EARTH SCIENCES
Published: 01 October 2024
doi: 10.3389/frym.2024.1433392

EARTH'S INTERCONNECTED CLIMATE: UNDERSTANDING OUR CHANGING WORLD

***Matthew Collins*[1*], *Vikki Thompson*[2,3] and *Gabriele C. Hegerl*[4]**

[1] *Department of Mathematics and Statistics, University of Exeter, Exeter, United Kingdom*
[2] *School of Geographical Sciences and Cabot Institute, University of Bristol, Bristol, United Kingdom*
[3] *Royal Netherlands Meteorological Institute (KNMI), Utrecht, Netherlands*
[4] *School of Geosciences, University of Edinburgh, Edinburgh, United Kingdom*

YOUNG REVIEWERS:

OLLIE
AGE: 12

Have you ever thought about what causes the weather conditions that you experience where you live? Maybe you are thinking, "Sure, when there are storm clouds overhead it rains or snows, and when the sun shines strongly in the summer, we have hot weather". This is true, but the "big" story is more complicated: the conditions you experience in your area can actually be caused by weather and climate events that occur thousands of kilometers away. These long-distance effects are called teleconnections, and they are a natural part of Earth's climate system. In this article, we provide examples of teleconnections and describe how scientists study them using powerful computer programs. We also explain how climate change might affect these invisible forces that stretch across the Earth, and how resulting changes in teleconnections could cause

extreme weather events, like powerful rainstorms or droughts, in certain areas. The more scientists understand about teleconnections, the better we can protect areas that are vulnerable to the dangerous effects of climate change.

EARTH'S COMPLEX CLIMATE NETWORK

Imagine Earth as a giant, complex system, with air, water, land, and ice all "talking" to each other through a language we call **climate**. Like talking on a telephone to a friend across the world, Earth's climate conversation stretches over thousands of kilometers, from the icy poles to the tropical regions near the equator. Not only do the parts of Earth's climate system "talk" to each other, but they can affect each other in all kinds of complicated ways to produce the **weather** you experience wherever you live, like heatwaves, dry spells, or heavy rains. These long-distance climate effects are called **teleconnections**, and they are a natural part of Earth's climate system.

In the remainder of this article, we will explain what causes teleconnections, how scientists understand and predict them, and how shifts in teleconnections caused by climate change can affect local weather patterns—maybe even in your part of the world!

TELECONNECTIONS EXPLAINED

Teleconnections are like invisible threads weaving across the Earth, connecting weather and climate events in one part of the world to things that happen thousands of kilometers away (remember that weather describes daily, short-term conditions of the atmosphere, while climate describes long-term patterns). There are several teleconnection pathways, and many of them are created by the constantly changing circulation of air in the atmosphere and water in the oceans. One of the most well-known examples of teleconnection is the **El Niño-Southern Oscillation** (ENSO), which involves natural, periodic changes in ocean water temperatures, air pressure, rainfall, and in the way water circulates in the Pacific Ocean. For example, when the Pacific Ocean warms up in the normally cool eastern tropics, it can cause floods in one part of the world and droughts in another (to learn more about ENSO, see this Frontiers for Young Minds article), The trade winds, which blow from the west to the east in tropical regions of the Earth, keep the warmest water near the Asian coast and bring up cold water from the depths near South America. Every now and then, the trade winds get weaker and, instead of Asian coastal waters, the waters in the middle of the Pacific get warmer. Warm waters make it easier for rain and thunderstorms to form, so these also move from the Asian coast further into the Pacific. Rain systems are all connected in the atmosphere, so regions that are normally wet get drier (such as

CLIMATE

The average weather conditions in a region over a long period, including temperature, precipitation, and wind patterns.

WEATHER

The daily conditions of the atmosphere, like temperature and rain, which can change quickly. Weather differs from climate in that it describes short-term changes, while climate describes long-term patterns.

TELECONNECTIONS

"Tele" means "distant" or "far from", so teleconnections are climate phenomena that link weather and climate events in different, sometimes very far apart, regions of the world.

EL NIÑO-SOUTHERN OSCILLATION

A climate pattern involving changing ocean temperatures in the central and eastern Pacific that influence global weather and climate.

Indonesia, which can experience wildfires), and other areas, such as California in the US, get more rain.

There are also teleconnections between Earth's polar regions and the rest of the planet. For example, the jet streams are giant, invisible rivers of air high up in the sky that move from west to east. Jet streams are caused by two things: Earth's rotation and the difference in temperature between the equator and the poles. Jet streams play a big role in Earth's weather—they can affect how storms move and how warm or cold it gets in various places. Jet streams are like highways for weather systems, helping them travel across the globe.

