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THE SOUTHERN OCEAN ECOSYSTEM AFFECTS THE ENTIRE WORLD

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YOUNG REVIEWERS:


ASHIMA
AGE: 14


AVANI
AGE: 11


HANNAH
AGE: 13

RIA
AGE: 12


RIMA
AGE: 13

The Southern Ocean, which flows around the Antarctic continent, is home to vast numbers of unique and remarkable animals, including penguins, albatrosses, petrels, seals, and whales. The ocean bursts into life every spring, fueling a summer feeding and breeding frenzy. During the dark winter months, there is little food and life is very harsh. Human activities such as fishing and pollution are affecting this ecosystem, as is climate change. These ecosystem changes matter *beyond* the Southern Ocean! Ocean currents carry nutrients and organisms into and out of the Southern Ocean. Many marine mammals and seabirds swim or fly in and out of the Southern Ocean, in search of food and breeding grounds, or to escape the harsh Antarctic winter. These movements and migrations connect the Southern Ocean ecosystem with other marine ecosystems around the world. This means that changes in the Southern Ocean ecosystem can affect ecosystems around the world.

SHAIVI

AGE: 11

VALERIE

AGE: 15

GLOBAL OCEAN

The oceans of the world are all connected together, with waters flowing from one ocean region to another. Together they are known as the global ocean.

FRONTAL SYSTEM

A boundary between ocean waters that have different temperatures and saltiness. Frontal systems can be hundreds of km wide.

Figure 1

The Southern Ocean is the central hub of the global ocean circulation, connecting all of the world's major ocean regions. The colored loops show the major flows and their directions in the ocean. Where the loops meet the ocean flows are connected and waters mix together.

EARTH SYSTEM

All the interacting physical, chemical, and biological processes on the planet. It includes all the land, oceans, atmosphere, and poles, as well as humans and other animals.

PHYTOPLANKTON

Microscopic marine algae that float and drift in the ocean. They get their energy from sunlight and nutrients from seawater. They provide food for zooplankton and other organisms.

THE SOUTHERN OCEAN: THE HUB OF THE WORLD'S OCEAN

At the bottom of the world, the Southern Ocean is the "hub" of the **global ocean**—connecting the Pacific, Atlantic, and Indian Oceans (Figure 1) [1]. It flows clockwise around the Antarctic continent and is dominated by the Antarctic Circumpolar Current, the coldest, biggest, and one of the fastest currents in the ocean. The colder surface waters of the Southern Ocean are separated from the warmer waters of the neighboring south Atlantic, south Pacific, and Indian Oceans by **frontal systems** that act like underwater boundaries. Frontal systems, which can be up to 100s of km wide, are boundaries between ocean waters that have different temperatures and saltiness. Water currents, some flowing very deep below the surface, can flow across these fronts and into other oceans. These water currents are full of salt, nutrients, and oxygen, and they are very important for a healthy global ocean and **Earth System**.

