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Modelling the effects of climate change on complex ocean currents

Professor Paul Myers

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Modelling the effects of climate change on complex ocean currents

Ocean currents are complicated systems, and their transport of heat, nutrients and oxygen around the planet is vital for life as we know it. The changing climate, in particular the melting of sea ice and glaciers at high latitudes, threatens to change these currents – which would have significant impacts on oceans and society. At the **University of Alberta** in Canada, **Professor Paul Myers** is using powerful numerical models to study these currents and predict how climate change will affect them.

Professor Paul Myers

Department of Earth and Atmospheric Sciences, University of Alberta, Canada

Field of research
Physical oceanography

Research project
Studying high-latitude ocean currents through numerical modelling

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PROFILE

Talk like an ...

oceanographer

Feedback loop — a system in which the output becomes the new input. In a positive feedback loop, this causes the initial effect to become amplified

Fluid dynamics — the branch of mathematics and physics that studies the flow of liquids and gases

Latitude — a geographic coordinate that measures a location's distance from the Earth's equator (high-latitude areas are near the poles)

Numerical model — a mathematical representation of real physical conditions solved on a computer

Ocean current — a large-scale, continuous movement of seawater

Salinity — saltiness

Surface waters — the upper layer of the ocean

Ocean currents, which transport water, heat and nutrients around the planet, are driven by forces, including wind, the rotation of the Earth and pressure gradients created by differences in the density of the water they contain. Water density is defined by two main key factors: heat and salinity, with colder and more saline (salty) waters being denser. Both factors are being impacted by climate change, as oceans become progressively warmer and increased meltwater from glaciers makes them less saline, which could have profound impacts on ocean currents.

However, while the climate affects the ocean, the ocean also affects the climate. For example, Labrador in Canada is on a similar latitude to the UK, but, because of ocean currents, its climate is significantly colder. "While the North Atlantic Current transports warm water northwards towards Europe, the Labrador Current carries cold polar water southwards from the Arctic Ocean to the Labrador Sea," explains Professor Paul Myers, an oceanographer at the University of Alberta.

A growing concern is the emergence of positive feedback loops. Climate change could alter ocean currents in ways that accelerate climate change, which could further alter ocean currents, and so on. Paul's research focuses on high-latitude currents – the large-scale movement of water between the Arctic Ocean and surrounding seas. Using sophisticated numerical models, drawing on established physical principles and real-world oceanographic data, Paul and his


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team are developing important scenarios for the future of our global ocean.

What factors affect ocean currents?

Physical geography has a big role to play in driving ocean currents. Sub-polar surface waters of the North Pacific and Atlantic Oceans flow into the Arctic Ocean through a few key passageways known as 'gateway straits'. "Most gateway straits are shallow, meaning they don't allow the exchange of deeper waters," says Paul. Warm saline water from the sub-tropical Mid-Atlantic flows north, and its high salinity means it is denser than the cold Arctic surface waters, so it sinks beneath them. "This isolates the heat from surface waters and prevents accelerated melting of sea ice," says Paul.

Freshwater also plays a role in these high-latitude currents. "Water from precipitation, rivers, and melting glaciers and icebergs is fresh, and so lowers the salinity of the ocean it enters," says Paul. These factors, plus the entrance of relatively fresh water from the Pacific, makes the upper layers of the Arctic Ocean among the least salty seawater in the world. When this water leaves the Arctic and enters the North Atlantic, winter temperatures cool the surface water and increase its density, sending it deeper. "This is an important process for ventilating the ocean," explains Paul. "Heat and oxygen are transported to deep waters, and carbon dioxide is sequestered in the deep sea where it doesn't contribute to global warming."

> ***We've found that warm water from the Atlantic, while it does sink to deep waters in the Arctic, still contributes to glacial melting.***

Another effect that comes into play is albedo – the ability of lighter-coloured surfaces to reflect incoming solar energy (i.e., heat). "In the high latitudes of the Arctic, the ocean is covered by sea ice for most of the year," says Paul. "This ice reflects incoming sunlight and associated heat back into space, keeping Arctic temperatures cooler." But as warming of the Arctic reduces sea ice coverage, the exposed darker water absorbs heat, further raising ocean temperatures.

