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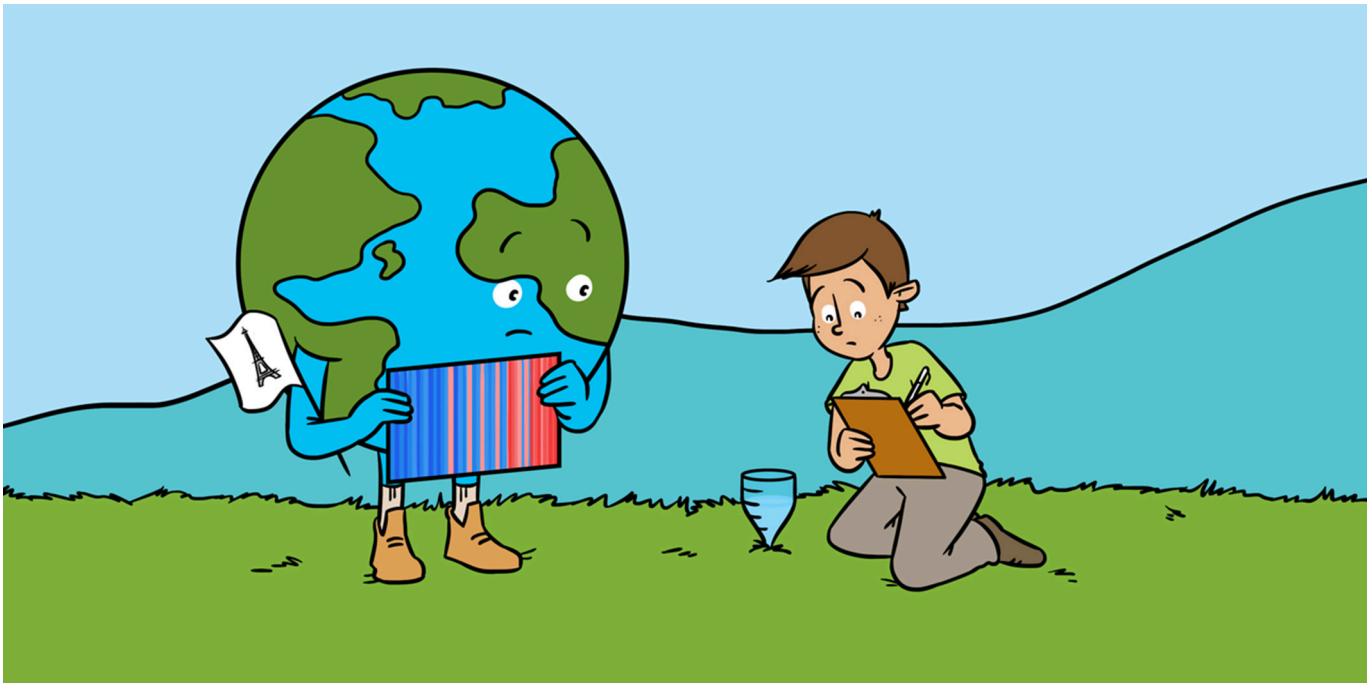
EARTH AND ITS RESOURCES
Published: 16 March 2023
doi: 10.3389/frym.2023.716536



HOW HAS OUR CLIMATE CHANGED ALREADY?

Ria Sarkar[1*], *Rene Orth*[2] *and Martha M. Vogel*[3]

[1] *Department of Earth and Planetary Sciences, Rutgers University, Piscataway, NJ, United States*
[2] *Department of Biogeochemical Integration, Max Planck Institute for Biogeochemistry, Jena, Germany*
[3] *Man and the Biosphere Programme, Division of Ecological and Earth Sciences, Natural Sciences Sector, UNESCO, Paris, France*

YOUNG REVIEWERS:


KAZIM
AGE: 13


PRICE
AGE: 14


PROVIDENCE
AGE: 10

It is easy to recognize that Earth's climate is changing. Scientists agree that the climate changes they observe are mostly caused by humans, primarily due to the greenhouse gases emitted by the burning of fossil fuels. Climate change has severe consequences—it leads to glaciers melting; sea levels rising; increased numbers of dangerous heatwaves, wildfires and droughts; decrease yields from food crops; and loss of ecosystems. We can monitor changes in Earth's climate by tracking the global average temperature. In this article, we will introduce the concept of climate and discuss how Earth's climate has changed in the past decades. We conclude with an explanation of the Paris Agreement, a treaty that nations have created to work together to limit global warming and to avoid the most dangerous of its impacts.

