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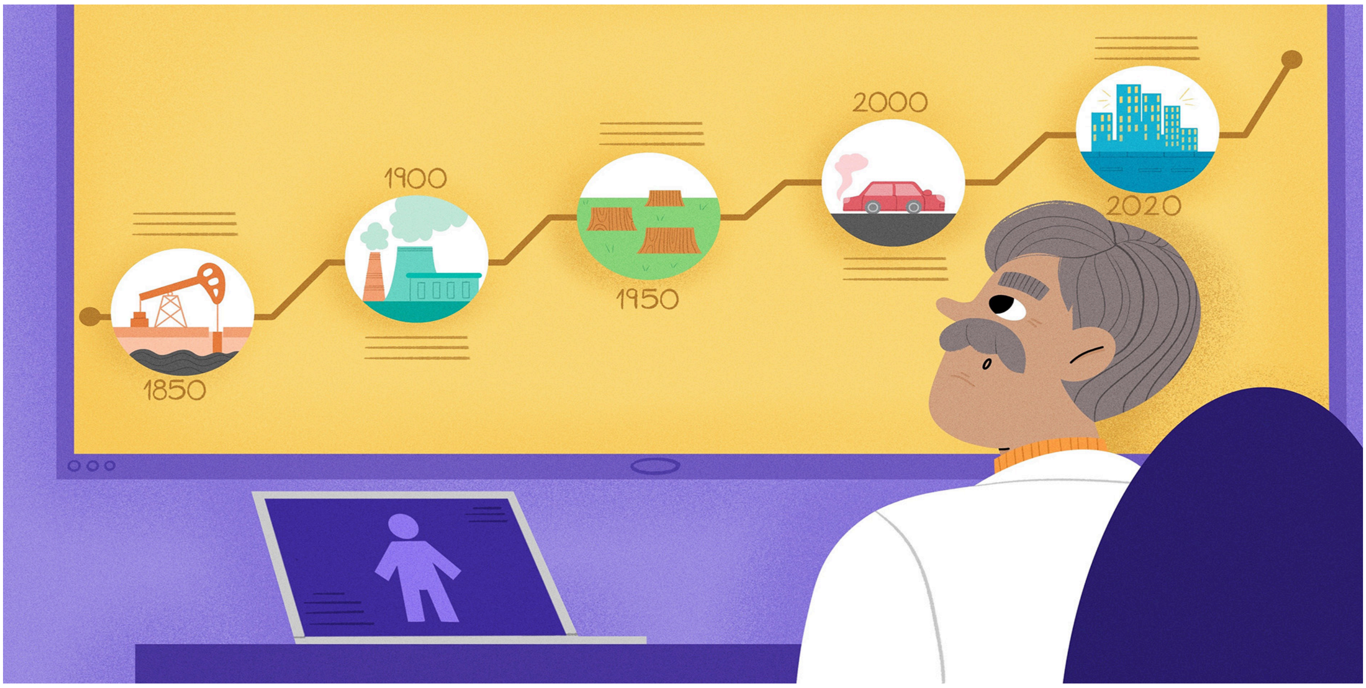

CLIMATE CHANGE IS HAPPENING AND HUMANS ARE RESPONSIBLE

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YOUNG REVIEWERS:


AYAT
AGE: 12


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AGE: 14

We know Earth is warming. Clear evidence of warming can be seen in observations of the atmosphere, oceans, ice, and living things. Computer simulations can tell us what the world would have looked like without increases in greenhouse gases and other human influences, and Earth would not have warmed up like we have seen. By comparing the changes scientists have observed to computer simulations of the climate including or excluding various potential causes, scientists can work out what or who is responsible for the climate changes. Again and again, it has been shown that these simulations can only explain observed climate changes when historic emissions of greenhouse gases, principally arising from burning coal, oil, and gas, are included. The best estimate is that all the warming we have observed since 1850–1900 is due to greenhouse gas emissions produced by human activities.

CLIMATE CHANGE IS HAPPENING ALL AROUND US

Scientists have been directly observing Earth's climate system for around 200 years, using an ever-increasing range of techniques. In the early days, we used thermometers, barometers, and other instruments to measure weather at Earth's surface. Over time, our ability to monitor the changing climate has increased, and we can now measure from the depths of the oceans to the edges of space, using a broad range of techniques including balloons, satellites, aircraft, and ocean profilers [1].