How can numerical models simulate the ocean?

"In our computer models of ocean currents, we include variables such as temperature, salinity, and sea ice thickness and extent," explains Paul. "Some models also include icebergs and biogeochemical properties such as nutrients, oxygen and ocean alkalinity." Paul's models use a very high spatial resolution, modelling the entire Arctic Ocean down to individual square kilometres. "This allows us to represent the detailed processes associated with exchange through the narrow gateway straits into and out of the Arctic," he explains. "We also represent where freshwater enters, and the mixing that happens in the deep ocean."
To build these models, Paul starts with mathematical equations from fluid dynamics that describe the movement of waters and places them onto grids representing real-life areas. "We provide the model with initial conditions calculated from historical observations collected over decades," says Paul. Real-life observations, such as data collected from ocean sampling and satellite imagery, are used to evaluate the model and determine its quality.

What has Paul discovered?

Paul's modelling studies have led to some important oceanographic discoveries. "We've found that warm water from the Atlantic, while it does sink to deep waters in the Arctic, still contributes to glacial melting," says Paul. "This is because it reaches the deepest parts of glaciers that flow into fjords in places like Greenland, accelerating their melting."

This links to a key climate concern – that warmer global temperatures are melting glaciers and sea ice more rapidly, which is lowering the salinity (and therefore density) of surface Arctic waters. "If Arctic surface densities become too low to allow for deep mixing, it would reduce ocean ventilation," explains Paul. "This could potentially have significant implications for the climate and Arctic marine ecosystems."

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About *oceanography*

Oceanography is the study of the ocean. Its broad scope involves contributions from a wide range of disciplines. "Researchers work in physical, chemical, biological and geological oceanography sub-disciplines, with results from one area dependent on new findings from another," says Paul. "Today, there is also a push to include the social science aspects of oceanography, such as marine policy, ocean transportation and ocean literacy for the general public." Being able to engage with society is the best way to ensure that oceanographic findings have a positive impact on humanity and the planet.

Oceanography involves combining advanced mathematics with real-world phenomena. "I like being able to integrate theoretical knowledge of fluid mechanics with computational approaches and real-world observation data," says Paul. "This work helps find answers related to one of the most important parts of the Earth's climate system." Scientists and civilians around the world are becoming increasingly concerned about how climate change is affecting the ocean. "Higher freshwater inputs into the high-latitude ocean limits mixing between depths, which impacts nutrient supply and ecosystem productivity," says Paul. "These inputs could also weaken the overturning circulation, impacting oceanic heat transport."

Pathway from school to *oceanography*

At school, a solid grounding in the sciences, mathematics and physical geography can set the foundations for a career in oceanography.

The range of educational backgrounds in Paul's team highlights the diverse pathways that can lead to oceanography. "The most important thing is having a desire to learn, linked to a strong quantitative background," says Paul.

A university degree in oceanography, marine science, geology, physics, mathematics, biology, chemistry, computer science or ocean engineering will prepare you for a career with the ocean. Whatever path you study, gaining technical skills in computational modelling and data analysis is important.

Look for opportunities to get involved with ocean-related research, such as volunteering in university laboratories or citizen science projects.

Explore careers in *oceanography*

Beyond academia, there is a diverse array of careers available in oceanography. "Companies working in marine transportation, offshore resources and aquaculture need oceanographic professionals," says Paul. "Governments need oceanographic specialists to develop marine policies, create sea ice forecasts and prepare scenarios for tsunamis and sea level rise."

The Canadian Meteorological and Oceanographic Society provides a useful hub for educational resources: **cmos.ca/site/education/cmos**

Fisheries and Oceans Canada provides student employment opportunities for budding oceanographers and information about of the range of careers available in the sector: **dfo-mpo.gc.ca/career-carriere/science/students-etudiant/index-eng.html**

Meet *the team*

Paul Myers
Professor

My grandfather was a fisherman and I grew up listening to his stories of the ocean. I also loved reading the tales of ocean explorers, from the 'Age of Sail' to the present. I was exposed to fluid mechanics and numerical methods while studying applied mathematics at university and realised that oceanography could combine these interests with my love of the ocean.

