESTION 2

How does global warming influence extreme weather events?

QUESTION 3

Why are extreme weather events particularly problematic?

A. Because they are always unpredictable.

B. Because they cause a great amount of disruption and damage, impacting society and the environment.

C. Because they are rare.

D. Because they only affect rural areas.

VIDEO #1
GENERAL OVERVIEW

QUESTION 1

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B. Because they cause a great amount of disruption and damage, impacting society and the environment.

C. Because they are rare.

D. Because they only affect rural areas.

WORKSHEET 7.1 PAGE 2/2 – ANSWERS

VIDEO #1 – FLASH CARDS ON EXTREME WEATHER EVENTS

Print double-sided and distribute one flash card per student.

VIDEO #1
GENERAL OVERVIEW

ANSWER 1

Floods and heatwaves.

ANSWER 2

The frequency and intensity of these events are changing. Some of them are becoming more common and more severe.

ANSWER 3

Answer B.

VIDEO #1
GENERAL OVERVIEW

ANSWER 1

Floods and heatwaves.

ANSWER 2

The frequency and intensity of these events are changing. Some of them are becoming more common and more severe.

ANSWER 3

Answer B.

VIDEO #1
GENERAL OVERVIEW

ANSWER 1

Floods and heatwaves.

ANSWER 2

The frequency and intensity of these events are changing. Some of them are becoming more common and more severe

ANSWER 3

Answer B.

VIDEO #1
GENERAL OVERVIEW

ANSWER 1

Floods and heatwaves.

ANSWER 2

The frequency and intensity of these events are changing. Some of them are becoming more common and more severe.

ANSWER 3

Answer B.

WORKSHEET 7.2 PAGE 1/4 – QUESTIONS

VIDEO #2 TO #8 – FLASH CARDS ON EXTREME WEATHER EVENTS

Print double-sided and distribute one flash card per group (one group = one video).

VIDEO #2
AI EXPERT

QUESTION 1

For what purpose do scientists use AI to study extreme weather events?

QUESTION 2

Are all extreme events caused by climate change?

QUESTION 3

What is attribution in relation to extreme events?

QUESTION 4

How do researchers assess whether an extreme weather event has been influenced by climate change?

A. By using climate models that compare scenarios with and without human influence.

B. By analysing only satellite data.

C. By observing extreme weather events over a 10-year period without further analysis.

VIDEO #3
HEATWAVES AND DROUGHTS EXPERT

QUESTION 1

What is a heatwave and how long does it usually last?

QUESTION 2

What causes heatwaves and how do they affect the local meteorology?

QUESTION 3

How do dry soils increase heat conditions?

A. By increasing the formation of heat-trapping clouds.

B. They don't contain enough moisture to have a cooling effect.

C. They prevent solar radiation from reaching the surface.

QUESTION 4

What characterizes a drought event and what consequences can you think of?

VIDEO #4
IMPACTS ON ECOSYSTEMS EXPERT

QUESTION 1

What effects do long periods of drought have on forests?

QUESTION 2

Why are forests important for humans?

A. Because they are used to produce furniture and they host significant biodiversity.

B. Because they release carbon dioxide through photosynthesis.

C. Because they limit sea level rise.

QUESTION 3

How do forests help to limit climate change?

VIDEO #5
SEVERE CONVECTIVE STORMS EXPERT

QUESTION 1

What is a severe convective storm and what are the signs that this is happening?

QUESTION 2

What can be the consequences of severe convective storms?

QUESTION 3

What conditions are needed for a convective storm to form?

A. A stable atmosphere, heat, and precipitation.

B. An unstable atmosphere, moisture, and a mechanism to lift the air.

C. A drop in temperature and light winds.

QUESTION 4

How could this type of event evolve with climate change?

VIDEO #2 TO #8 – FLASH CARDS ON EXTREME WEATHER EVENTS

Print double-sided and distribute one flash card per group (one group = one video).

VIDEO #5 SEVERE CONVECTIVE STORMS EXPERT

ANSWER 1

A severe convective storm is a powerful thunderstorm that can bring dangerous weather. Some signs that a severe convective storm is happening are, for example: heavy rain, lightning and tornadoes.