We can also use things that change with the climate, to infer changes that happened to the climate long before we started taking modern measurements. These so-called **climate proxies** include amongst many others the annual growth of trees, measured through tree ring width, and analysis of ice cores which capture changes in greenhouse gas concentrations. Climate proxies are like fuzzy recordings of Earth's climate history—they can provide some indication of the past climate but not in the detail we can get from modern observations [1].

CLIMATE PROXIES

Changes in natural systems such as the annual growth of tree rings which vary mainly as a result of the climate and hence can be used to infer information about long-term changes in climate prior to the availability of modern observations.

The combination of direct measurements and proxy records tells us that Earth's surface temperature is warming faster than it has at any time in at least the last 2,000 years. Earth's oceans, ice, and living things are also now in states unseen for hundreds to many thousands of years [2]. This matters because the last several thousand years are the period in which humanity has developed from hunter-gatherers to our modern societies. The climate over this period was remarkably stable in the context of last several million years and this stability helped modern humans to flourish.

Earth's climate is warming rapidly. From 1850–1900 to 2013–2022, the best estimate is that the global average temperature warmed by 1.15°C, with much larger changes in some regions [3]. Overall, land is warming considerably faster than the oceans, and the Arctic is warming fastest of all [2]. 2023 was the warmest year on record, and 2024 may well-exceed 1.5°C warming for the first time. The **Paris Agreement**, which almost all countries have signed, has a goal to limit global warming since pre-industrial to well-below 2°C and to strive to limit it to below 1.5°C (Read more here). Because of natural variability, one year above 1.5°C will not mean this level has permanently been exceeded, but we expect 1.5°C to be exceeded within the next 15 years. We know that, even at 1.5°C of global warming, there will already be many negative impacts [4].

PARIS AGREEMENT

An international agreement that aims to limit long-term warming of the planet while minimizing the negative impacts of climate change on the planet and society.

Earth has probably not consistently been as warm as it has been this most recent decade for at least 125,000 years. However, observations of a warming surface climate are far from the only piece of evidence we have. Evidence across the atmosphere, oceans, frozen planet and living things all point to one inescapable conclusion: the world is warming (Figure 1) [2].

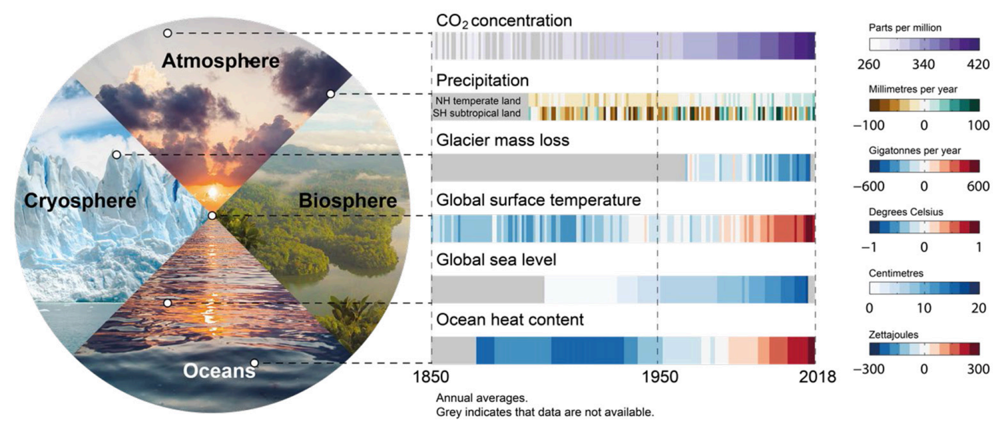

Figure 1

Evidence that Earth is warming comes from multiple sources across all components of the climate system. By measuring various indicators of climate change (middle bars, with scales shown by right hand bars), we can see the effects that these changes are having on the planet—the CO_2 concentration in the atmosphere is increasing, rainfall is increasing, glaciers are melting and contributing to sea-level rise, and the temperatures of both Earth's surface and the oceans are going up [figure Inspired by the warming stripes (https://www.reading.ac.uk/planet/climate-resources/climate-stripes)]. Source: IPCC AR6 WGI Figure 1.4 [1]. Reproduced with permission.

COMPUTER SIMULATIONS REPRESENT THE CLIMATE WELL

Scientists have a strong understanding of how the climate system works, and they can use this to simulate weather and climate using **computer models** of the atmosphere and climate system. As a well-known example, simulations of the atmosphere can be used to generate weather forecasts for the next 10–20 days. These weather forecasts have great skill and, in the case of extreme weather events, they can help to save lives and livelihoods. The same processes are simulated in climate simulations but, in addition, climate simulations also simulate the oceans, the frozen parts of the planet, and living things. Climate simulations can be used to simulate past changes and project into the future for hundreds of years, to understand how the climate has changed and how it might change in the future. These models cannot reliably tell us whether it will be sunny or rainy on a particular day 50 years from now, but they *can* tell us how the average weather, or climate, will change in response to increases in **greenhouse gases** and other factors (for more details on climate changes, see this Frontiers for Young Minds article).