USING COMPUTERS TO PREDICT CLIMATE CHANGE

Figuring out climate complexities and how teleconnections work is the job of researchers called **climate scientists**. Climate scientists use powerful computers to create programs called **climate models**, which can help them understand climate teleconnections of the present climate and "project" (predict) the effects that climate change will have—both on teleconnections and on the resulting weather conditions in specific regions of the world. A climate model is basically a virtual version of the real world, in which scientists can do "experiments" to see how changes in one thing (like the amount of greenhouse gases that humans release) affect other things (like global temperatures or the amount of rainfall in a certain region). Many climate models exist, but they all represent the different components of climate, including sea ice changes, sea level rise, rainfall amounts (as described in this Frontiers for Young Minds article), or the number and strength of heatwaves, for example, and how they interact (Figure 1).

CLIMATE SCIENTIST

A scientist who uses climate models to understand Earth's current climate and predict how the climate might change in the future.

CLIMATE MODEL

A computer simulation used to understand various aspects of Earth's climate system.

TELECONNECTIONS AND CLIMATE CHANGE

You may have heard that 2023 was the world's warmest year on record. But temperatures are not increasing in exactly the same way all over the world, and other effects of climate change vary by location, too (for more info, read this Frontiers for Young minds article). So, what might rising global temperatures mean for the weather and climate where *you* live? That is a very difficult question for climate scientists to answer, especially since, as Earth's climate changes due to human activities, the behavior of teleconnections is changing, too!

For example, monsoons bring vital rain to many parts of the world, but the rain they bring has become more intense in some places in recent years due to climate change. Monsoons are heavy rainstorms that happen mostly in tropical areas during the "rainy season". As greenhouse gases like carbon dioxide build up, they change the temperatures of the oceans and the atmosphere. When these

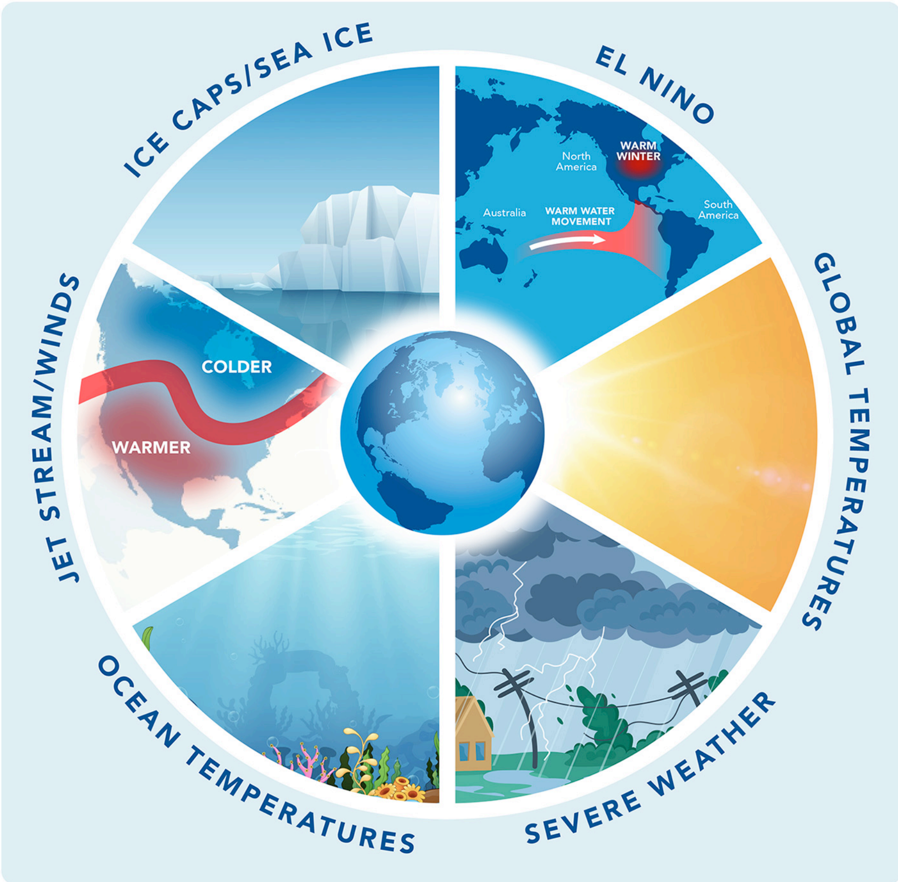


Figure 1

Figure 1

Earth's climate is extremely complex and consists of many components that influence each other *via* invisible "threads" called teleconnections. As just one example, giant rivers of air called jet streams are influenced by the temperature difference between the equator (where it is very warm) and the poles (where it is very cold). As temperatures in the polar regions rise due to global warming, changes in the temperature difference between the poles and the equator could cause jet streams to shift, changing ocean temperatures and leading to severe weather in certain regions.

temperatures are out of balance, natural teleconnections can be disrupted. For example, scientists have observed that changes in ENSO can make monsoons stronger [1] and can also lead to increases in other extreme weather conditions in some regions, such as more and stronger hurricanes and longer droughts.

