Saturated sink

One of the world's most important carbon sinks has stopped behaving as expected. Cause for concern? **Corinne Le Quéré** investigates.

Professor Corinne Le Quéré.

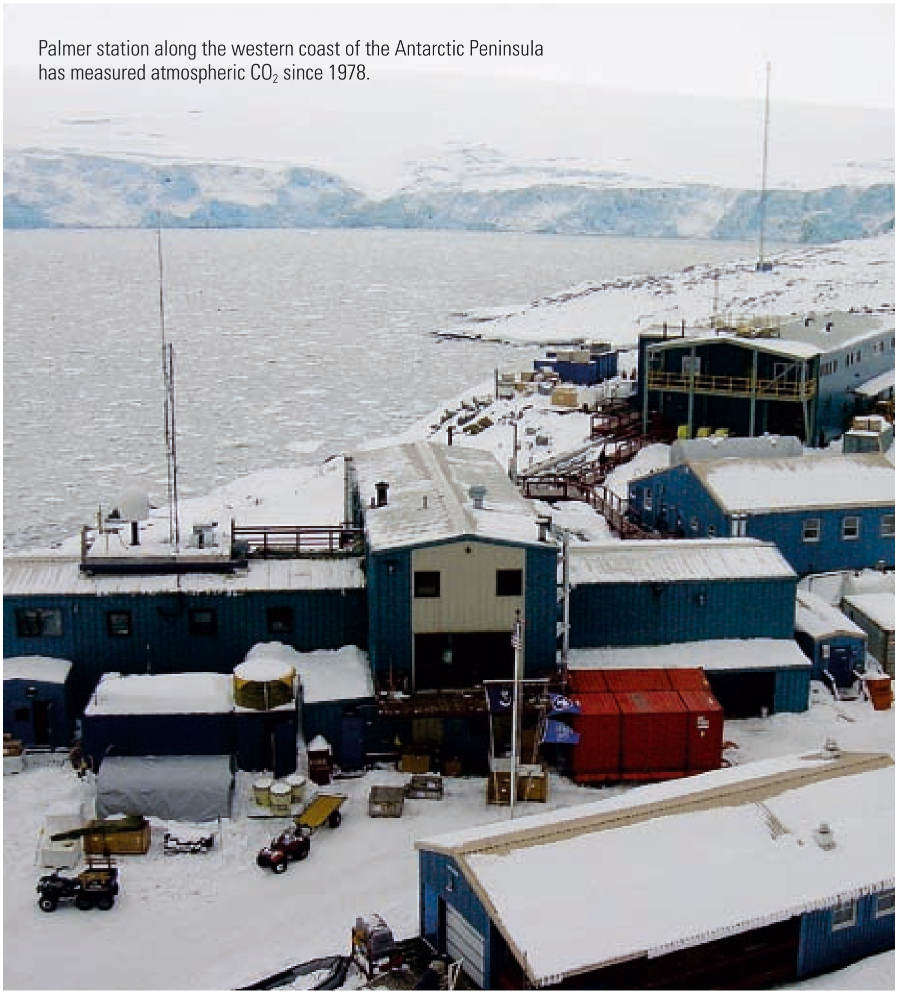
The Earth's carbon sinks – the land and oceans – absorb around half of the carbon dioxide (CO_2) emitted by humans. The Southern Ocean encircling Antarctica is one of the most important carbon sinks. It slows down global warming by absorbing CO_2. Scientists have known about this effect for a long time and call it the 'Southern Ocean CO_2 sink'. We expected that as human CO_2 emissions increased, the Southern Ocean CO_2 sink would increase too. But in 2007, we were surprised to discover that this assumption was incorrect. In the past 25 years, CO_2 emissions increased by 40 per cent, but the Southern Ocean CO_2 sink has not moved at all. The sink has saturated.

So how do you measure an ocean-wide carbon sink? It is not easy. We could not use measurements taken directly from the ocean because nobody (not even scientists!) wants to be on a ship in the windiest and coldest of all oceans in winter. Instead, we used atmospheric CO_2 measurements from 11 stations scattered around the coast of Antarctica, Tierra del Fuego on the tip of South America, Cape Point in South Africa, Cape Grim and Baring Head in Australia and New Zealand and another 29 stations farther north. We estimated changes in the Southern Ocean CO_2 sink by comparing the rates at which CO_2 increased around Antarctica with increases farther north.

We have no idea how marine ecosystems will respond.

Something odd was happening to CO_2 levels around the Southern Ocean. From the atmospheric data, we could see that the Southern Ocean was absorbing the same amount of CO_2 per year now as it was 25 years ago, or perhaps even a tiny bit less. Since CO_2 had been increasing in the atmosphere, the Southern Ocean sink was losing ten per cent in efficiency every decade. But this data could not explain why. To get to the causes, we used a complex computer model to reproduce the ocean carbon cycle, including marine ecosystems, ocean circulation, and global warming.