ANSWER 2

Severe convective storms can cause flooding and landslides (e.g. in Italy in August 2023).

ANSWER 3

Answer B.

ANSWER 4

The atmosphere will get warmer and more unstable, promoting the formation of convective storms. Additionally, heavier rain is expected.

VIDEO #4 IMPACTS ON ECOSYSTEMS EXPERT

ANSWER 1

Trees cannot grow normally, use up their energy reserves, and become weak, making them vulnerable to insect attacks. Dry forests and dead trees are also more likely to catch fire.

ANSWER 2

Answer A.

ANSWER 3

They absorb carbon dioxide (CO_2) from the atmosphere when they grow, which slows the increase in atmospheric CO_2 caused by humans.

VIDEO #3 HEATWAVES AND DROUGHTS EXPERT

ANSWER 1

A heatwave occurs when temperatures are higher than usual and generally lasts for at least two or three days.

ANSWER 2

They are caused by areas of high pressure that remain blocked over a region for days or weeks. Heat is trapped and cloud formation is prevented, leading to clear skies and a reduction in precipitation.

ANSWER 3

Answer B.

ANSWER 4

Drought events are characterised by periods of abnormally dry weather. They can lead to water deficits in the soils, and rivers can be affected and carry less water. This impacts the environment including all living organisms.

VIDEO #2 AI EXPERT

ANSWER 1

To detect and predict extreme events in time and space, and to understand their mechanisms, causes, and roots.

ANSWER 2

Not all extreme events are caused by climate change, but scientists show that many are intensifying because of it.

ANSWER 3

Connecting specific weather events to climate change.

ANSWER 4

Answer A.

VIDEO #2 TO #8 – FLASH CARDS ON EXTREME WEATHER EVENTS

Print double-sided and distribute one flash card per group (one group = one video).

VIDEO #6
COLD EXTREME EVENTS EXPERT

QUESTION 1

Are we only facing warm events in this context of climate change?

QUESTION 2

What is the stratospheric polar vortex?

A. Powerful winds that circulate around the North Pole in winter.

B. An area of high pressure that only forms during the summer.

C. A phenomenon that warms the Arctic during cold waves.

QUESTION 3

What are 'teleconnections' in the climate system?

VIDEO #7
COMPOUND EVENTS EXPERT

QUESTION 1

What is a compound event?

QUESTION 2

Why are compound events particularly challenging?

A. Because they can never be predicted.

B. Because their combined effects are often more severe than those of isolated events.

C. Because they only occur in coastal areas.

QUESTION 3

Can you give one example of a compound events?

QUESTION 4

How is climate change impacting this kind of event, and what are the reasons for that? Name two reasons.

VIDEO #8
MANAGEMENT OF EXTREME EVENTS EXPERT

QUESTION 1

What are the four key steps in extreme weather events management?

QUESTION 2

Why is adaptation essential in the management of extreme weather events?

A. To completely prevent extreme weather events from occurring.

B. To reduce the severity of future impacts by strengthening infrastructures and adopting sustainable practices.

C. To enable international coordination during relief efforts.

QUESTION 3

Is the management of extreme weather events the duty of one person/entity?

VIDEO #2 TO #8 – FLASH CARDS ON EXTREME WEATHER EVENTS

Print double-sided and distribute one flash card per group (one group = one video).

VIDEO #8
MANAGEMENT OF EXTREME EVENTS EXPERT

ANSWER 1

The four key steps are: preparation, response, recovery, and adaptation.

ANSWER 2

Answer B.

ANSWER 3

No, the management of extreme weather events requires collaboration and coordination between different actors such as local, national or international organisations and governments and communities for example. It is a global challenge.

VIDEO #7
COMPOUND EVENTS EXPERT

ANSWER 1

It is the combination of extreme weather events happening simultaneously or in quick succession.

ANSWER 2

Answer B.

ANSWER 3

Heavy rainfall occurring after a wildfire. The soil is burnt, which prevents an efficient water absorption process, which subsequently promotes the risk of floods and landslides.