Similarly, as sea ice melts in the Arctic, it might weaken and shift the jet stream southward. This could bring stormier conditions to the Mediterranean and drier, more settled conditions to Western Europe. Jet streams are naturally quite variable. They do not stay in the same place or move at the same speed all the time. So, scientists are still uncertain about exactly how much the melting ice at the poles might be shifting the jet stream and increasing its variability, leading to extreme weather events. There is still much work to be done to fully understand this and other teleconnections, and the role that climate change might be playing in changing them.

COMPUTER MODELS ARE NOT PERFECT

Climate scientists are unsure what caused 2023's record-breaking temperatures because, as you have seen, Earth's climate is extremely complicated. This means that, to make the most accurate predictions, climate models must be complicated, too! There is not enough computing power in the world to create one model that includes every possible feature of the Earth's climate accurately. Also, climate scientists use different methods to model different features, such as ocean currents, atmospheric conditions, ice caps melting, and the effects of human activities like deforestation and pollution. Even the best models are not perfect—they cannot capture every aspect of extremely complex climate processes with complete accuracy, so the predictions they provide are never 100% certain. This explains why different climate models do not always give the same results. For example, one model might say storms more frequently move northwards, while another might say they more often move southwards. One way to deal with this is for climate scientists to look at lots of models to figure out which models are the best for which questions. They can also combine information from multiple models to help make the best predictions of how climate change will affect specific areas (Figure 2).

Figure 2

Figure 2

The complexity of Earth's climate means that it is very difficult to make predictions about how climate change will affect climate and weather in the future. **(A)** Climate scientists use powerful computer programs called climate models to predict future climate. There are many kinds of climate models that scientists must consult to make accurate predictions. **(B)** Scientists can combine data from separate climate models to improve their predictions. **(C)** Along with climate models, scientists use real-life observations of weather and climate events in their predictions. **(D)** Information collected in the past, as well as the knowledge and opinions of experts, can also make predictions stronger.

Analyzing and combining information from climate models is extremely important, because knowledge is power! The more certain scientists can be about how climate change will affect specific locations, the more effectively local authorities will be able to protect those areas [2, 3]. For example, if scientists can project with very high certainty that sea level rise and increased rainfall will flood New York City over the next 50 years, steps can be taken in advance to protect people—like building flood walls or moving people out of areas most likely to flood. Accurate climate knowledge also helps scientists to measure the success of actions taken to fight climate change, like laws to reduce emissions of greenhouse gases.

PREPARING FOR THE FUTURE

As Earth warms, we are seeing more—and more extreme—weather and climate events, from blistering heatwaves to torrential rains. We now know that, due to climate teleconnections, the specific causes for certain weather events might be thousands of kilometers away. Teleconnections show us that Earth's climate system is deeply interconnected, with changes in one area rippling across the globe. Understanding teleconnections is an important part of predicting how climate change will affect communities in the future, and climate modeling is helping climate scientists to do just that. By studying information from many climate models, scientists can better forecast weather and climate trends, helping communities prepare for and fight climate change and extreme weather events. Hopefully, the more we learn about Earth's fascinating and complex climate system, the easier it will be to learn to live within its limits and reduce the negative impact that humans are having on the environment.

ACKNOWLEDGMENTS

Edited by Susan Debad Ph.D., graduate of UMass Chan Medical School Graduate School of Biomedical Sciences (USA) and scientific writer/editor at SJD Consulting, LLC. We would like to thank the coauthors of the original manuscript: Jonathan D. Beverley, Tom Bracegirdle, Jennifer Catto, Michelle McCrystall, Andrea Dittus, Nicolas Freychet, Jeremy Grist, Paul Holland, Caroline Holmes, Simon Josey, Manoj Joshi, Ed Hawkins, Eunice Lo, Natalie Lord, Dann Mitchell, Paul-Arthur Monerie, Matthew D. K. Priestley, Adam Scaife, James Screen, Natasha Senior, David Sexton, Emily Shuckburgh, Stefan Siegert, Charles Simpson, David B. Stephenson, Rowan Sutton, Laura Wilcox, and Tim Woollings. This paper is largely based on the results of two grants from the UK Natural Environment Research Council—Robust Spatial Projections of Real-World Climate Change, NE/N018486/1 and Emergence of Climate Hazards, NE/S004645/1.

