How does carbon cycle through the oceans?

Authors: Thomas Weber, Jacob Cram, Shirley Leung, Timothy DeVries, and Curtis Deutsch
Associate editor: Gogi Kalka

Abstract

Imagine you were a detective following a carbon dioxide (CO₂) molecule, for instance one of millions you just exhaled. Where does it go? Up away into the atmosphere? Is it used by a plant to build a green leaf? Guess what: a lot of the carbon we (and our cars and factories) ‘exhale’ actually ends up in the ocean. So get ready to get wet! Once in the ocean, the CO₂ molecule might hang around in the surface for a short while before jumping back to the air above, or it might travel deep down to the bottom of the ocean where it stays trapped for hundreds of years.

We created a computer model (a type of ‘virtual ocean’) to act like such a detective, tracking CO₂ in the ocean to discover where it goes and how long it will stay. We found that carbon cycles very differently in different latitudes of the ocean. This was not known before, and provides important clues about how the ocean will respond to, and contribute to, global climate change.

Introduction

The oceans play an important role in controlling Earth’s climate by taking up and storing carbon from the atmosphere. In fact, more than 93% of all the carbon dioxide (CO₂) in the world – including what we exhale, or what we produce when we burn gasoline or other fossil fuels – is stored in our oceans. Tracking what happens to carbon in our oceans is crucial to understanding the global carbon cycle.

We humans are lucky that so much CO₂ is stored in the oceans, leaving less CO₂ to heat up the atmosphere. Greenhouse gases like CO₂ act like a blanket in the atmosphere, trapping heat that is radiated back from Earth. Without the oceans storing so much CO₂ our planet would be too warm for humans to survive. But why do the oceans store so much carbon?

One reason is that tiny plants called phytoplankton (Fig. 1) live in sunlit surface waters, and take up CO₂ from the atmosphere to build their bodies, just like plants do on land. When they die, phytoplankton sink into deep ocean, where bacteria break them down and release the stored carbon back into the seawater. Overall, these processes act like a biological carbon pump, pumping carbon into the deep ocean where it is locked away from the atmosphere for many years. In our new study, we wanted to understand:

- how deep carbon reaches in the ocean
- how long carbon is stored before it is released back in the atmosphere,
- and whether there are differences in how the pump works in different parts of the ocean.

Figure 1: Phytoplankton
A) Small cyanobacteria, most common in low latitudes.
B) Large diatom, most common in high latitudes (photo courtesy of Bryndan Durham).
Methods

We have a pretty good understanding of how much CO₂ is taken up by phytoplankton, because that happens at the surface of the ocean, where it is easy to observe. What we don’t know is what happens to the CO₂ in deeper layers of the ocean, which cannot be observed directly. Previously, marine scientists have dropped “traps” on long ropes (hundreds or even thousands of meters long) from their ships to see how deep plankton sink before the carbon in their bodies is released. This is very expensive and does not always provide accurate information, so reliable data are scarce.

Results

Our results reveal that carbon is released at different depths in different regions of the ocean. (Fig. 2):

In low latitude regions close to the equator – the tropics and subtropics – sinking plankton are broken down quickly, and the vast majority of the carbon they contain is released in the upper ocean. Only a small fraction (around 5-10%) of the breakdown occurs in the deeper layers. However, in high latitude regions closer to the North and South poles, dead plants sink much deeper before they get broken down. So in these regions a much larger fraction (20-30%) of the carbon is released in the deep ocean compared to the tropics and subtropics.

We tackled the problem in a different way. When bacteria break down dead plankton, they release nutrients such as phosphate, into seawater along with the CO₂. Phosphate concentrations have been very well measured and mapped throughout the ocean, so we used them as a proxy for CO₂ storage. We used a computer model of ocean circulation to estimate how much phosphate (and thus also CO₂) from dead plankton builds up in seawater as it moves through the ocean. Our model tells us how much CO₂ is released in the upper ocean (above 1000m) versus the deep ocean (1000m and below).