My education in applied mathematics gave me the framework to understand how equations can represent our ocean and climate systems. In my journey to oceanography, I gained a strong foundation in mathematics and computing first, then used this to explore how the ocean works.

Fiona Davidson
PhD student

I love how interdisciplinary oceanography is. You can study everything from the physics of water currents to changing biogeochemical patterns to how glacial meltwater and rivers impact ocean dynamics. The realities of climate change are hard to ignore and studying how the ocean interacts with the climate is a dynamic field right now.

I studied physical geography and geomatics at university. My master's research focused on how environmental variables influence the distribution of deep-ocean species. I later worked as a data scientist, leading to a role at the Institute of Ocean Sciences, where I worked on my first ocean physics and biogeochemical model.

Tahya Weiss-Gibbons
PhD student

I've always loved the ocean as I've lived by it for most of my life. So many people are affected by the ocean and understanding how we rely on it makes studying the ocean interesting and rewarding. The ocean covers most of our planet, yet so much about it remains undiscovered and poorly understood.

I studied computer science and physics at university. I did an internship at the Canadian Centre for Climate Modelling and Analysis, which exposed me to climate modelling as a career. My technical background opened doors that I didn't know existed when I started my degree.

Inge Deschepper
Postdoctoral researcher

I've always been fascinated by the power of the ocean. Oceanography is the doorway to understanding how the ocean shapes our world. If you're interested in how the climate influences the ocean or vice versa, it's the field for you! And oceanography opens the doors to study hard-to-observe environments, through modelling or field trips on the ocean. We explore the unknown!

My university courses focused on the marine environment. I'm a curious person, and took courses in oceanography, marine biology, geography, atmospheric science and even archaeology. I've found that this diverse overview of different Earth systems, alongside a good mathematics background, has helped a lot throughout my career.

Oceanography

with Professor Paul Myers

Talking *points*

Knowledge

1. What factors influence the density of seawater?
2. Why are the upper layers of the Arctic Ocean less salty than other oceans?

Comprehension

3. How can numerical modelling be used to understand ocean processes?
4. How might climate change affect ocean currents in high latitudes?

Application

5. What is meant by a 'positive feedback loop'? What other real-world examples of positive feedback loops can you think of?
6. How do you think companies working in marine transportation, offshore resources and aquaculture benefit from oceanographic knowledge?

Analysis

7. Why do you think the transport of both oxygen and carbon dioxide to deep ocean waters is important?
8. It is possible that climate change will weaken the North Atlantic Current, reducing air-sea heat exchange and potentially leading to colder average temperatures in Europe. Based on your understanding of Paul's article, how might climate change drive this process?

Evaluation

9. Paul mentions improving 'ocean literacy'. Why do you think it is important for the public to have a good knowledge of ocean systems?
10. It is estimated that the ocean has absorbed about 30% of the carbon dioxide emissions released by human activities. How do you think this might affect the global ocean and climate?

Activity

In small groups, assemble the following: a large sheet of transparent material (e.g., perspex), a piece of card of the same size, a way to raise the perspex vertically above the card (e.g., using clamp stands, or tins as 'legs' at the four corners), and stationery equipment (coloured pens, coloured card, scissors, glue, etc.).

On both the perspex and card, draw a map of the Arctic Ocean and surrounding seas and landmasses (e.g., from **nsidc.org/sea-ice-today/maps**). The North Pole should be in the centre of your map, and the coastlines and islands do not need to be too detailed.

Position and fix the perspex directly above the card so the maps align, if you look down from above. You have now built a semi-3D map of the high-latitude oceans. The perspex represents shallow waters, while the card below represents deeper waters.

From the information in Paul's article, supplemented by your own further research, use the stationery materials to add information and annotations to your model to show the flow of ocean currents into, out of and around the Arctic Ocean. Think about how to represent:

- Direction of flow (both horizontally and vertically)
- Differences in temperature
- Differences in salinity
- Sources of freshwater

