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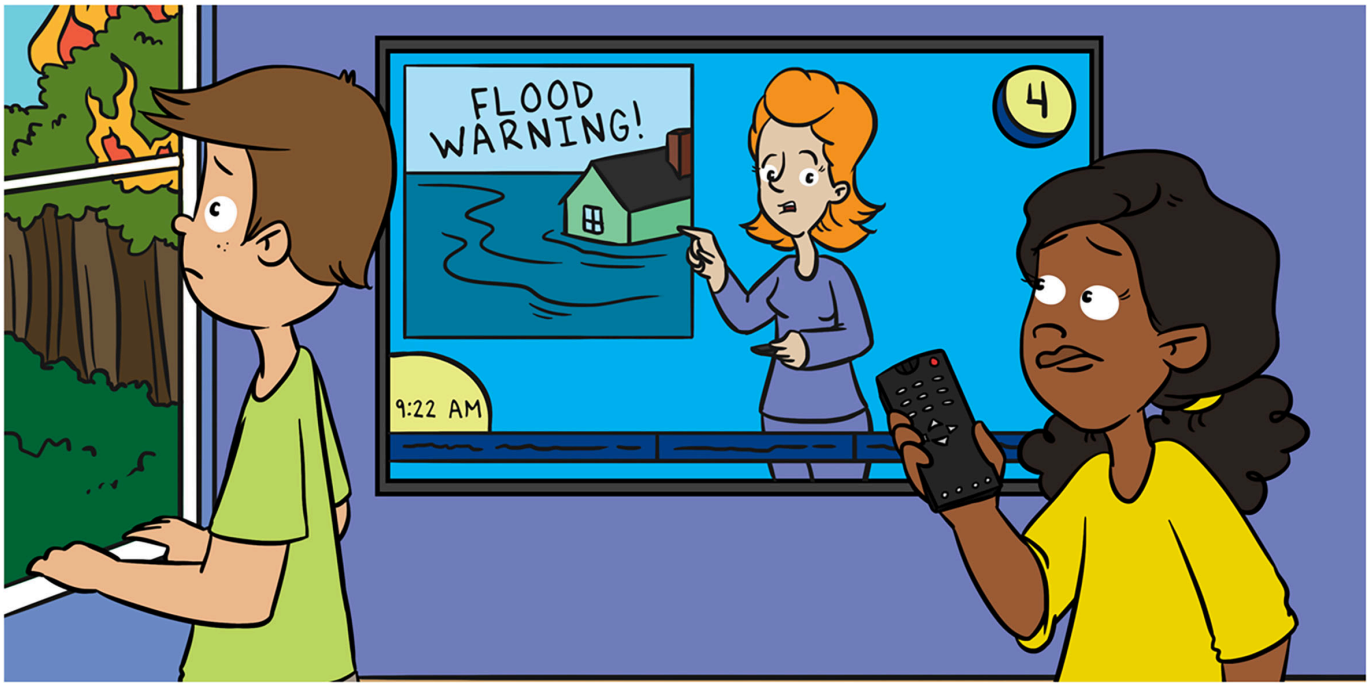

EXTREME CLIMATE AND WEATHER EVENTS IN A WARMER WORLD

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AGE: 14

HAYTAM
AGE: 14

KATELYN
AGE: 13

Extreme climate and weather events are unusual and rare events that often cause a lot of damage both to nature and to people. They take place in the air (storms, tornadoes, heavy rain, atmospheric rivers), in the ocean (storm surges, marine heatwaves), and on the land (wildfires, heatwaves, floods, droughts). Many weather and climate extremes happen naturally, even without climate change. But Earth's changing climate *does* change where and how often some extreme events take place, and how strong those events are. What are extreme climate and weather events? Will new or stronger extreme events happen due to climate change? How is climate change impacting extreme events? These are the type of questions that our team of

MACKENZIE

AGE: 15

SOUNDOUSS

AGE: 15

climate and earth scientists from around the world will answer in this article.