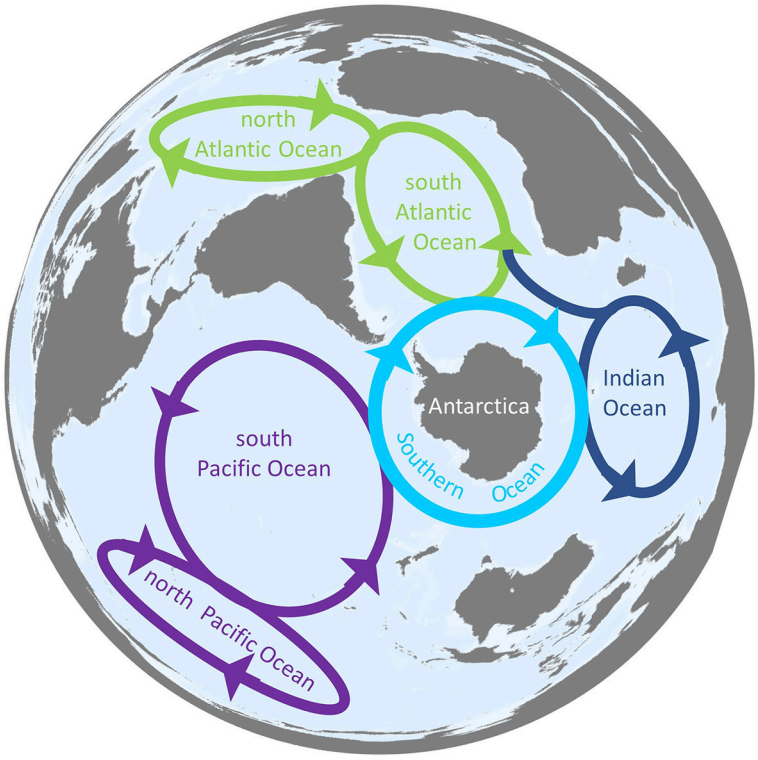

Figure 1

THE SOUTHERN OCEAN ECOSYSTEM IS GLOBALLY CONNECTED

The Southern Ocean ecosystem includes vast numbers of unique and remarkable organisms—from microscopic species of free-floating algae (called **phytoplankton**) and tiny animals (like **zooplankton**), bigger plankton (like jellyfish), to fish and squid, all the way up to

seabirds and marine mammals, as well as species that live on the sea floor. Up until recently, the Southern Ocean ecosystem was thought to be largely separated from the rest of the world. However, scientists have made exciting new discoveries about how well the Southern Ocean ecosystem is connected with the global ocean and how important it is in the Earth System [1].

Many species that live in the Southern Ocean affect the nutrient concentrations in the currents that flow from the Southern Ocean to the rest of the world. Similarly, species (and physical processes) in other parts of the global ocean influence the nutrient concentrations of waters flowing *back into* the Southern Ocean. Smaller organisms (such as phytoplankton and zooplankton) are swept in and out of the Southern Ocean by currents, and larger species (such as squid, fish, and whales) can swim in and out of the Southern Ocean. Many of the species that spend some of their time on land (like seals, penguins, and other seabirds), migrate in and out of the Southern Ocean to find food or complete their life cycles. Together, all these currents, movements, and migrations mean that the Southern Ocean ecosystem is strongly connected with all other ocean ecosystems.

ZOOPLANKTON

Small animals in the ocean. Some are tiny and microscopic, others are millimeters or even several centimeters in size. Most are not strong swimmers and drift with the ocean currents.

MOVEMENT OF SMALL ORGANISMS IN AND OUT OF THE SOUTHERN OCEAN

Phytoplankton and zooplankton drift in the currents of the Southern Ocean. Phytoplankton get their energy from sunlight and nutrients from seawater and provide food for zooplankton and other organisms. Zooplankton in turn provide food for many other larger species including squid, fish, marine mammals, and seabirds. One very important zooplankton species is Antarctic krill, *Euphausia superba* [2]. These large (a few millimeters to several centimeters in length) shrimp-like crustaceans are found throughout much of the Southern Ocean and have a biomass which is estimated to exceed that of all humans on the planet! Krill is a key species in Southern Ocean **food webs**, and it is the target of a commercial **fishery**. Phytoplankton and zooplankton are not very strong swimmers and they are transported by ocean currents into or out of the Southern Ocean across the frontal systems. These organisms may also get trapped in very large whirlpools (eddies) that can drift across fronts and deposit them in various parts of the ocean. Antarctic krill, other larger zooplankton species, and small fish can swim and move short distances and up or down the **water column**, where they encounter currents that may move them in or out of the Southern Ocean. Other larger marine species like fish and squid are stronger swimmers, which allows them to move into or out of the Southern Ocean as they grow and develop.

FOOD WEBS

A food web is the network of who-eats-whom interactions in an area of the ocean. Food webs vary between different areas of the ocean.

FISHERY

A local fishing operation or where fishing is targeted at a particular species of fish or shellfish.

WATER COLUMN

The ocean waters at different depths in a particular place, from the surface to the seabed.