ANSWER 4

In this context of climate change, the frequency and intensity of compound events increase. This is due to several factors such as temperature rise and sea level rise, for example.

VIDEO #6
COLD EXTREME EVENTS EXPERT

ANSWER 1

No, we also observe cold extreme events – they can become more frequent in some areas due to climate change.

ANSWER 2

Answer A.

ANSWER 3

These are long-distance interactions in the climate system. For example, a change in one region of the Earth can have an impact on other regions.

VIDEO #2 TO #8 – QUESTION CARDS ON EXTREME WEATHER EVENTS

Print one-sided and distribute one worksheet per group.

VIDEO #2
AI EXPERT

QUESTION 1

What is the main role of artificial intelligence (AI) in the study of extreme weather events?

☐ **A.** It identifies the mechanisms, causes, and attribution of extreme weather events.

☐ **B.** It prevents extreme weather events from occurring.

☐ **C.** It replaces meteorologists by analysing weather data in real time.

QUESTION 2

What does 'attribution' mean when talking about extreme weather events and climate change?

☐ **A.** Predicting the occurrence of weather events before they happen.

☐ **B.** Linking specific extreme events to human-caused climate change.

☐ **C.** Measuring the rate of global warming.

QUESTION 3

How do scientists use climate models to understand the impact of human activity on extreme weather events? ....

....

....

VIDEO #3
HEATWAVES AND DROUGHTS EXPERT

QUESTION 1

What is the main cause of heatwaves?

☐ **A.** The rapid formation of clouds over a region.

☐ **B.** A sudden increase in precipitation and humidity.

☐ **C.** High-pressure systems that get stuck over a region.

QUESTION 2

What is the impact of heatwaves on soils?

....

....

....

....

....

QUESTION 3

What can help people cope with heatwaves and droughts?

☐ **A.** Encourage the use of artificial rainfall.

☐ **B.** Reduce energy consumption to limit temperatures during summer.

☐ **C.** Improve forecasting and manage water more effectively.

VIDEO #4
SEVERE CONVECTIVE STORMS EXPERT

QUESTION 1

What are the three main essential ingredients for convective storms to form?

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....

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....

QUESTION 2

What impact does climate change have on convective storms?

☐ **A.** They will be less frequent but will cause more snow.

☐ **B.** The atmosphere will become more unstable, and rainfall will be more intense.

☐ **C.** They will be less frequent and will affect larger areas.

VIDEO #5
IMPACTS ON ECOSYSTEMS EXPERT

QUESTION 1

Why do extended periods of drought weaken trees?

☐ **A.** Trees are exhausted because drought increases their growth.

☐ **B.** Because they increase biodiversity, which is harmful for their development.

☐ **C.** Because they reduce their energy reserves and make them vulnerable to insect attacks.

QUESTION 2

Why are forests important to limit climate change?

☐ **A.** They absorb carbon dioxide from the atmosphere as they grow.

☐ **B.** They prevent fires from occurring.

☐ **C.** They increase local temperatures to warm ecosystems.

QUESTION 3

Why are forests important to humans? Give at least 2 reasons.

....

....

....

....

....

VIDEO #2 TO #8 – QUESTION CARDS ON EXTREME WEATHER EVENTS

Print one-sided and distribute one worksheet per group.

VIDEO #6
COLD EXTREME EVENTS EXPERT

QUESTION 1

What is the stratospheric polar vortex and what are its consequences?

....
....
....
....
....

QUESTION 2

How do cold waves reach mid-latitudes?

- [ ] **A.** When the polar vortex is stronger, it pushes cold air southwards.
- [ ] **B.** When the winds of the polar vortex weaken, cold air from the Arctic can head southwards.
- [ ] **C.** When climate models predict a rapid rise in temperatures.

QUESTION 3

How do extreme cold events evolve with climate change?

- [ ] **A.** Extreme cold events become rarer and less intense.
- [ ] **B.** Extreme cold events become more frequent and intense.
- [ ] **C.** Extreme cold events remain constant despite climate change.