CLIMATE VS. WEATHER

Many people think of climate change as something we must protect humans from *in the future*. But Earth's climate has *already* changed and will likely continue to change for years to come [1]. What kinds of changes will we continue to see? "Before jumping into the details, we must first explain what we actually mean by the terms "climate" and climate change". Earth's **climate system** has five main parts: the atmosphere, which is the air around and above us; the hydrosphere, which is the liquid water in oceans, rivers, soils, and lakes; the cryosphere, which is the snow and ice, including glaciers and sea ice; the pedosphere and lithosphere, which are the layers of soils and rocks beneath our feet; and the biosphere, which contains living things like animals, plants, and humans (Figure 1). See also this Frontiers for Young Minds article.

CLIMATE SYSTEM

The combination of all domains affecting our climate, including the atmosphere (air), hydrosphere (water), cryosphere (ice), lithosphere (soil and rock), and the biosphere (living organisms).

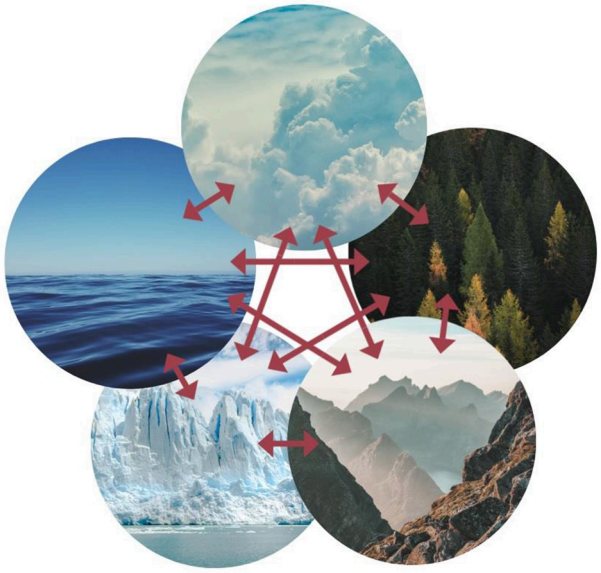


Figure 1

The Earth's climate system has several interacting parts. Emissions of greenhouse gases, no matter if from natural sources or human activities, consequently affect all parts of the climate system through their interactions (Image credit: Femkenilene, https://en.wikipedia.org/wiki/Climate_system#/media/File:Climate-system.jpg).

WEATHER

The state of e.g., temperature, sunshine, rain, snow, and wind at the moment.

CLIMATE

The average of weather conditions over many years.

CLIMATE CHANGE

Changes in temperature, but also rain, wind, and sunshine, which happen slow but steady such that they can go unnoticed over some years but will become apparent after a few decades.

The parts of the climate system interact with each other. For example, clouds form rain (atmosphere) that hits the soil (pedosphere) and is then taken up by plants (biosphere). To get an idea of the condition of the climate system, scientists can measure properties of the climate, such as temperature, precipitation (rainfall, snowfall, hail, etc.), sea level, and glacier size. Any changes in the atmosphere that occur over hours or days are referred to as **weather**, while **climate** describes weather over longer time periods, typically in the range of 30 years or more. By comparing more recent measurements with data from the past, we can study **climate change**. Changes in climate can be natural, for example through volcanic eruptions, which can reduce incoming sunlight, or through changes in the Sun's activity or the Earth's distance to the Sun. But climate change can also be caused by humans. Humans change the climate by burning fossil fuels, e.g., with cars (fuel from oil), airplanes (fuel from oil), heating (using oil or gas), or power plants

(using coal or gas). This burning releases gases such as carbon dioxide into the atmosphere, and these gases send back some of the radiation emitted by Earth like a heat-trapping blanket. This greenhouse gas effect warms our planet. In addition, changes in climate also occur naturally, for example through volcanoes, which can reduce incoming sunlight, or through changes in solar activity or the Earth's distance to the Sun. Scientists agree that the climate changes we have observed since 1850 are primarily caused by humans, not natural causes.

HOW CAN GREENHOUSE GAS EMISSIONS CHANGE THE GLOBAL CLIMATE?

Humans change Earth's climate by burning fossil fuels (oil, gas, or coal) in cars, airplanes, heaters, or power plants. Fossil fuels are made of two elements: hydrogen and carbon. Burning produces energy and releases **greenhouse gases**, including carbon dioxide, into the atmosphere. Greenhouse gases in the atmosphere trap heat and send some of it back to Earth, instead of letting it escape into space. This way, greenhouse gases warm our planet. Without carbon dioxide in the atmosphere, Earth would be frozen. So, greenhouse gases keep our planet warm enough for life!