MOVEMENT OF LARGE ORGANISMS IN AND OUT OF THE SOUTHERN OCEAN

Large animals, such as various species of seabirds and seals, that live year-round in the Southern Ocean must be able to cope with long winter periods when sea ice covers much of the ocean and there is low light, cold temperatures, and little food. During this period, many animals can reduce their activity or use up energy they stored as fat during the summer months of plentiful food. Every year, vast numbers of whales, seals, and seabirds deal with the long, cold winters by swimming or flying north to warmer waters of the Atlantic, Pacific, or Indian Oceans. Albatrosses are one type of large, migrating seabird. There are 22 species in the albatross family, of which 18 breed and feed in the southern hemisphere oceans. Many albatross populations are declining due to hooking or entanglement in longline fishing gear, or collision with trawler cables, invasive species like mice in their breeding colonies, diseases, or climate change. Petrels are another type of seabird. Some petrel species breed in the Antarctic region while others feed there but breed further north. Although most petrels are small, their population sizes can run into the tens of millions, making them major consumers of prey, including Antarctic krill. Some seabird species are examples of truly amazing migrations into and out of the Southern Ocean. The small Arctic tern breeds in the Arctic during the summer. To escape the Arctic winter, it flies across the equator and all the way down to the Southern Ocean, feeding around Antarctica during the southern summer. Two other bird species, sooty shearwaters and south polar skuas, do the complete opposite: they breed in the Southern Ocean and then fly to the northern hemisphere, experiencing an eternal summer!

Scientists have recently estimated just how many seabirds and whales migrate in and out of the Southern Ocean each year, by fitting animals with tags that can be tracked by satellite or that record light and can be used estimate position by a process called geolocation, combined with surveys done from the ground or the air (Figure 2) [1]. An amazing 68.5 million seabirds leave the Southern Ocean as the Antarctic winter approaches and migrate back in the spring. Around 600,000 whales also migrate in and out of the Southern Ocean each year. These numbers may change in the future with the anticipated recovery of Southern Ocean whale populations. Whale numbers in the Southern Ocean were very low throughout the second half of the 20th century because they were hunted for many years before this was banned in the 1980s. Since the late 1990s and 2000s there have been truly spectacular increases in the numbers of some whale species, such as the humpback whale [3].

These new and exciting studies of animal movements reveal the enormity of the annual migration of Southern Ocean species. These migrations mean that the seabirds and whales are part of food webs in ecosystems outside of the Southern Ocean, where they may feed,

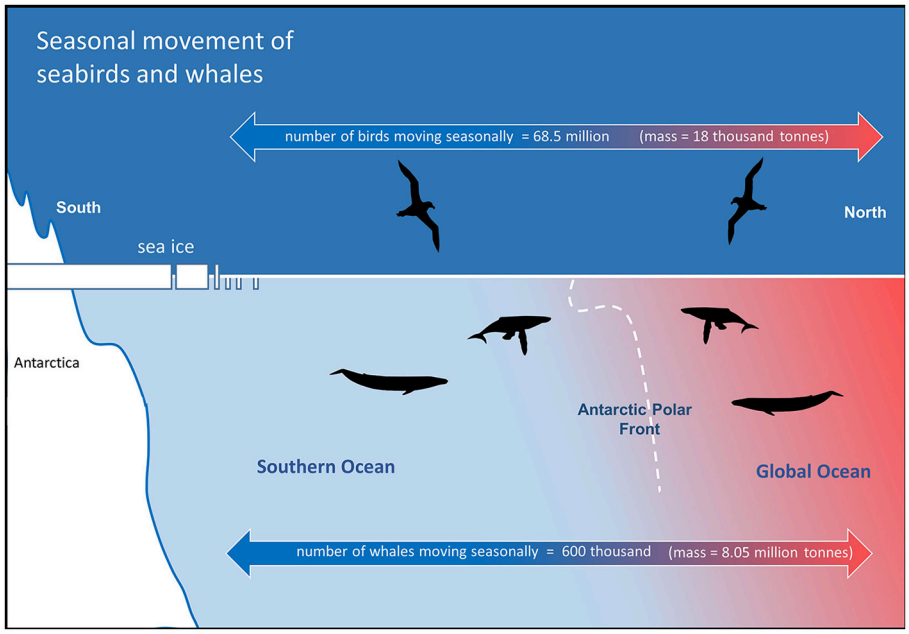

Figure 2

Each spring large numbers of seabirds and whales move south across the Antarctic Polar Front (an important frontal system) and migrate north. Antarctica is on the left. The Antarctic Polar Front (dashed white line) indicates the region where the cold Southern Ocean waters to the south (blue) meet warmer (red) waters to the north. Modified from Murphy et al. [1].

breed, or die. This means that migrating animals transfer vast amounts of energy and nutrients into and out of other ecosystems.