Discussion

What does this mean for the global carbon cycle? Previous studies have shown that if bacteria break down plants in the upper ocean, then the CO₂ is quickly transported by currents back to surface waters, and is released back into the atmosphere. In contrast, if plants are broken down (decompose) in deeper waters, then the carbon they release stays trapped in the ocean for a very long time – hundreds or even thousands of years.
This means that phytoplankton sinking in cold ocean regions near the poles (in higher latitudes) are much better at storing carbon long term than plankton sinking in warmer regions near the equator.

**But why is this so? We thought of two possible explanations:**

1. The phytoplankton in colder areas of the ocean near the poles are usually fairly big (for plankton, that is!) and stick together into large clumps when they die. This makes them heavier and causes them to sink faster and therefore deeper before they get decomposed by bacteria, compared to small plankton that are common in low latitudes (Fig. 1).

2. Colder water (in areas near the poles) slows down the growth of bacteria that decompose the sinking plankton. This gives the dead plants more time to sink deeper before carbon is released.

**Discussion**

Our results point to an unexpected and worrisome positive feedback effect of carbon cycling in the oceans. It seems that warmer oceans are less effective at storing carbon by the biological carbon pump than colder oceans. If humans continue to add CO₂ to the atmosphere, the whole world, including the oceans, will get warmer. This will reduce the amount of carbon stored in the oceans, and CO₂ will escape to the atmosphere where it can trap even more heat, further warming the Earth. In order to break this vicious cycle, we humans will need to work together to reduce our use of fossil fuels for energy and transport.

**Conclusion**

**Glossary of Key Terms**

- **Biological carbon pump** – the process by which CO₂ is taken out of the atmosphere by tiny plants in the ocean, called phytoplankton, which sink and release carbon in deeper waters.

- **Carbon** – is a chemical element with the symbol C. It’s part of our bodies and that of all other living and dead animals (such as dead dinosaurs, or fossil fuels). It comes in many forms – one of them is a gas called carbon dioxide (CO₂), that we and other animals exhale.

- **Carbon cycle** – describes how carbon moves around our planet, from the atmosphere to being taken up by plants, into the soil, or ocean.

- **CO₂ molecule** – a gas that is formed when the carbon in plant or animal matter breaks down, or when fuels are burned. Plants need CO₂ to grow.

- **Data** – information/facts that scientists collect to test their research question (hypothesis).

- **Decompose** – When dead organisms rot, usually with help of bacteria. Bacteria in the ocean help dead plants to decompose.

- **Latitude** – Imagined parallel lines that run from East to West all around our planet which describe a location relative to the poles. High latitudes describe areas closer to the poles, while lower latitudes are further away from the poles and closer to the equator.

- **Nutrients** – a tiny part of food that organisms use to eat and grow. Phosphate is a very important nutrient for plants. Vitamin C is another example of a nutrient, and one that is very important for humans.

- **Ocean circulation** – large movements of water in the oceans. Circulation near the surface is usually caused by wind, while circulation in deeper areas is caused by sinking of colder water.
Phytoplankton – tiny types of algae (a type of plant) in the ocean. Most phytoplankton live near the surface of the water, because like plants on land, they need light to grow, and the ocean gets darker with depth. Plankton move around with waves and water currents or sink.

Positive feedback effect – A set of processes that act to increase an initial change. In our case, the warming of the ocean water leads to less carbon being stored in the ocean, which releases more carbon into the atmosphere, which traps more heat and further warms the oceans. And the cycle continues.

Proxy – something that represents something else. Here, we used the amount of phosphate as a proxy to calculate the amount of released carbon in the ocean.

Tropics – Regions that lie around the Equator, furthest away from the poles. You might have heard of the tropical rainforest.

Subtropics – areas next to the tropics, but closer to the poles. They are slightly less warm and much less rainy than the tropics. All the large deserts on land (e.g. Sahara) are found in the subtropics.

Check your understanding

1. Can you name all the different places you can find carbon on Earth?

2. What do oceans have to do with our climate, especially when we think about climate change?

3. Why are oceans in colder areas more efficient at storing carbon than oceans in warmer, more tropical areas?

4. What was the positive feedback effect you learned about in this article?

5. How are all of us contributing to changing the climate? And how can we reduce that impact?

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