Climate models have been developed at several institutes around the world, and having multiple models helps scientists understand the uncertainties in climate simulations. These models are used to run coordinated simulations of how the climate would have changed since 1850 in response to only natural influences, like changes in the sun's brightness and large volcanoes. They are also used to simulate climate change since 1850 in response to natural influences *and* human emissions of greenhouse gases and other chemicals. Finally, long climate simulations are also carried out with no changes in any **climate drivers**, to better understand climate variability [1].

Simulations of the present-day climate capture very many aspects of Earth's climate system well. They can simulate the seasonal cycle of

COMPUTER MODELS

Simulations of the climate system run on massively powerful supercomputers which provide estimates of changes in the atmosphere, ocean, frozen planet and living things under different assumptions of past and future climate drivers.

GREENHOUSE GASES

A subset of atmospheric gases which trap outgoing energy from the Earth and raise the temperature of our planet. Increases in greenhouse gases lead to increased warming.

CLIMATE DRIVERS

Changes in factors such as the strength of the sun or the amount of greenhouse gases which can lead to changes in climate by altering the balance of incoming and/or outgoing energy from the Earth.

surface temperatures over much of Earth within 1–2°C. They simulate seasonal rainfall and snowfall in most areas of the world realistically. Many models can also simulate changes in storms across seasons. The variability in the models also looks realistic with many models simulating realistic variability in the tropical Pacific where El Nino occurs [5].

The better simulations can capture key aspects of the climate system, the more confidence scientists can have in their use. Of course, computer models are not perfect, but they are certainly good enough for many purposes. Climate models have also improved over recent decades and will almost certainly continue to improve into the future (Figure 2) [5].

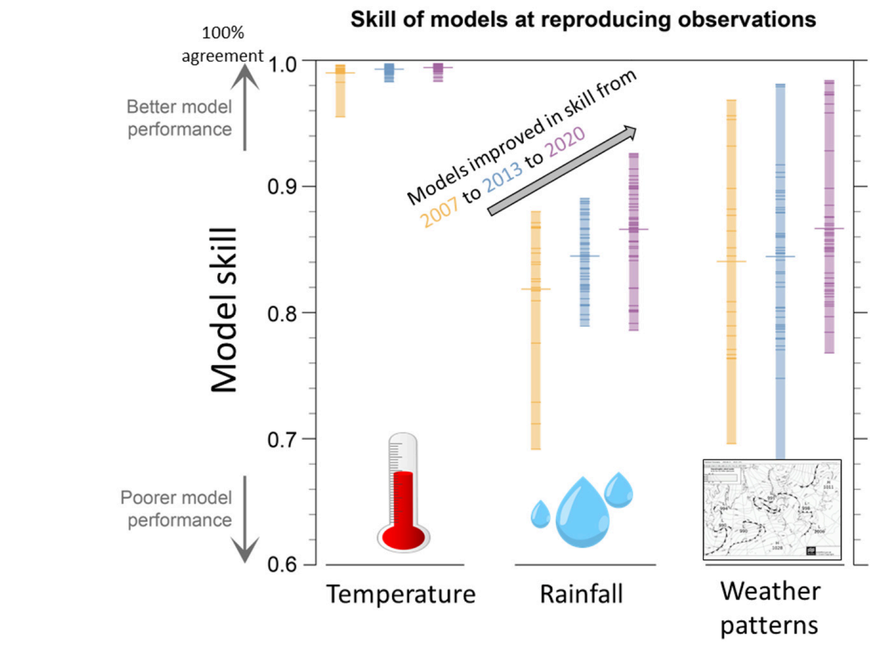

Figure 2

Figure 2

The skill of climate models at predicting climate behaviors like temperature, rainfall, and atmospheric pressure (which corresponds to weather patterns) has generally increased from 2006 to 2020. The vertical bars show data from many models and the average result of all those models is indicated by the horizontal line. Models closer to the top of the graph are more skillful, meaning they are better at simulating the temperature, rainfall or weather patterns, than those lower down. Overall, models perform better for temperature than rainfall or weather patterns. Source: IPCC WGI Figure FAQ 3.3 [5]. Modified with permission. Modifications undertaken by collection editor Dr. Chris Jones for this paper.