SOUTHERN OCEAN ECOSYSTEM CHANGE HAS GLOBAL CONSEQUENCES

There are major concerns about how future climate change and other human pressures, such as fishing, tourism, and pollution, will impact the Southern Ocean ecosystem [1, 4, 5]. Scientists know that climate-related changes are already affecting many Southern Ocean species—changing their numbers, where they live, and how well they function and reproduce. Changes have already been observed in many species of phytoplankton, zooplankton, fish, large marine mammals, and seabirds, for example. Along with climate-related changes, the increasing whale populations and commercial fishing of fish and Antarctic krill will also affect the balance of this ecosystem.

The new perspective about how connected the Southern Ocean ecosystem is to the rest of the world's ecosystems means that changes in the Southern Ocean will have global consequences. We now understand that the Southern Ocean ecosystem is linked not just to other ocean ecosystems, but to the Earth's climate system as well. Southern Ocean ecosystems can help to absorb carbon dioxide from the atmosphere, locking it up for hundreds or thousands of years in the deep ocean and helping limit atmospheric warming. Nutrients exported from the Southern Ocean also help fuel productivity in other ecosystems in the global ocean. The Southern Ocean also supports economies through fishing and tourism (Figure 3). The Southern

Ocean ecosystem is, therefore, important to the planet and everyone on it [1].

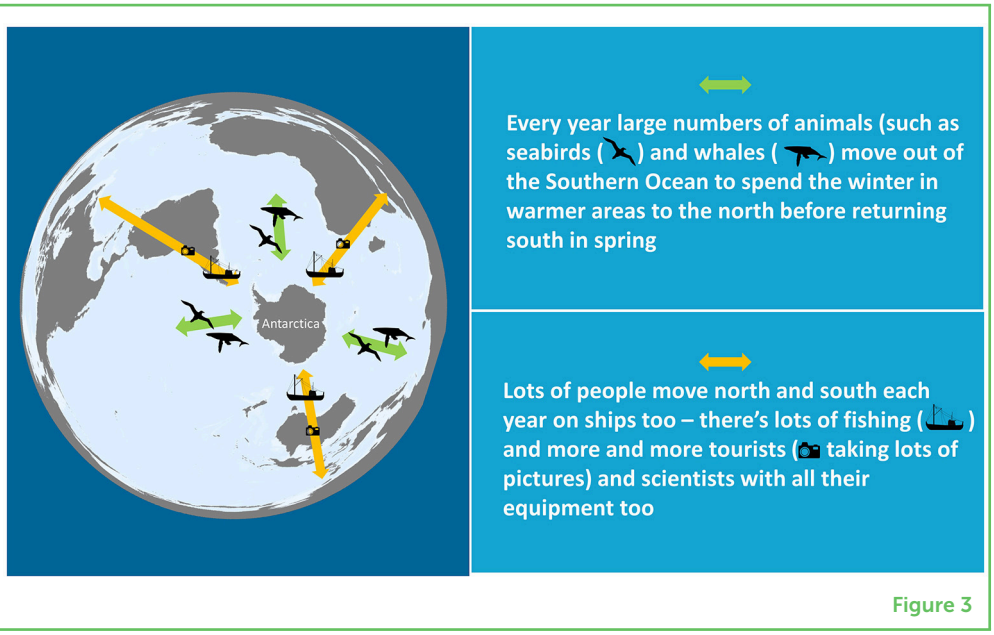

Figure 3

Figure 3

There are extensive connections between the Southern Ocean ecosystem and ecosystems in the global ocean. The Southern Ocean ecosystem is important in global processes affecting climate, biological productivity and diversity, and also in human social, cultural and economic systems [1, 6]. Every year animals (seabirds and whales) move in and out of the Southern Ocean (green arrows), and lots of people move south and north too (yellow arrows).