VIDEO #7
COMPOUND EVENTS EXPERT

QUESTION 1

What is a compound event?

- [ ] **A.** A series of extreme temperatures over a short period of time.
- [ ] **B.** A combination of several extreme weather events.
- [ ] **C.** An isolated event with a significant impact on water cycle.

QUESTION 2

Why do they represent a bigger threat than a single extreme event?

....
....
....
....
....

QUESTION 3

What is contributing to the increase in compound events in this context of climate change?

- [ ] **A.** Lower temperatures and more droughts.
- [ ] **B.** Rising temperatures, rising sea levels, and more extreme rainfall.
- [ ] **C.** Reduced rainfall and fewer storms.

VIDEO #8
MANAGEMENT OF EXTREME EVENTS EXPERT

QUESTION 1

What is the main goal of the preparation phase in the management of extreme weather events?

- [ ] **A.** To react immediately after an event by providing medical care.
- [ ] **B.** Prepare in advance by developing early warning systems.
- [ ] **C.** Rebuilding damaged infrastructures after an event.

QUESTION 2

What does the recovery phase include after an extreme weather event?

- [ ] **A.** Evacuating communities before an event.
- [ ] **B.** Coordinating relief efforts and providing food and water.
- [ ] **C.** Rebuilding infrastructures, homes, and lives, while improving future resilience.

QUESTION 3

Can you describe the adaptation step? ....
....
....

WORKSHEET 7.4
NON-EXHAUSTIVE LIST OF WORDS

→ This list will help you elaborate the mind map. You can cut out the cards to create it.

CLIMATE CHANGE	DURATION	INTENSITY
PREDICTION	ADAPTATION	HUMAN SOCIETIES AND ECOSYSTEMS
UNCERTAINTY	ATTRIBUTION	IMPACTS
WATER CYCLE	VULNERABILITY	DISASTER MANAGEMENT
HUMAN ACTIVITIES	FREQUENCY	MODELS
EXTREME WEATHER EVENTS	ARTIFICIAL INTELLIGENCE	

WORKSHEET 7.5

CREATING A VIDEO: NON-EXHAUSTIVE LIST OF MILESTONES

	STEPS THROUGH VIDEO MAKING	TEACHER'S ASSESSMENT
#1	**Identification of one extreme weather event** ☐ Determine which extreme weather event will be addressed. ☐ Search for key information about this event: causes, impacts, attribution, potential testimonies, etc. ☐ The sources of information are relevant and reliable (mainstream press, reports, etc.).	
#2	**Writing a structured script** ☐ **Introduction:** brief presentation of the event (what it is, where and when it occurs). ☐ **Development:** scientific causes, human/environmental consequences, attribution to climate change, etc. ☐ **Conclusion:** solutions to mitigate impacts, potential improvements in forecasting, etc. ☐ Communication is clear, complete and comprehensible, with no language errors. ☐ The script clearly specifies the type of extreme event and cites the sources of information.	
#3	**Preparation of roles and equipment** ☐ Assign different roles (presenters, camera operator, technician, video editor, etc.). ☐ Check the equipment (camera, smartphone, microphone, tripod, lighting, etc.).	
#4	**Selection of the place and visuals to include in the video** ☐ Identify a suitable location for filming. ☐ Choose images, videos, graphics, etc., to improve understanding and / or to make the video more engaging.	
#5	**Optimise the shooting** ☐ Make short and clear takes to limit editing issues. ☐ Use varied shots (e.g. close-ups, wide shots) to make the video more dynamic.	
#6	**Post-production steps** ☐ Add subtitles and possible sound effects. ☐ Review the video before the presentation to ensure clarity.	

GLOSSARY [1]

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 beneficial opportunities.

ARTIFICIAL INTELLIGENCE
Computer systems capable of performing tasks that normally require human intelligence.