GREENHOUSE GASES

These are components of the air which are invisible but minimize the heat loss from the Earth's surface into space.

However, as more and more fossil fuels are burned, carbon dioxide builds up in the atmosphere. Once carbon dioxide is emitted, it spreads across the whole atmosphere—it does not matter which countries released it. Carbon dioxide stays in the atmosphere for hundreds to thousands of years! Increasing carbon dioxide concentrations in the atmosphere causes the **global average temperature** (which is the average surface air temperature on land and the average temperature of the ocean surface) to increase. Global average temperature is calculated from measurements taken in many locations across the planet, and more recently from satellite observations. Global temperature increases causes stronger heatwaves, droughts, wildfires, and storms, as well as melting glaciers and decreased snowfall. This is a problem for the entire Earth—vegetation, animals, and people. Even if greenhouse gas emissions were reduced today, the long-lasting carbon dioxide in the atmosphere would keep the Earth too warm... and if we *continue* to emit carbon dioxide, climate change will continue to increase.

GLOBAL AVERAGE TEMPERATURE

The average of the surface air temperatures on land and ocean surface temperatures.

Interestingly, the climate system is dampening human-made climate change. Approximately half of the human-made carbon dioxide emissions remain in the atmosphere to contribute to rising temperatures while the rest is taken up by oceans and the biosphere. However, we cannot be sure that these "ecosystem services" will continue in the same way. For example, warmer ocean water stores less gases and vegetation is threatened by droughts and wildfires.

WHAT TEMPERATURE CHANGES HAVE WE OBSERVED?

The warming stripes in Figure 2 show the global average temperature (you can also look at warming stripes for your own region at https://showyourstripes.info/s/globe). The stripes are arranged from left to right, representing the years 1901–2020. The stripes in recent years are red, which shows that temperatures are much hotter now than they were at the beginning of the twentieth century.

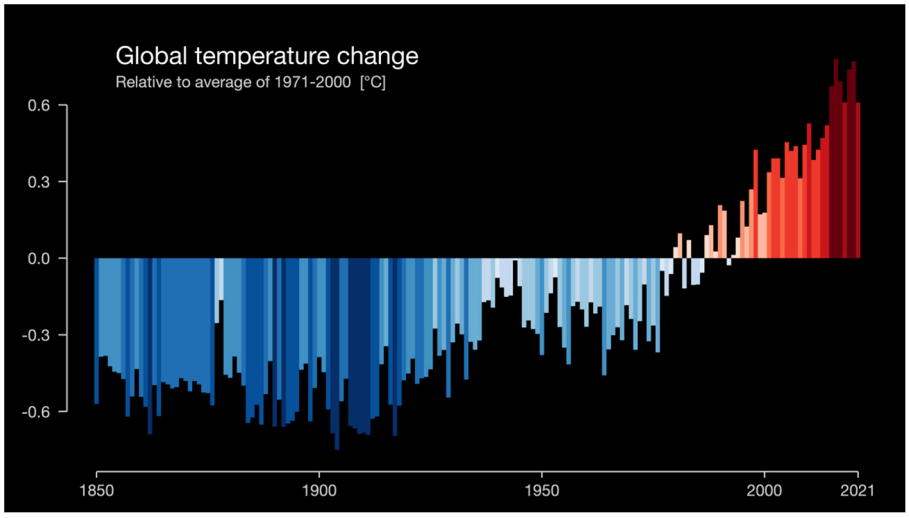


Figure 2

Figure 2

Earth's temperature is increasing. The colors of the stripes illustrate changes in global average temperature from 1901 to 2020, compared to a reference period from 1971 to 2000. The stripes turn from blue to red in more recent years, illustrating the increase in global mean temperature (Image credit: https://showyourstripes.info/c/globe).

The increase in global average temperature corresponds to the sharp increase in carbon dioxide emissions that began during the Industrial Revolution. In 2020, the global average temperature was around 1.25°C higher than it was from 1850 to 1900. Averaged over 30 years, today's global average temperature is currently around 1°C higher than it was in the mid-1800's.

WHY DOES AN INCREASE IN THE GLOBAL AVERAGE TEMPERATURE MATTER?