ORIGINAL SOURCE ARTICLE

Collins, M., Beverley, J. D., Bracegirdle, T. J., Catto, J., McCrystall, M., Dittus, A., et al. (2024). Emerging signals of climate change from the

equator to the poles: new insights into a warming world. *Front. Sci.* 2:1340323. doi: 10.3389/fsci.2024.1340323

REFERENCES

1. 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*, eds. V. Masson-Delmotte, P. Zhai, A. Pirani, S. L. Connors, C. Péan, S. Berger, et al. (Cambridge: Cambridge University Press), 3–32. doi: 10.1017/9781009157896.001
2. IPCC 2022. "Summary for policymakers", in *Climate Change 2022: Impacts, Adaptation, and Vulnerability. Contribution of Working Group II to the Sixth Assessment Report of the Intergovernmental Panel on Climate Change*, eds. H.-O. Pörtner, D. C. Roberts, M. Tignor, E. S. Poloczanska, K. Mintenbeck, A. Alegría, et al. (Cambridge: Cambridge University Press), 3–33. doi: 10.1017/9781009325844.001
3. IPCC 2022. "Summary for policymakers", in *Climate Change 2022: Mitigation of Climate Change. Contribution of Working Group III to the Sixth Assessment Report of the Intergovernmental Panel on Climate Chang*, eds. P. R. Shukla, J. Skea, R. Slade, A. Al Khourdajie, R. van Diemen, D. McCollum, et al. (Cambridge: Cambridge University Press), 3–48. doi: 10.1017/9781009157926.001

SUBMITTED: 15 May 2024; **ACCEPTED:** 17 July 2024;
PUBLISHED ONLINE: 01 October 2024.

EDITOR: Robert T. Knight, University of California, Berkeley, United States

SCIENCE MENTORS: Valerie Kern

CITATION: Collins M, Thompson V and Hegerl GC (2024) Earth's Interconnected Climate: Understanding Our Changing World. Front. Young Minds 12:1433392. doi: 10.3389/frym.2024.1433392

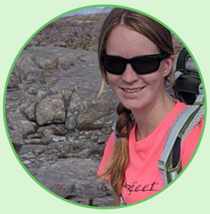
CONFLICT OF INTEREST: The authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

YOUNG REVIEWERS

OLLIE, AGE: 12
Resident of Earth, owner of hostile cats, requires oxygen and loves baseball!

AUTHORS

MATTHEW COLLINS
Mat Collins is a climate scientist and mathematician from the University of Exeter, UK. His research uses computer models of Earth's climate to examine future man-made climate changes. He is specifically focused on physical aspects such as temperatures, rainfall, winds, etc. Mat's training in mathematics and computing led him into a Ph.D. studying the weather systems on Mars. These days he is more interested in the climate of Earth, with a focus on the changes in the atmosphere and ocean system that might come about because of climate change. Natural phenomena, like El Niño, may become more frequent in the future and their impact on worldwide weather and climate may become more severe. Because we do not have much information about climate change from the past, we use computer models to simulate the future. *m.collins@exeter.ac.uk



VIKKI THOMPSON
Vikki is a climate scientist who studies extreme weather events such as heatwaves and heavy rainfall. She is currently working on extreme European summer weather at the Royal Netherlands Meteorological Institute. In the past, Vikki has worked on a range of climate extremes—UK rainfall at the UK Met Office, flooding in the Scottish Highlands at the Scottish Environment Protection Agency, and heatwaves globally at Bristol University. Outside of work, Vikki enjoys being in the mountains—though she is learning to love the flatness of the Netherlands, too.

GABRIELE C. HEGERL
Gabriele Hegerl is a professor of climate system science at the University of Edinburgh. Prior to coming to Edinburgh, she was at the Max-Planck Institute for Meteorology in Germany, and at the University of Washington, Texas A&M, and Duke University in the US. Her research focuses on understanding the causes of climate change and using observations to make more accurate predictions of future climate change. Her work has determined causes of change in temperature, rainfall, and extreme events, and she had key roles in Intergovernmental Panel on Climate Change assessments of climate change. Gabriele is a fellow of the Royal Society.