ATTRIBUTION
Event attribution studies seek to determine to what extent anthropogenic climate change has altered the probability or magnitude of particular extreme weather and climate-related events. They have shown clear evidence for human influence having increased the probability of many extremely warm seasonal temperatures and reduced the probability of extremely cold seasonal temperatures in many parts of the world. The evidence for human influence on the probability of extreme precipitation events, droughts, and storms is more mixed.

CLAUSIUS-CLAPEYRON RELATION
A scientific principle which explains that warmer air can hold more water vapor. Studies show high confidence that the maximum amount of moisture the atmosphere can hold increases by approximately 7% for every 1°C of global warming.

CLIMATE JUSTICE
This term is used to acknowledge the social and political dimensions of the challenges associated with 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).

CLIMATE PROJECTION
Simulation of a future climate based on a scenario.

COLLECTIVE CHOICES
A decision-making problem where a certain number of stakeholders must choose actions among a large number of potential alternatives in order to achieve some collective as well as individual objectives.

COMPOUND VULNERABILITY
A situation where multiple factors – such as social, economic, environmental, and institutional conditions – accumulate, overlap, and interact to increase the susceptibility of individuals or communities to harm from hazards like climate change or natural disasters.

COMPOUND EVENT
Sometimes, several extreme events can occur simultaneously or successively. This has been demonstrated for a wide range of climate hazards, such as droughts, heatwaves, fires and floods. We talk about compound events: these combinations can lead to extreme effects that are much greater than the effects of each individual event on its own. Indeed, multiple stress factors can quickly overwhelm a system's ability to cope.

Compound events can be:
- extremes occurring simultaneously or successively;
- extremes occurring in the same place;
- combinations of events which are not themselves extreme but which lead to an extreme event.

CONFIDENCE (LEVEL OF CONFIDENCE)
In the IPCC report, the level of confidence refers to the degree of certainty in the validity of a finding, based on the type, amount, quality, and consistency of evidence and the degree of agreement among experts. The level of confidence is indicated by a qualitative scale ranging from very low to very high, with corresponding probabilities ranging from less than 10% to over 90%. The level of confidence is used to communicate the degree of uncertainty associated with a particular finding or statement.

DEVELOPMENT
A comprehensive economic, social and political process aimed at the constant improvement of the well-being of the entire population (UN Declaration on the Right to Development (1986)).

DISASTER
Severe alterations in the normal functioning of a community or a society due to hazardous physical events (such as extreme weather events) interacting with vulnerable social conditions, leading to widespread adverse human, material, economic, or environmental effects that require immediate emergency response to satisfy critical human needs and that may require external support for recovery.

DISTRIBUTION OF DATA
The distribution of data shows how the values in a dataset are spread out or organised. For example, if we record temperatures in one place over many years, most values are close to an average, while some are much higher or lower.

DROUGHT
An exceptional period of water shortage for existing ecosystems and the human population (due to low rainfall, high temperature, and/or wind).
- **Agricultural and ecological drought:** depending on the affected biome: a period with abnormal soil moisture deficit, which results from combined shortage of precipitation and excess evapotranspiration, and during the growing season impinges on crop production or ecosystem function in general.
- **Hydrological drought:** a period with large runoff and water deficits in rivers, lakes and reservoirs.
- **Meteorological drought:** a period with an abnormal precipitation deficit.

EXTREME COLD EVENT
A very rare episode of extreme cold, e.g. in North America in February 2021, with temperatures reaching -30°C in Havre, Montana, in the United States.

1 Note that this glossary is listening only the terms referred as key concepts for each activities. If you need definitions of other notions important for climate change education, please refer to the general glossary available on OCE's website.

EXTREME WEATHER EVENT
A rare meteorological event with a strong negative impact on human society and ecosystems (e.g. tornadoes, major fires, droughts, or heatwaves). Climate change is increasing the frequency and amplitude of some extreme events worldwide (extreme cold events are reduced however).

EVAPORATION
The physical process by which a liquid (e.g. water) becomes a gas (e.g. water vapour).

EVAPOTRANSPIRATION
The combined processes through which water is transferred to the atmosphere from open water and ice surfaces, bare soil, and vegetation that make up the Earth's surface.

