Air bubbles in a slice of ice core.
Photo: © Tas van Ommen/AAD

OUR CLIMATE SHOCK ABSORBER

A SCIENCE BRIEFING ABOUT SOUTHERN OCEAN CO_2 UPTAKE

AUGUST 2026

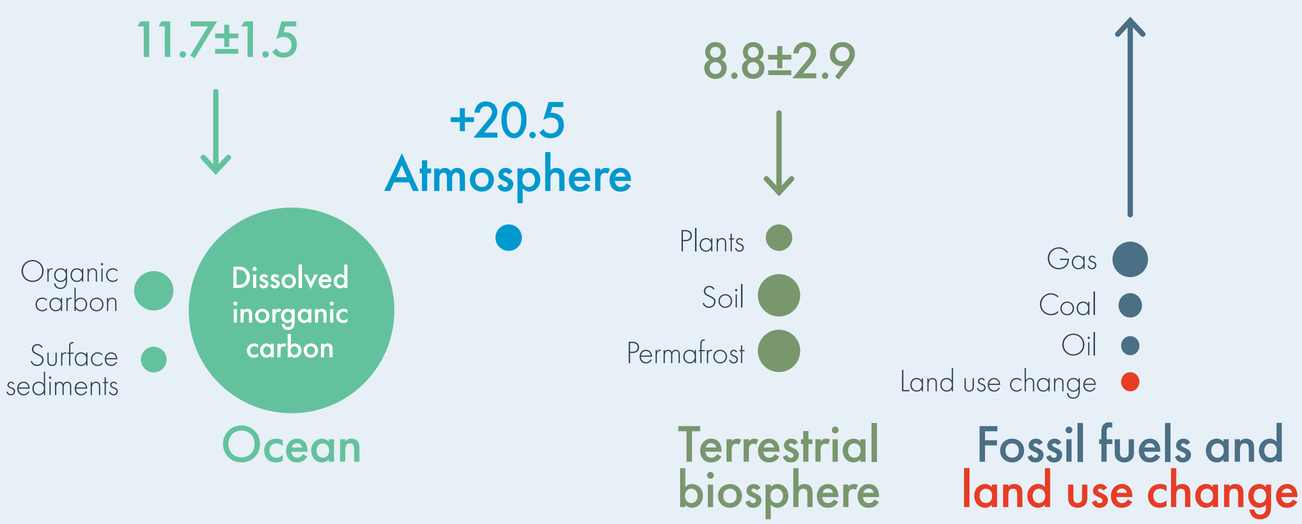
Carbon controls life and climate on Earth. Carbon in the biosphere is the principal currency through which plants and animals exchange biomass and energy. Carbon in the atmosphere is the primary control on global temperature and climate variability. However, the vast majority of carbon is neither in the atmosphere, nor in the terrestrial biosphere. It is in the ocean.

The global ocean is the largest reservoir of carbon, holding some 40 times more carbon than the atmosphere. As such, a relatively small change in the ocean carbon reservoir results in large change in the amount of carbon dioxide (CO_2) in the atmosphere, and in turn the average temperature of the planet. As a critical component of the carbon cycle, the ocean provides an essential service to humanity by absorbing more than a quarter of our emissions every year, slowing the pace of climate change.

Whether the global ocean continues to absorb carbon dioxide (CO_2) from human emissions at the current rate is an open question that depends largely on how the Southern Ocean CO_2 uptake evolves in a changing climate.