The increase in Earth's global average temperature due to greenhouse gas emissions has harmful consequences not only for the climate, but also for humans and nature (to learn more, see this Frontiers for Young Minds article). Every region of the globe is experiencing the impacts of climate change (Figure 3). For example, warmer air can hold more water vapor, which can lead to heavier rainfall, causing landslides and flash floods. On the other hand, some regions experience drier conditions, which can generate dangerous heatwaves and droughts. Hot, dry conditions can also cause wildfires, which have recently destroyed homes and habitats in southern Europe, the west coast of the US, and Australia. Increasing global average temperatures can also impact ecosystems, affecting fish migrations, coral reefs, forests, and more.

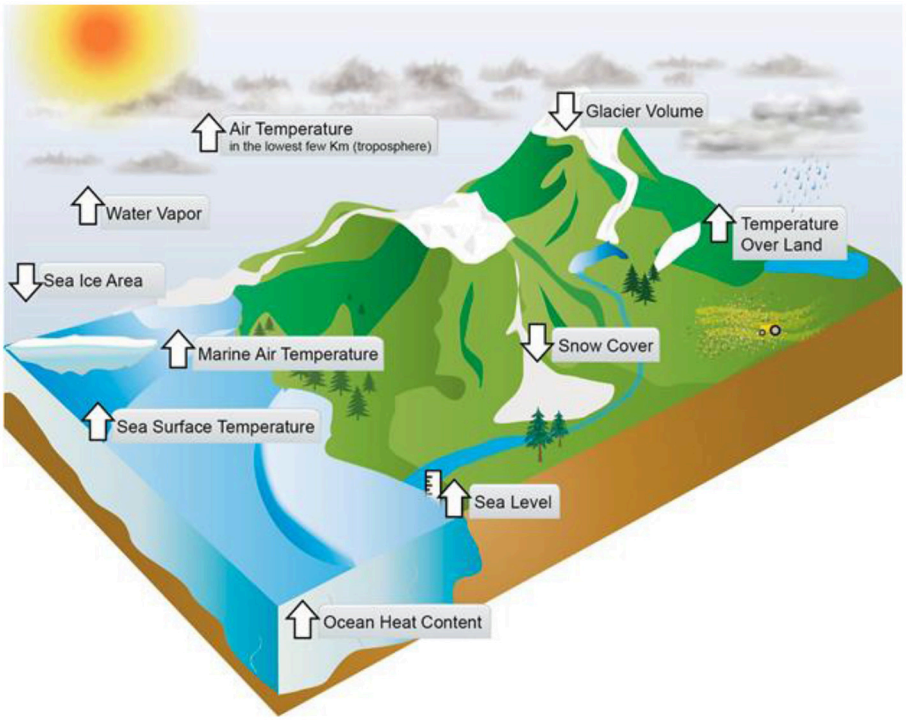


Figure 3

How Earth's climate system is changing. As temperatures increase in a changing climate, this leads to reduced snow, sea ice and glaciers and consequently more water in the oceans which increases their sea level. At the same time, higher temperatures provide more energy to evaporate water which increases the amount of water vapor in the air. Note that ocean heat content is a measure of the amount of warming in the ocean (Image credit: https://www.ipcc.ch/report/ar5/wg1/observations-atmosphere-and-surface/faq2-2-figure2-2/).

Unfortunately, when it comes to feeling the effects of climate change, some people are at higher risk than others. For example, people who live on islands or coastlines only a few meters above the sea (or even below sea level), could see their homes and livelihoods endangered. This is already happening on small island states in the Pacific Ocean and the Caribbean region, and in some highly populated delta regions in Asia. Also, people in sub-Saharan Africa, many of whom already suffer from hunger and poverty, will be more strongly affected by floods, droughts, heatwaves, and storms.

WHAT IS BEING DONE TO LIMIT GLOBAL WARMING?

Across the Earth, we are already observing the impacts of climate change. To avoid the most dangerous impacts of climate change, we must immediately reduce greenhouse gas emissions. It is also important that we prepare for climate-change effects that we cannot avoid, such as more heat waves and drier soils in summer, less snow cover in winter, and more intense storms throughout all seasons (to learn more, see this Frontiers for Young Minds article).

PARIS AGREEMENT

A contract signed by 196 countries from all over the world in 2015 in Paris in which these countries agree to try to take actions to limit global warming well below 2° increase of average global temperatures.

While there is no "safe" level of global warming, and *any* additional greenhouse emissions will increase warming and its adverse effects, 1.5 and 2°C of warming have become anchor points of the public discussion [2]. The **Paris Agreement**, which is a treaty between most countries of the world to limit global warming, set a goal to keep the global average temperature well below a 2°C

increase over pre-industrial times, aiming for 1.5°C. To meet these temperature goals, the countries in the Paris Agreement must now implement solutions to reduce and eventually stop greenhouse gas emissions.