FREQUENCY
How often a particular event or phenomenon occurs within a specific time frame. In climate science, it is commonly used to describe the number of times extreme weather events – such as heatwaves, floods, or storms – happen over a given period. An increase in frequency indicates that these events are becoming more common.

FLOODS
The overflowing of the normal confines of a stream or other water body, or the accumulation of water over areas that are not normally submerged. Floods can be caused by unusually heavy rain, for example, during storms and cyclones. Floods include river (fluvial) floods, flash floods, urban floods, rain (pluvial) floods, etc.

FLUX
A movement (a flow) of matter (e.g. water vapour, particles), heat or energy from one place to another, or from one medium (e.g. land surface) to another (e.g. atmosphere).

HAZARD
The potential occurrence of a natural or human-induced physical event that may cause loss of life, injury, or other health impacts, as well as damage and loss to property, infrastructure, livelihoods, service provision, and environmental resources.

HEATWAVE
A period of abnormally hot weather, often defined with reference to a relative temperature threshold, lasting from two days to months.

HEAVY PRECIPITATION
A very large-scale event that occurs very rarely in a given location. The categories of extreme precipitation can be defined by their duration (hourly, daily or longer period, e.g. 5 days), although all are qualitatively of high magnitude.

HURRICANE
A strong tropical cyclone that occurs in the Atlantic Ocean or northeastern Pacific Ocean. A tropical cyclone is a rapidly rotating storm system with a low-pressure area, a closed low-level atmospheric circulation, strong winds, and a spiral arrangement of thunderstorms that produce heavy rain and squalls.

INTENSITY
The magnitude or severity of an extreme weather event – such as the maximum daily rainfall, peak wind speeds during a storm, or highest temperatures in a heatwave.

INTERSECTIONALITY
The complex, cumulative way in which the effects of multiple forms of discrimination (e.g. racism, sexism, classism) combine, overlap, or intersect especially in the experiences of marginalised individuals or groups.

INTERGOVERNMENTAL PANEL ON CLIMATE CHANGE (IPCC)
The Intergovernmental Panel on Climate Change (IPCC) was established in 1988 to provide comprehensive assessments of the state of scientific, technical, and socio-economic knowledge on climate change, its causes, potential impacts, and response strategies. Since then, the IPCC has produced six multi-volume assessment reports. It also publishes special reports on specific topics such as disasters and extreme events, the ocean and cryosphere, land use, and more. The IPCC is open to all United Nations member countries and includes 195 states. Its reports are written by hundreds of scientists from these member states. The IPCC's work also results in Summaries for Policymakers, which are reviewed line by line and formally approved unanimously by state delegates, with the consent of the scientific authors.

INVESTMENT
The allocation of resources – such as money, time, or effort – into projects or assets with the expectation of generating beneficial returns in the future. In the context of sustainable development and climate action, investment involves funding initiatives that aim to produce positive environmental, social, and economic outcomes, alongside financial gains.

MALADAPTATION
Actions that may lead to increased risk of adverse climate-related outcomes, including via increased greenhouse gas emissions, increased or shifted vulnerability to climate change, more inequitable outcomes, or diminished welfare, now or in the future. Most often, maladaptation is an unintended consequence.

MARINE HEATWAVE
A sustained period during which sea-surface temperatures remain anomalously high for several days to months, relative to a historical baseline (usually above the 90th percentile). These events can span local to ocean-basin-scale areas.

METEOROLOGICAL PARAMETERS
Quantifiable elements of weather, such as temperature, precipitation, wind, humidity, and pressure, used to describe and characterize climate and weather systems, following World Meteorological Organization standards.

MODEL
Simplified representation of reality. Using models has many advantages, but it also has its limitations. It cannot represent all the complexity of reality. Climate models are analogies for reality to make predictions/projections, they are based on physical equations to quantify global and regional climate change, and its impacts such as extreme weather events. Climate models are evolving thanks to the integration of new parameters and improvements in computers and technical power, leading to greater resolution and accuracy. There are different types of models:
- Analog model: simplified representation of reality using physical objects.
- Digital model: simplified representation of reality using numeric data. The accuracy and resolution determine the quality of the model.