WHAT ARE EXTREME EVENTS?

Extreme **climate** and **weather** events are defined as unusual and rare events. They are so intense or out of place that they get special mention. Heatwaves, extreme rainfalls, floods, thunderstorms, typhoons, hurricanes, tornadoes, tropical cyclones, hailstorms, storm surges, droughts, and wildfires are all **extreme events** (Figure 1).

Extreme events are important because they often cause damage, both to nature and to people. The damage caused by extreme events can cost individuals, businesses, and governments a lot of money. For example, the October–November 2019 wildfires in California (USA) caused $25 billion in damage [1]. Extreme events also cause health problems and can even cause the deaths of people and animals. However, not all extreme events bring damage, and some can bring good changes. For example, some extreme rainfall events in California bring a precious supply of water to the region. We cannot stop extreme events from happening, but we can prepare and protect ourselves from them, and learn how to better take advantage of them when possible.

Many weather and climate extremes happen naturally, but **climate change** *does* change where and how often some extreme events take place, and how strong those events are. Some extreme events are already happening more often, are more intense, and will continue to worsen.

TYPES OF CLIMATE AND WEATHER EXTREMES

Most of us have experienced at least one type of climate and weather extreme, and some of us have experienced many. Types of storms like tropical cyclones, tornadoes, hailstorms, and storm surges are well-known extreme events (Figures 1g,i,j). These storms can be very intense and often do a lot of damage. Another group of extremes is linked to floods, and includes extreme rainfall and **atmospheric rivers**, or "rivers in the sky" (Figure 1h). Extreme events also include droughts (Figure 1a), heatwaves, and coldwaves. Heatwaves are common and happen in many regions of the planet, including the oceans! Wildfires are also extreme events (Figures 1b,k). Wildfires have many names: forest fires, grass fires, peat fires, bushfires, or hill fires. While they can be very dangerous, wildfires are also a natural part of the environment and are needed to maintain healthy **ecosystems**.

CLIMATE

The pattern of weather over many years. Climate includes things such as clouds, temperature, wind, humidity, snow, and rain. Climate is like weather but over a long time.

WEATHER

A specific event, like a hot day or a storm, that happens over a few hours, days, or weeks. Weather changes daily.

EXTREME EVENTS

Unusual and rare weather and climate events that are particularly intense or happen in unexpected locations.

CLIMATE CHANGE

Over the past 150 years, gases released by human activities have trapped more heat on the Earth than in the past, resulting in increased temperatures, glacial melting, and sea-level rise.

ATMOSPHERIC RIVER

A long, narrow corridor of strong horizontal moisture flow in the air. Atmospheric rivers usually bring heavy rainfall or snowfall.

ECOSYSTEM

A biological community of living and non-living things (and their interactions) in an area.

Figure 1

Different types of climate and weather extremes and their impacts: **(a)** Drought conditions near Jaguari dam, Brazil (January 2014). **(b)** Smoke from the Williams Flat Fire (WA, USA, 8 August 2019). **(c)** The "Victoria's hailstone" in Villa Carlos Paz in Argentina (8 February 2018). **(d)** Paris during a heatwave (France). **(e)** New Jersey shoreline after a storm surge (USA). **(f)** Flooding following hurricane Eta (Central America, November 2020). **(g)** Four tropical cyclones across the Pacific Ocean (1 September 2015): Typhoon Kilo, Hurricane Ignacio, Hurricane Jimena, and Tropical Depression 14E. **(h)** Atmospheric river bringing moisture from the tropics to the Western U.S. (2018). **(i)** Thunderstorm off the coast of Byron Bay, Australia. **(j)** Tornado. **(k)** Wildfire and firefighters near Bilpin, Australia (19 December 2019). See the Author's Note section for photo credits.

STORMS: HOW THEY FORM AND THEIR FUTURE

Air, water, and heat are the three main ingredients that make the weather. Depending on the combinations of these ingredients, different types of weather form and some can create storms. Updrafts (warm air moving upwards in the atmosphere) create clouds, which are made of small water droplets. When clouds move higher, the droplets get colder and form ice particles. As the particles get bigger and heavier, they start to fall as snow or rain.