So, what difference can YOU make, and how much can one person's contribution even matter? Individual people make surprisingly large contributions to climate change. For example, let us look at the melting of sea ice due to global warming caused by carbon dioxide emissions. Each ton of emitted carbon dioxide (the weight of a small car) leads to the loss of 3 m^2 of Arctic sea ice [3]. The typical annual carbon dioxide emissions of individuals vary by country: 2.2 tons in Brazil, 5.5 tons in the UK, and 16 tons in the US. This means that, in the US, each person is "responsible" for 48 m^2 of ice melt per year—approximately the size of an apartment. By making small changes like (1) reducing car and airplane travel, or replacing it with bicycle and train rides, (2) replacing old electric devices which more efficient ones which consume less energy, and (3) use of heating and air conditioning only when needed and as much as needed, we can all work to protect Earth's climate—both by reducing our own contribution to greenhouse gas emissions and by being role models for others (to learn more, see this Frontiers for Young Minds article]. It is only by working together that we will be able to slow global warming, keeping the Earth safe for future generations.

ADDITIONAL MATERIALS

- https://ourworldindata.org/co2-emissions
- https://www.ncdc.noaa.gov/sotc/global/201913
- https://unfccc.int/process/conferences/pastconferences/paris-climate-change-conference-november-2015/paris-agreement

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SUBMITTED: 28 May 2021; **ACCEPTED:** 20 February 2023;
PUBLISHED ONLINE: 16 March 2023.

EDITOR: Robin Matthews, Université Paris-Saclay, France

SCIENCE MENTORS: Rafeah Wahi and Florence Barbara Awino

CITATION: Sarkar R, Orth R and Vogel MM (2023) How Has Our Climate Changed Already? Front. Young Minds 11:716536. doi: 10.3389/frym.2023.716536

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.

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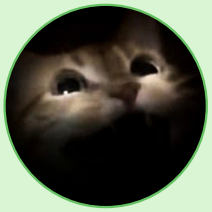

KAZIM, AGE: 13
Kazim is a 13-year old student from Malaysia. His main interest is in gaming and digital technology exploration. Science, English, and Sports Education are his favorite subjects. He really enjoys street football.

PRICE, AGE: 14
Price loves making up stories and has also written a book (Ms. Wasteson and the waste empire). She enjoys gymnastics, athletics, volleyball, and basketball. She is brave and bouncy. Price also enjoys quality time with family and is very creative. At her school, she is part of a "green team" that works to protect the environment. She likes debating and has a passion to study and become an activist against social injustices.

PROVIDENCE, AGE: 10
Providence is the youngest amongst her three sisters. She is playful and bouncy. Providence is curious, talkative, and likes asking many funny questions, that leaves others laughing. She loves making new friends and traveling. Providence loves science experiments. During this process, she may destroy, repair or recycle some household items. As part of this adventure, Providence repaired a spoilt speaker. But after weeks of action, she modeled the speaker wires into skipping ropes. She is passionate about music and sports including volleyball.

AUTHORS

RIA SARKAR
Ria Sarkar is a graduate student in the Department of Earth and Planetary Sciences at Rutgers University. Currently, her research is focused on studying the changes in how much ocean water sinks from the surface of the North Atlantic ocean into deeper depths North Atlantic Deepwater formation since the last ice age about 20,000 years ago, and how this water sinking may have caused other climate changes to happen since then. She also works as a tour guide for the Rutgers University Geology Museum and Rutgers Science Explorer bus. *rs1069@eps.rutgers.edu

RENE ORTH
Rene Orth is a climate scientist interested in the interplay between hydrology, vegetation, and climate. He leads a research group on this topic at the Max Planck Institute for Biogeochemistry in Jena, Germany. In particular, he is interested in dry conditions where the soil moisture content influences plant functioning. In these conditions, the land surface can influence weather through the amount of evaporation and the amount of heat reflected. This is particularly relevant during heatwaves or droughts. He uses climate models and measurements to better understand these relationships.

MARTHA M. VOGEL
Martha M. Vogel is a climate scientist, lately worked for UNESCO's Man and the Biosphere Programme. She has expertise in temperature extremes and heatwaves. In particular, she is interested droughts, heat waves and their impacts and how they will change in a warming world. She advised UNESCO's climate change task force and worked on the effects of heat waves in biosphere reserves, as well as on spreading climate knowledge across citizens and politicians.