AAPP
Australian Antarctic Program Partnership
CSIRO

Carbon reservoirs



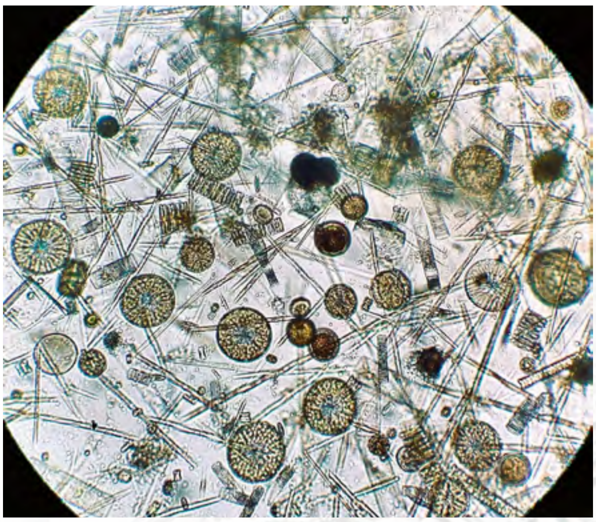
The Global Carbon Budget for the decade 2015-2024 (modified from Friedlingstein et al., 2026). The size of the circles is proportional to the size of the carbon reservoir, with the ocean dwarfing the amount of carbon stored in the atmosphere, the terrestrial biosphere, and the fossil fuel reserves. The transfers of carbon into reservoirs (sinks) and out of reservoirs (sources) are indicated by the arrows, with annual values in gigatons of CO_2 per year and their uncertainty also shown.

The Southern Ocean CO_2 sink

The Southern Ocean, which covers 30% of the global ocean surface, accounts for 40% of the global ocean CO_2 uptake. The Southern Ocean carbon sink operates through a combination of biological and physical processes.

The Biological Carbon Pump

Tiny marine plants called phytoplankton grow in the upper sunlit layer of the ocean, using photosynthesis just like plants on land to convert CO_2 and nutrients into biomass. This biomass forms the base of the ocean food chain, supplying energy to higher trophic levels from zooplankton to fish to whales. Some of the biomass escapes being eaten and sinks, where it might be respired back to CO_2, or settle to the seafloor. Over time this results in a gradient where carbon accumulates in the ocean interior, allowing atmospheric CO_2 to be absorbed at the surface.



Antarctic diatoms and other phytoplankton.
Photo: © Robert Strzepek/AAPP

The Physical Solubility Pump

Gases like CO_2 (and oxygen) are more soluble in cold water. In polar regions, cold dense water sinks to the ocean depths carrying large quantities of dissolved CO_2 as it moves towards the equator. Some of this CO_2 will be released back to the atmosphere, while some remains sequestered, or locked away, in the deep ocean for centuries.

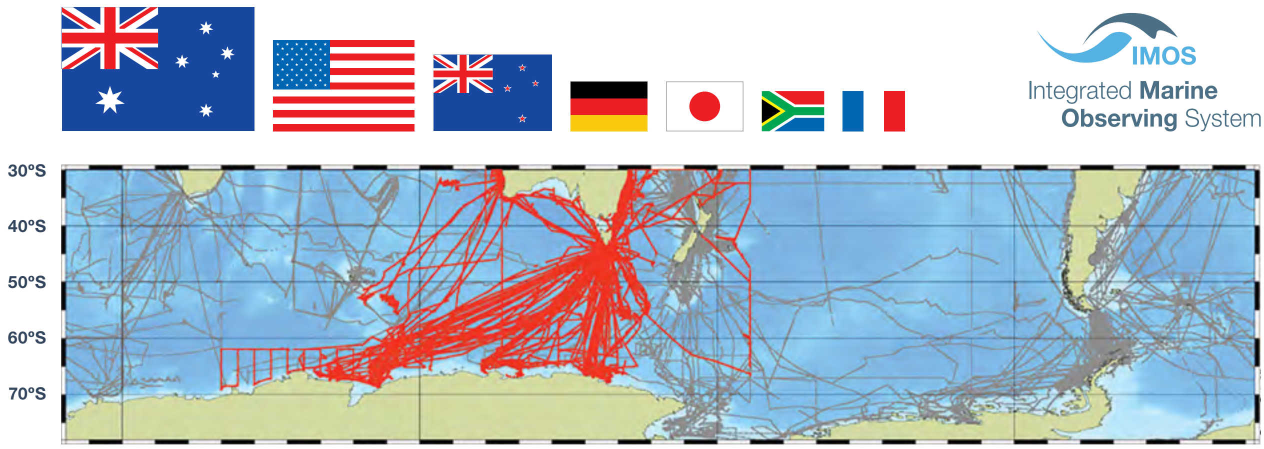
Warming and changes in ocean circulation, as well as changes in biological processes, will impact the strength of the Southern Ocean carbon sink and therefore how much atmospheric CO_2 it will continue to absorb.