Thunderstorms are storms with lightning, thunder, and hail. In winter, freezing air temperatures associated with strong winds can create snowstorms (blizzards). Some really big and intense storms, called typhoons, hurricanes, or cyclones (different names in different regions), can form over the ocean. These storms can be up to 200 km wide and can cause ocean water to flood onto the land when approaching the coasts. This is called a storm surge. Tornadoes are rotating air columns about 150 m wide that link clouds to the ground, and they have winds between 100 and 500 km per hour (faster than a car)!

Some storms are quite rare and only develop under very specific conditions. However, as Earth's climate warms, storms are predicted to happen more often and they will be stronger [2]. Warming air is more unstable and has more winds and updrafts, creating more powerful thunderstorms, tornadoes, and blizzards. The ocean is also getting warmer and the extra heat can fuel big cyclones, which can create more extreme storm surges in coastal regions.

ATMOSPHERIC RIVERS AND EXTREME RAINFALL

Away from the equator and tropics, there are storms called extra-tropical cyclones. These cyclones transport heat and moisture away from the tropics. Some of these storms become extreme when they pick up a lot of moisture. All this moisture can be carried very long distances (more than 2,000 km) in narrow corridors (<500 km across), and can travel as far as the Arctic and Antarctic regions. Scientists named these long corridors of moisture atmospheric rivers because they are like rivers in the sky [3]. A typical atmospheric river can carry more than double the flow of the Amazon River!

As atmospheric rivers rise high into the air, they become colder and form clouds. This happens quickly, especially when the atmospheric rivers hit a coast or a mountain range, and the moisture transforms into intense rain or snow [3]. While rain is a key part of Earth's water cycle, extreme rain can cause too much water to fall in too short a time. We call rainfall "violent" when the ground receives more than 5 cm of water in 1 h. The most extreme rainfall in a day occurred in La Réunion, an island in the southern Indian Ocean, where 1.8 m of rain fell during the passage of Cyclone Denise over 2 days in 1966. Extreme rainfall brings severe risks to human health, the environment, and our economy. Impacts include flash flooding, landslides, damage to buildings and farmland, loss of livestock, and damage to lands and forests that increase soil erosion.

HEATWAVES AND DROUGHTS

Heatwaves are usually defined as times when temperatures are much higher than expected over a few days in a row. Heatwaves can happen everywhere—from Siberia to India. There are many reasons why heatwaves occur, including some weather patterns like anticyclones (also called "highs"), and climate patterns such as El Niño. Climate change also influences heatwaves. We know that the more the planet warms due to climate change, the more heatwaves we will experience, and these heatwaves will get longer and hotter [4]. Heatwaves like the European heatwave of July 2019 are now 100 times more likely to occur, due to climate change.

Droughts occur when there is low water availability over a period of a few months or longer. Although droughts occur on different timescales and for different reasons, droughts and heatwaves are linked. During droughts, we are more likely to experience heatwaves because dry conditions favor warmer temperatures. Also, when a heatwave occurs, the heat can increase the rate at which moisture evaporates from vegetation and the land, increasing the severity of drought.

Understanding how climate change impacts droughts is trickier than it is for heatwaves. Decreased rainfall can be caused by several different climate patterns. Because of the **natural variability** of these patterns, it can be difficult to detect a long-term change in rainfall. However, some weather patterns that normally bring rainfall are shifting due to climate change, which can increase the likelihood of drought over these areas.

NATURAL VARIABILITY

Changes in climate caused by non-human forces. For example, changes in the sun, volcanic eruptions, and interacting climate patterns result in natural climate variability.

WILDFIRES

Fire is a natural and essential part of many ecosystems around the world. Fire is needed to regenerate and maintain healthy forests and grasslands. However, wildfires can also do a lot of damage, destroying homes, killing people, causing breathing illnesses from smoke, and impacting ecosystems, particularly fire-sensitive species and communities. Climate change increases wildfire risk by making Earth hotter, which dries out the vegetation and makes it more flammable. Fire seasons are starting earlier in the year and lasting longer.