We compiled the weather conditions



Palmer station along the western coast of the Antarctic Peninsula has measured atmospheric CO_2 since 1978.

and CO_2 increases every day since January 1948 and put these into our model. We took the same model and started again, but this time without changing the weather. Instead, we used the weather conditions for one specific year. No matter which year we used, we always obtained the same result: when weather remained the same, the Southern Ocean sink drew down more carbon in line with human emissions; when we used real weather, the sink became saturated. With one additional test, we pinpointed the cause of the problem: increasing winds over the Southern Ocean. Winds have been increasing over the Southern Ocean for at least 50 years, causing much local warming and melting of glaciers over the Antarctic peninsula (the tip of Antarctica that sticks out into the Southern Ocean and nearly meets the tip of South America).

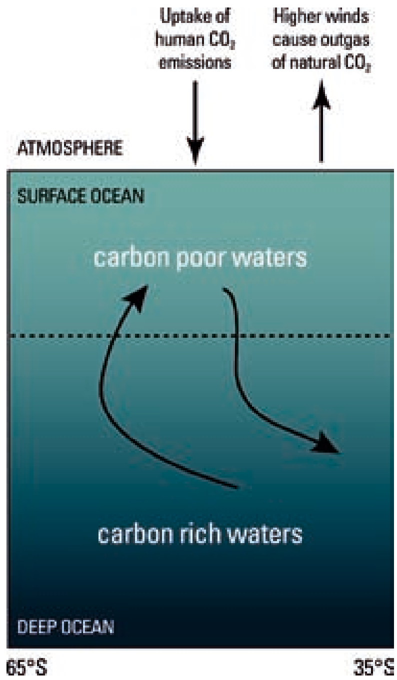
When winds blow over oceans they create strong vertical currents called upwellings that mix and replace surface waters with waters from the deep ocean – an enormous store of natural carbon. This natural carbon used to be isolated from the atmosphere: now it is not. Stronger winds in the Southern Ocean have caused the natural equilibrium to change. This is preventing further absorption of human CO_2 emissions.

The reason for the strong winds is heavily debated. But we know one thing: it is caused by humans. High-level ozone depletion in the stratosphere, that is, above an altitude of 11 kilometres, is responsible for part of the change. We know this because ozone depletion has caused the stratosphere to cool. Scientists have linked stronger winds in the lower atmosphere with the patterns, timing, and amplitude of climate changes in the upper atmosphere.

Global warming may also play a role. Climate models that simulate global warming also produce stronger winds in the Southern Ocean because of the uneven warming around the world.

There is another knock-on effect: ocean acidification. In the last few years, scientists have realised that carbon emissions to the atmosphere from human activity are building up in the surface of the ocean, making it more acidic. With the upwelling caused by the stronger winds bringing even more carbon to these surface waters, the upper ocean is likely to become more acidic.

Until now, when researchers used computer models to see the effects of this lower pH, they tended to include only the acidity caused by human emissions. In these models, the Southern Ocean becomes undersaturated for aragonite – a form of calcium carbonate – in around 2050 depending on emissions scenarios. Many sea creatures cannot make shells without aragonite. But, if you include carbon contributions from the deep ocean, this date could move forward by some decades.



Stronger winds in the Southern Ocean draw natural carbon from the deep ocean to the surface, preventing absorption of human CO_2 emissions.

Researchers are in a poor position to make projections.

Marine ecosystems drive carbon to the deep ocean. We have no idea (and I mean no idea) how marine ecosystems will respond to climate change, ocean acidification, and fishing pressures. If this natural sinking weakens, it will further prevent the absorption of human emissions.

Predicting the future of the Southern Ocean sink in the near future is not straightforward. If ozone depletion caused the winds to increase, then the Montreal Protocol and the consequent recovery of the ozone layer should mean winds will revert to pre-industrial levels by mid-century. If global warming is the cause, the winds will strengthen further.

So, how will the Southern Ocean sink respond to this? If emissions become really large – two or three times today's levels – the increasing winds could temporarily begin to push more human CO_2 down to the deep ocean than natural carbon up to the surface. That is only because the upwelling transports human CO_2 downwards at the same time as it transports natural carbon upwards. In recent decades, the increasing upwelling from the strengthening winds moved more CO_2 upwards than downwards. Right now, researchers are in a poor position to make projections.

Surprisingly, it is easier to project what will happen in the more distant future. A few centuries after CO_2 emissions stop (yes I mean completely stop), the ocean carbon cycle will reach a new equilibrium, probably based on a new ocean circulation with more upwelling in the Southern Ocean. Most likely the winds will be stronger than during pre-industrial times. This will continue to cause more carbon from the deep ocean to reach the surface and escape to the atmosphere where it will be permanently stored. From our knowledge of oceans and atmosphere in the distant past, we expect CO_2 stored in the atmosphere from this process to be a few tens of parts per million (ppm) for the Southern Ocean alone. For comparison, 100ppm of CO_2 causes roughly 1°C of global warming, so the ocean's response will surely make stabilising atmospheric CO_2 and climate more challenging than we realise.

Now that was for the Southern Ocean. The North Atlantic and the western equatorial Pacific are also showing signs of change. The drawdown of human CO_2 emissions from the atmosphere is slower than expected. These results are really significant. With all these observations falling into place, we can say another major part of Earth's climate system has begun to respond to global change. ❖

Corinne Le Quéré is professor of Environmental Sciences at the School of Environmental Sciences University of East Anglia, Norwich, and a researcher at the British Antarctic Survey, Cambridge, UK, email: cleq@bas.ac.uk