The good news is that there is a lot that people can do to protect the Southern Ocean ecosystem. Scientists and politicians can and must work together to ensure the future health of the Southern Ocean ecosystem and the continued recovery of whales. One exciting and challenging next step is for scientists to develop realistic predictions or "best estimates" of how climate change and human activities will affect the Southern Ocean ecosystem. These predictions are important for making decisions in time to keep the Southern Ocean ecosystem—and the Earth as a whole—healthy. Educating as many people as possible about the global importance of the Southern Ocean ecosystem will help scientists to make sure our global ocean can continue to thrive and provide people with benefits like food, fascinating species, and climate regulation. This is an exciting new time for everyone who is trying to protect the Southern Ocean.

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ORIGINAL SOURCE

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REFERENCES

1. Murphy, E. J., Johnston, N. M., Hofmann, E. E., Phillips, R. A., Jackson, J. A., Constable, A. J., et al. 2021. Global connectivity of Southern Ocean ecosystems. *Front. Ecol. Evol.* 9:624451. doi: 10.3389/fevo.2021.624451
2. Johnston, N. M., Murphy, E. J., Atkinson, A., Constable, A. J., Cotté, C., Cox, M., et al. 2022. Status, change, and futures of zooplankton in the Southern Ocean. *Front. Ecol. Evol.* 9:624692. doi: 10.3389/fevo.2021.624692
3. Zerbini, A. N., Adams, G., Best, J., Clapham, P. J., Jackson, J. A., and Punt, A. E. 2019. Assessing the recovery of an Antarctic predator from historical exploitation. *R Soc. Open Sci.* 6:190368. doi: 10.1098/rsos.190368
4. Henley, S. F., Cavan, E. L., Fawcett, S. E., Kerr, R., Monteiro, T., Sherrell, R. M., et al. 2020. Changing biogeochemistry of the Southern Ocean and its ecosystem implications. *Front. Mar. Sci.* 7, 31. doi: 10.3389/fmars.2020.00581
5. Morley, S. A., Abele, D., Barnes, D. K. A., Cardenas, C. A., Cotte, C., Gutt, J., et al. 2020. Global drivers on Southern Ocean ecosystems: changing physical environments and anthropogenic pressures in an earth system. *Front. Mar. Sci.* 7:547188. doi: 10.3389/fmars.2020.547188
6. Cavanagh, R. D., Melbourne-Thomas, J., Grant, S. M., Barnes, D. K. A., Hughes, K. A., Halfter, S., et al. 2021. Future risk for Southern Ocean ecosystem services under climate change. *Front. Mar. Sci.* 7:615214. doi: 10.3389/fmars.2020.615214

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YOUNG REVIEWERS

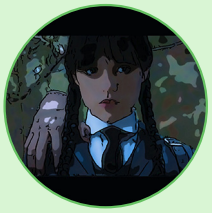
ASHIMA, AGE: 14
Hi, I am Ashima. I like to read fiction books and swim. I love to study. My favorite subject is mathematics. Quadratic functions are my favorite topic in mathematics.

AVANI, AGE: 11
Hello, I am Avani. I enjoy running and swimming. I am also a dancer. I love going on walks with my dog, or collecting stones. I love math, science and I love sports. I enjoy playing video games, and calling friends. I love nature and cold windy weather.

HANNAH, AGE: 13
I am currently attending 4th grade of secondary school. My hobby is bike riding. I also like listening to music and hanging out with my friends.

RIA, AGE: 12
I am a middle schooler and a robotics Gateway student. I love competing in taekwondo tournaments. I also like dancing and painting. In my free time I like to spend time with my family, friends, or discover new hobbies. Science is also an interesting concept and I am excited to learn much more.

RIMA, AGE: 13
Hi, my name is Rima. Some of my hobbies are reading books, swimming, and baking! My favorite subjects are Science and Math. When I grow up I would love to be a Computer Engineer or an Astronomer!



SHAIVI, AGE: 11
I am a middle schooler STEM student. I like to read fiction and mystery books and watch movies on those topics. I am an avid swimmer and currently doing competitive swimming. I have participated in various swimming competitions at multiple levels such as local, divisional, and state. In my spare time I ride my bicycle or take a walk with my neighborhood buddies. I finished my first 5K marathon and looking forward to complete many more.

VALERIE, AGE: 15

I am a sophomore in an Austrian High School. My main hobby is horsebackriding. I have got a young dog called Micco. I also like meeting my friends and listening to some music.