Wildfires are occurring more often and burning larger areas in many parts of the world, such as the Amazon region, Australia, Siberia, and North America, but it is not always easy to determine how much of the increased wildfire activity is due to climate change. Other factors, like deforestation, expansion of agriculture, and short-term changes in weather and climate conditions, can also have a big influence on fire activity. However, the link between climate change and the recent increase in wildfires and area burned has been proven in Australia and North America [5, 6]. The 2019/20 Black Summer wildfires in Australia were unprecedented in their size, strength, and impact. Areas that burnt included parts of rainforests that would not normally have wildfires [7].

More severe wildfires are likely to occur in a hotter and drier world, increasing the risk of wildfires in areas where fires were not previously common. Wildfires lead to more wildfires, because wildfires release large amounts of carbon into the atmosphere, further increasing global warming and amplifying climate change.

WHAT DO CLIMATE EXTREMES LOOK LIKE IN THE FUTURE?

Climate change is increasing the frequency, severity, and impacts of some extreme events. The world has already warmed an average of 1.1°C since the late 1800s. Because of Earth's changing climate, we can expect hotter heatwaves, drier droughts, stronger storms, and more extreme rainfall (Figure 2).

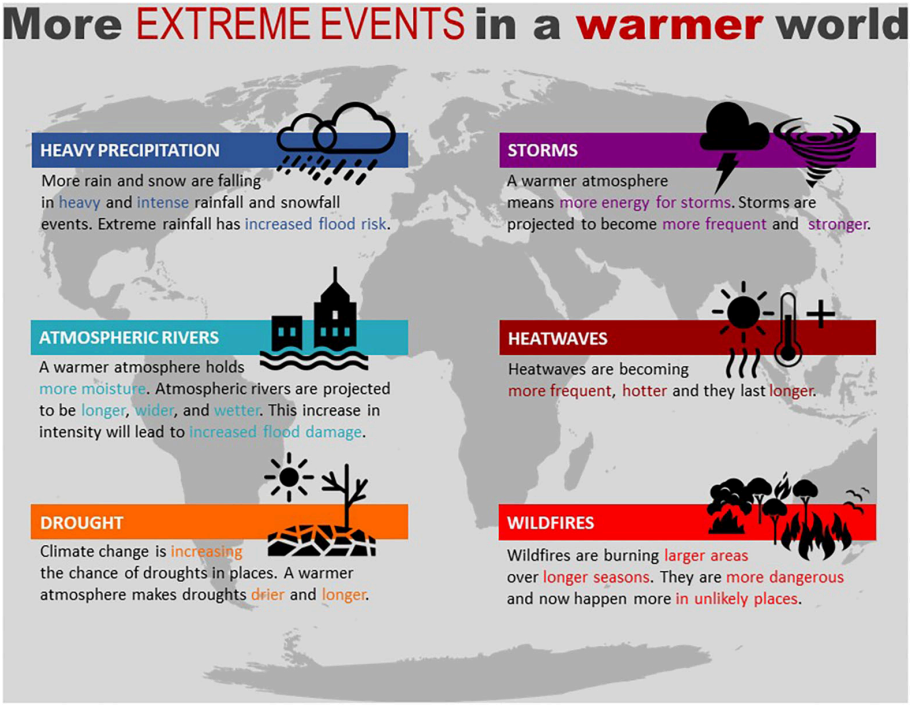

Figure 2

Climate change has already increased the frequency, severity, and impact of some extreme events. Wildfires are more frequent and larger, and heatwaves happen more often and are hotter. In the future, we can expect drier droughts, stronger storms, more extreme rainfall, and more intense atmospheric rivers.