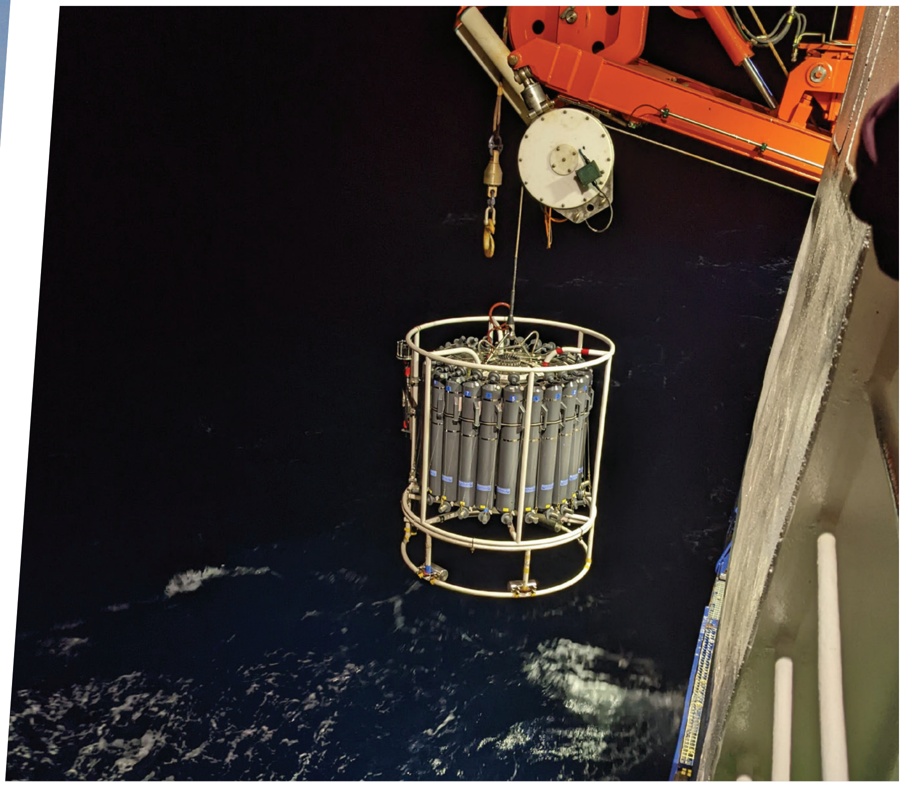
Gather as a class and showcase each group's model. What similarities and differences do you notice among the models? Did you differ in your approaches to creating the model? Which model do you think is the best, and why?

More *resources*

- NASA created some of the first detailed models of ocean currents: **science.nasa.gov/earth/oceans/going-with-the-flow-visualizing-ocean-currents-with-ecco**

- This TED talk from oceanographer Professor Susan Lozier explores how climate change is influencing ocean currents: **youtube.com/watch?v=n6ql90yGWt0**

- UNESCO's Ocean Literacy Portal provides access to a vast range of resources about the ocean: **oceanliteracy.unesco.org**



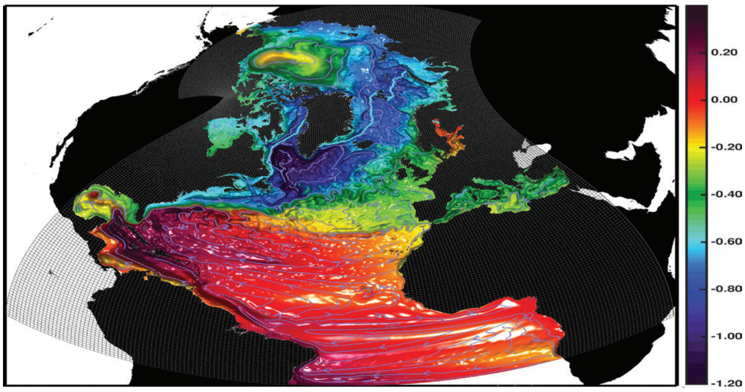


Photo *montage*

Top row: ***Left:*** *Arctic sea ice © Paul Myers*

Right: *A rosette sampler is lowered from a research ship to collect water samples from different depths in the ocean to provide data that will inform numerical ocean models © Tahya Weiss-Gibbons*

Middle row: ***Left:*** *Inge met an Adélie penguin on the sea ice during an expedition to Antarctica © Akta Bukta*

Right: *A numerical model of the ocean showing aspects of ocean circulation (colours represent sea surface height) © Paul Myers*

Bottom: *The view of endless ocean from onboard a research ship © Tahya Weiss-Gibbons*

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