AUTHORS

EUGENE J. MURPHY

Prof. Eugene Murphy is a marine scientist with a particular interest in big ocean ecosystems. His research is centered on understanding physical-chemical-biological interactions in ecosystems and includes studies of many species, from tiny plankton to penguins and whales, how they interact in food webs and the impacts of fishing and climate change in Southern Ocean and global ocean ecosystems. His studies include the use of big computer models of the ocean to track currents and examine pathways of transport of animals in the ocean, and combining information from samples collected from ships with data from satellites to work out how changing sea ice cover affects marine ecosystems. His work provides information for conservation and fisheries management and assessing the impacts of climate change in the ocean. He has been involved in several international Southern Ocean and global environmental programmes, including the Integrating Climate and Ecosystem Dynamics in the Southern Ocean (ICED) programme. *e.murphy@bas.ac.uk

NADINE M. JOHNSTON

Dr. Nadine Johnston is a marine ecologist at the British Antarctic Survey. Her research focusses on understanding the structure (biodiversity and community composition) and functioning (carbon and nutrient cycling, climate regulation, and the transfer of energy through food webs, fisheries, and wildlife tourism) of marine ecosystems within the Scotia Sea region and wider circumpolar Southern Ocean, and the impacts that climate change and direct human activities (fisheries, pollutants, and tourism) are having on this system. This provides vital information to support regional and global conservation and management decisions in the context of global change. She has been involved in a range global environmental change programs, including the Integrating Climate and Ecosystem Dynamics in the Southern Ocean (ICED) and the Marine Ecosystem Assessment for the Southern Ocean (MEASO), generating scientific outputs and disseminating this to policy makers.

EILEEN E. HOFMANN

Prof. Eileen Hofmann is an oceanographer who studies interactions between marine ecosystems and the environment. Her training as a scientist started with a B.S. in biology. A Ph.D. degree in marine science let her combine biology and physical oceanography to understand how ocean circulation influences marine ecosystems. Her interest in physical-biological interactions has expanded to include studies of climate change, diseases of marine organisms, and harmful algal blooms. Her research has taken her to many parts of the ocean, including Antarctic coastal regions and the Southern Ocean. She has been involved in global environmental change programmes, most recently the Southern Ocean Observing System.

RICHARD A. PHILLIPS

Prof. Richard Phillips is leader of the Predators Group and Deputy Science Leader within the Ecosystems Team at the British Antarctic Survey and has honorary positions at the Universities of Exeter and Cambridge. His research interests are in the ecology and conservation of seabirds, particularly albatrosses and petrels, and in food webs in temperate and polar ecosystems. He is involved with several international agreements, including the Commission for the Conservation of Antarctic Marine Living Resources, and the Agreement on the Conservation of Albatrosses and Petrels, that develop strategies to promote research on seabirds and other marine organisms, particularly where this is of relevance to understanding and managing marine and terrestrial threats.

JENNIFER A. JACKSON

Dr. Jennifer Jackson is a marine ecologist who studies the oceanic interconnections and population recovery of baleen whales in the Southern Hemisphere. She is interested in the recovery of whale populations from whaling, how connected whale populations are across the oceans and the barriers to their movement, and how their populations and habitats have changed over the past century. She is also interested in new methods of monitoring whale populations using very high-resolution satellites, as populations recover in remote and difficult-to-survey regions such as the Southern Ocean.

ANDREW J. CONSTABLE

Dr. Andrew Constable is a marine scientist forever wondering about how to sustain our Earth System. After finishing a marine science degree, he embarked on a journey through a long Ph.D. that involved quantitative theoretical ecology, mathematical modelling and statistics, and the use of science by decision-makers. While he has worked and advised on most marine habitats except coral reefs, my passion has been Antarctica and the Southern Ocean-science (field work, modelling), policy, and management (the Commission for the Conservation of Antarctic Marine Living Resources). He is indebted to the vast community of passionate scientists, enthusiasts, and policy makers that make up the Antarctic community and that enabled him to work on Integrating Climate and Ecosystem Dynamics of the Southern Ocean, the Southern Ocean Observing System, the Marine Ecosystem Assessment for the Southern Ocean, and Working Group II of the Intergovernmental Panel on Climate Change.