A warmer and wetter atmosphere can hold more water—about 7% more water for every degree of warming. The extra heat and water in the atmosphere mean that there is more energy for storms that generate intense rainfall. As a result, we expect more intense rainfall in the future, with increased floods and damage to structures like buildings and roads. Climate change also increases the risk of coastal flooding due to higher sea levels and more storms.

Some extreme events have already been affected by climate change. Wildfires are now more dangerous and fire seasons have lengthened. Climate change has also already increased how often heatwaves happen. If we want to protect ourselves and our planet from a future full of many more extreme events, governments around the world must plan to rapidly stop deforestation and the burning of coal, oil, and gas. These activities have been driving climate change over the past century and contributing to the increased risk of extreme events. The world must pull together to create a future in which extreme events, and the damage they cause, remain relatively rare.

AUTHOR'S NOTE

The credits and sources for the photos used in Figure 1 are **(a)** Nacho Doce, Reuters; **(b)** David Peterson, U.S. Naval Research Laboratory; **(c)** Victoria Druetta; **(d)** Beboy, Shutterstock; **(e)** N.C. DOT and U.S. DOT; **(f)** The Guardian; **(g)** NASA/NOAA GOES Project; **(h)** NOAA NESDIS;

(i) Enrique Diaz, Getty Images; **(j)** Jason Persoff, Alamy; and **(k)** David Gray, Getty Images.

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This article is dedicated to Dr. Rebecca Harris and her work. Rebecca was an outstanding and inspiring scientist and colleague, who very sadly passed away in December 2021. She worked tirelessly on climate risks and adaptation solutions for a better future. In addition to recognising Rebecca and her life's contributions to the field of climate science, we would like to thank the many other climate and earth scientists around the world, who are passionate about our planet and make understanding climate change and its impacts possible. This work puts together many results from this large research community. We also give a big thank you to the young reviewers for their time and effort; their commitment to improve science literacy is valued. AM and SP-K acknowledge support from the ARC Center of Excellence for Climate Extremes (CE170100023). IG thanks FCT/MCTES for support to CESAM [UIDP(UIDB)/500017/2020] and Project ATLACE (CIRCNA/CAC/0273/2019) through national funds. SP-K acknowledges funding from the Australian Research Council grant number FT170100106.

REFERENCES

1. National Academies of Sciences, Engineering, and Medicine. 2016. *Attribution of Extreme Weather Events in the Context of Climate Change (Report).* Washington, DC: The National Academies Press.
2. Steffen, W., Dean, A., and Rice, M. 2019. *Weather Gone Wild: Climate Change-Fuelled Extreme Weather in 2018*. Sydney, NSW: Climate Council of Australia Report.
3. Ralph, F. M., Rutz, J. J., Cordeira, J. M., Dettinger, M., Anderson, M., Reynolds, D., et al. 2019. A scale to characterize the strength and impacts of atmospheric rivers, *Bull. Am. Meteorol. Soc.* 100:269–89. doi: 10.1175/BAMS-D-18-0023.1
4. Steffen, W., Hughes, L., and Perkins, S. 2014. *Heatwaves: Hotter, Longer, More Often*. Sydney, NSW: Climate Council of Australia Report.
5. Abatzoglou, J. T., and Williams, A. P. 2016. Impact of anthropogenic climate change on wildfire across western US forests. *Proc. Natl. Acad. Sci. U.S.A.* 113:11770–5. doi: 10.1073/pnas.1607171113
6. Abram, N. J., Henley, B. J., Sen Gupta, A., Lippmann, T. J., Clarke, H., Sharples, J. J., et al. 2021. Connections of climate change and variability to large and extreme forest fires in southeast Australia. *Commun. Earth Environ*. 2:8. doi: 10.1038/s43247-020-00065-8
7. Canadell, J. G., Meyer, C. P., Cook, G. D., Dowdy, A., Briggs, P. R., Knauer, J., et al. 2021. Multi-decadal increase of forest burned area in Australia is linked to climate change. *Nat. Commun.* 12:6921. doi: 10.1038/s41467-021-27225-4

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CONFLICT OF INTEREST: The authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

YOUNG REVIEWERS

FARAH, AGE: 14
My name is Farah, I am 14 years old, my school level is the first year of high school, my favorite subjects are physics and mathematics, in my free time I read books and surf the net. As a social person, I like discussions on scientific phenomena and discoveries, my dream is to be an engineer.