PRECIPITATION
Any product of the condensation of atmospheric water vapour that falls from clouds due to gravitational pull. The main forms of precipitation include drizzle, rain, sleet, snow, ice pellets, graupel and hail. Precipitation occurs when a portion of the atmosphere becomes saturated with water vapour (reaching 100% relative humidity), so that the water condenses and 'precipitates' or falls.

PREPAREDNESS
The process and capacity – such as plans, institutions, infrastructure, resources, and early-warning systems – that enable societies to anticipate, respond to, and recover from climate-related hazards, thereby reducing potential harm.

PROBABILITY
A measure of how likely it is that a particular event will occur. In climate science, probability is used to express the likelihood of specific outcomes, such as the occurrence of extreme weather events or the effectiveness of mitigation strategies.

RESERVOIR (OF WATER)
A component or components of the water cycle where water is stored (e.g. glaciers, rivers, ocean, groundwater).

RISK
The likelihood of a climate hazard (drought, cyclone, flood, etc.) occurring in a vulnerable area. The most significant risks cause potentially severe damage to humans and socio-ecological systems due to the interaction between climate hazards and the vulnerabilities of exposed societies and systems.

RISK MANAGEMENT
Plans, actions, strategies or policies to reduce the likelihood and / or magnitude of adverse potential consequences, based on assessed or perceived risks.

RUNOFF
The flow of water over the surface or through the subsurface, which typically originates from the part of liquid precipitation and / or snow- / ice-melt that does not evaporate, transpire or refreeze, and returns to water bodies.

SCIENTIFIC EXPERIMENT
In a scientific experiment, you need at least two devices that vary from each other by only one difference. This single difference always concerns the parameter to be tested. If the experiment consists of two devices, one of them can be called the test and the other the control.

STATISTICAL INDICATORS
Metrics used to quantify extremes, such as 99th or 90th percentiles, block maxima (e.g. annual maximum precipitation), and peak-over-threshold methods. These indicators identify events that are statistically 'rare' within the historical record, as defined by IPCC assessments.

STORM
Any disturbed state of the natural environment or the atmosphere. It may be marked by significant disruptions to normal conditions such as strong wind, hail, thunder and lightning (a thunderstorm), heavy precipitation (snowstorm, rainstorm), heavy freezing rain (ice storm), strong winds, etc. Storms have the potential to harm lives and property via storm surge, heavy rain or snow causing flooding or road impassibility, lightning, wildfires.

STORM SURGE
The temporary increase, at a particular locality, in the height of the sea due to extreme meteorological conditions (low atmospheric pressure and / or strong winds). The storm surge is defined as being the excess above the level expected from the tidal variation alone at that time and place.

VULNERABILITY
The propensity or predisposition to be adversely affected. Vulnerability encompasses a variety of concepts and elements, including sensitivity or susceptibility to harm and lack of capacity to cope and adapt.

WATER CYCLE
The cycle in which water evaporates from the ocean and the land surface, is carried over the Earth in atmospheric circulation as water vapour, condenses to form clouds, precipitates over the ocean and land as rain or snow, which on land can be intercepted by trees and vegetation, potentially accumulating as snow or ice, provides runoff on the land surface, infiltrates into soils, recharges groundwater, discharges into streams, and ultimately, flows into the oceans as rivers, polar glaciers and ice sheets, from which it will eventually evaporate again. The various systems involved in the hydrological cycle are usually referred to as hydrological systems.

WATER STATES
Water is present on Earth in three states gas (water vapour in the air), liquid (oceans, rivers, groundwater, rain, clouds, etc.), and solid (glaciers, snow crystals, hail, and ice). It constantly moves between the oceans, the atmosphere, and land. This movement is known as the *Water Cycle*.

WILDFIRE
An unplanned, uncontrolled and unpredictable fire in an area of combustible vegetation. Depending on the type of vegetation present, a wildfire may be more specifically identified as a bushfire (in Australia), desert fire, grass fire, etc.