OBSERVED CLIMATE CHANGES CAN ONLY BE EXPLAINED BY HUMAN INFLUENCE

Scientists can use climate simulations to do the detective work of finding out what is responsible for observed changes in Earth's climate. This detective work includes in-depth statistical analysis to sort through the available lines of evidence and identify the culprit (or culprits).

The first question is whether the changes we have observed are unusual. Here, we can use the long simulations run without any changes in climate drivers, to see whether the observed changes are unusual compared to the variability we would expect by chance. If an observed change *is* unusual, then the next step is to work out what the most likely explanation is for the observed change.

To find the most likely cause(s), we can use simulations run from 1850 to near-present. Simulations including greenhouse gas increases and other human factors can reproduce the observed warming in surface temperature (Figure 3) and a broad range of other changes across the atmosphere, ocean, frozen planet, and living things, but simulations without these human factors cannot. Time and time again, it has been found that humans are principally responsible for the climate changes that have been observed [5].

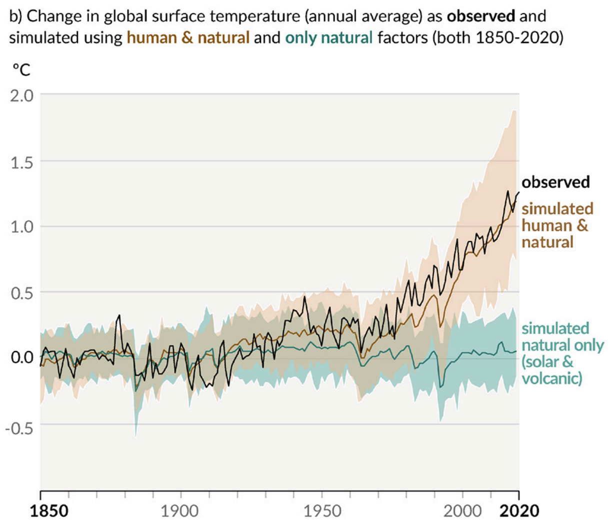

Figure 3

Comparison of observed warming at Earth's surface since 1850 using two sets of simulations: one with only changes in the sun's brightness and large volcanic eruptions (green), and one with these natural influences *and* human factors (mainly increasing greenhouse gases from the burning of coal, oil, and gas). The observed change can be explained only when human factors are included. Source: IPCC WGI AR6 Figure SPM1.b [6]. Reproduced with permission.

So, how much of the climate change scientists have observed is caused by humans? For surface temperature changes, this can be calculated. It turns out that the best estimate for the warming due to humans from 1850–1900 to 2013–2022 (1.14°C) almost exactly matches the observed warming over the same period (1.15°C). In other words, all of the warming we have experienced since the second half of the 19th Century is down to human activities [3].

TAKE HOME

Earth's climate is now in a state and changing at a speed unseen in at least thousands of years and probably considerably longer. Based on detailed comparisons of observed changes with climate model simulations, there is no doubt that human activities have warmed (and continue to warm) the climate, primarily through the burning of coal, oil, and gas. Those same computer model simulations can also tell us what potential futures await us depending upon the actions we take to slow and ultimately stop further global warming.

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YOUNG REVIEWERS

AYAT, AGE: 12

I am 12 years old and an elementary school student. I love sketching, painting, playing chess, and reading books. My favorite books include "Amari" and "The Magicians of Paris", and anything and everything about fantasy books. I like nature, cycling, badminton and frequently go out hiking to observe the beauty of nature, take notes and make sketches in my notebook.

YASH, AGE: 14

I am a rising high-schooler with a wide range of interests in math, science, music, downhill skiing, geography, and building large lego sets. I love volunteering in my community. I play the drums, and am learning to play many other instruments in my school band, most recent one being the Euphonium. I have a keen interest in public health and how our lifestyle, access to healthcare and the environment contributes to our overall wellbeing.

AUTHORS

PETER W. THORNE

I have long had a fascination for weather and climate. I remember flicking between TV channels to catch every forecast as a child. Nowadays I spend most of my time trying to work out how the climate has changed, why and what that might mean for the future. I advise policymakers and governments on what can be done through involvement in assessments and advisory bodies both nationally and internationally.

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My work primarily focuses on the detective work of understanding the causes of past climate change and what this means for how climate might change into the future. I managed the development of the latest version of the Canadian climate simulations. I have been involved in numerous assessment activities both nationally and internationally. These inform policy decisions by governments around the world.