HAYTAM, AGE: 14
My name's Haytam, I am 14 years old. My academic level is the third preparatory. My favorite subjects are: maths, physics, science, and English. My hobbies are: swimming, drawing and reading. I have practiced taekwondo for 2 years. I speak English and French fluently, I have previously participated in the Arab reading challenge and I participated in the math Olympiad too. My dream is to be a doctor or a vet.

KATELYN, AGE: 13
I am a 13 year old girl who enjoys reading and doing art. My favorite animal is a cat and I like to write short stories.

MACKENZIE, AGE: 15

My name is Mackenzie, and I enjoy music (both playing and listening), books (fantasy in particular), and sports (my favorite is tennis). I also enjoy science, math, and language, but the thing I enjoy most is backpack camping.

SOUNDOUSS, AGE: 15

My name is soundouss, I am 15 years old, my Academy level is first year in high school, my favorite subjects are Physics, French and English, my hobbies are swimming and reading, I speak Arabic and English, my dream is to become a bank manager, company manager, or a journalist.

AUTHORS

AMELIE MEYER

Dr. Amelie Meyer is passionate about climate change, polar science, and ocean circulation. Her work looks at how and why the polar oceans are changing. Amelie has spent several months both in the Arctic and in the Southern Ocean collecting data to answer these questions. She currently works for the ARC Center of Excellence for Climate Extremes based at IMAS, at the University of Tasmania in Australia. *Amelie.Meyer@utas.edu.au

HÉLÈNE BRESSON

Dr. Hélène Bresson has always been passionate about nature and science. She has studied many forms of severe weather such as thunderstorms, lightning, tornadoes, and tropical and polar cyclones. She loves traveling, experiencing different weather, and learning about weather's impact on our planet and our lives. Hélène is currently studying ice clouds with satellite and model data, to understand how they form and evolve and how they impact the weather and the climate. She is currently working at the Laboratoire d'Optique Atmosphérique, in the north of France.

IRINA V. GORODETSKAYA

Dr. Irina Gorodetskaya is a meteorologist who loves studying extreme environments, such as the Arctic and Antarctic regions, and extreme phenomena, such as atmospheric rivers. She believes that to understand these phenomena, we must measure them! She has been measuring and analyzing snow and atmospheric rivers in Antarctica for more than 10 years. She is one of the lead authors of the Intergovernmental Panel on Climate Change 6th Assessment Report, in which she explains how polar regions change. Irina currently works at the University of Aveiro, Portugal.

REBECCA M. B. HARRIS

Dr. Rebecca Harris was an outstanding and inspiring climate impact scientist. An ecologist by training, her work focused on the combined impacts of climate change and extreme events on natural and human systems. She recently contributed as a Lead Author to the Intergovernmental Panel on Climate Change Sixth Assessment Report, which gave her hope that governments around the world will make the changes needed to slowdown climate change and safeguard our future. Rebecca

was not only a great researcher, but also a great leader, an inspiring lecturer, and a respected supervisor, both in and outside the School of Geography, Planning, and Spatial Sciences at the University of Tasmania in Australia where she worked. Alas, Rebecca Harris passed away in December 2021. She is greatly missed by the many people that knew and admired her.

SARAH E. PERKINS-KIRKPATRICK

Dr. Sarah Perkins-Kirkpatrick is a climate scientist who loves studying heatwaves. She has spent the last 10 years learning everything she can about them! Sarah's work has focused on how to measure heatwaves, what drives them, how they are changing, and how climate change may explain current and future heatwaves. She is also very interested in the health impacts they cause, and how these impacts may also be driven by climate change. Sarah currently works at the ARC Center of Excellence for Climate Extremes at UNSW in Sydney, Australia.