ACKNOWLEDGEMENTS

This project is the result of extensive collaboration between the Office for Climate Education team, IPSL, and many scientific and educational partners, especially those involved in the XAIDA project.

The authors would like to thank:

The experts who support the OCE and who, through their critical review and suggestions contributed to the design of pedagogical activities. In alphabetical order: **Apurva Barve, Gabriel Brunnich Dunand, Nada Caud, Caroline Côté, Dim Coumou, Clotilde Dubois, Aglaé Jézéquel, Rebecca Ellis, Davide Faranda, Cliona Murphy, Manon Rousselle, Anwar Bhai Rumjaun, Jenny Schlüpman, Peter Stott, Alison Trew, Robert Vautard, Pascal Yiou.**

The experts who participated in the development of the interactive activities and video clips which accompany this teaching guide. In alphabetical order: **Clair Barnes, Emanuele Bevacqua, Dim Coumou, Miguel Angel Fernandez Torres, Raed Hamed, Nora Linscheid, Chen Lu, Xiaocen Shen.**

Teachers and their students who have tested the activities in their classrooms, as well as education inspectors who distributed the call to test the handbook. In alphabetical order: **Audrey Bassau, Florence Bouteloup, Julien Loche, Hélène Molina, Anne Parillaud, Laetitia Pireye, Julien Vanscoor.**

The people who have authorised the use of their teaching resources in this handbook: **Red Cross Climate Center** (lesson 5), **Ana Casanti** (lesson 6).

The following organisations, which have authorised the use of content from their own publications. In alphabetical order: **European Commission (Joint Research Center), IPCC, NASA, Nature, Nature Climate Change, Odile Jacob, UNESCO.**

The graphic designers and directors who contributed to the usability and attractiveness of these resources: **Dorothée Adam** (CLIM videos)**, Mareva Sacoun.**

Finally, the OCE would like to thank the following organisations, whose scientific, operational and financial support has been essential to the production of these educational tools. In alphabetical order:

Agence Française de Développement, Association Météo et Climat, Banque des Territoires – Groupe Caisse des Dépôts, CASDEN, Centre National de Recherche Scientifique, French ministries of Education, Ecological Transition, Europe and Foreign Affairs, and Higher Education and Research, European Commission, Fondation Crédit Mutuel – Alliance Fédérale, Fondation Domorrow, Fondation Ginkgo, Fondation Luciole, Fonds Français pour l'Environnement Mondial, Institut de Recherche pour le Développement, Institut Pierre-Simon Laplace, IPCC Working Groups I, II and III Technical Support Units, Météo-France, Siemens Stiftung, Sorbonne Université, UNESCO, Worldline Corporate Foundation.

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to provide us with your feedback on this guidebook.

Published by the Office for Climate Education, https://oce.global
ISBN 978-2-491585-24-2

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 fourth volume, ***Extreme Weather Events***, provides ready-to-use lessons for teachers that will help students understand climate change 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.

This volume focuses on the links between climate change and extreme weather events. It explores the spatial dimension of extreme events, their characteristics and their detection and attribution to climate change. Finally, it gives the opportunity to work on local adaptation to extreme events.

This handbook is part of a European project on extreme events called XAIDA (eXtreme events: Artificial Intelligence to Detect and Attribute Extreme Events to Climate Change), coordinated by seventeen European research institutes. The project aims to develop innovative methods to analyze recent high-impact weather events in order to better understand the role of climate change. It also seeks to assess whether such events, or even more intense ones, are likely to occur in the future. By involving key stakeholders across multiple sectors, XAIDA contributes to the development of improved risk assessments and adaptation strategies for extreme weather.

This resource:
- targets secondary school teachers (for 11+ year-old students);
- includes scientific and pedagogical backgrounds, lesson plans, activities, worksheets and
- links to external resources (videos and multimedia activities);
- is interdisciplinary with lessons covering the natural sciences, the social sciences, the arts
- and philosophy;
- promotes active pedagogies: inquiry, roleplay, debate and project-based learning, arts.

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N° 101003469

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ISBN 978-2-491585-24-2