A critical knowledge gap

A weakening of the Southern Ocean CO_2 sink in the 1990s is now attributed to a strengthening of the westerly winds and associated intensification of the upwelling of carbon-rich water from the ocean interior. This apparent stagnation was followed in the 2000s by a reinvigoration of the Southern Ocean carbon sink, the cause of which is not as well understood, but may also be linked to changes in physical circulation and circumpolar winds.

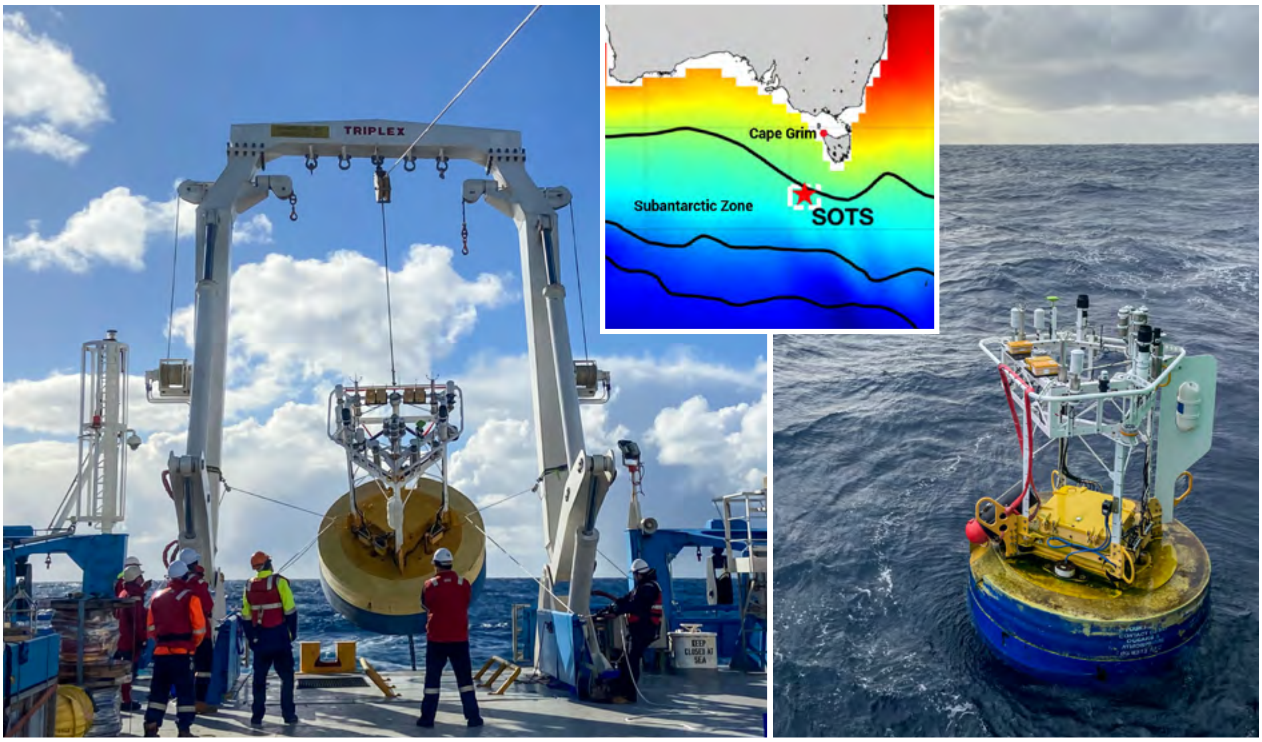
Atmospheric CO_2 concentrations are now nearly 50% higher than in the pre-industrial era and are predicted to increase at similar or accelerating rates over the next century. Because of the distribution of continental land masses, almost the entire carbon sink south of 30S is due to ocean uptake. A reduction, or stagnation, of the Southern Ocean carbon sink in the coming decades would lead to more CO_2 remaining in the atmosphere. This would intensify warming and the climate risks associated with that warming.

IMOS
Integrated Marine Observing System



Tracks showing ship-board CO_2 observations in the Southern Ocean collected between 2009 and 2025. Lines maintained by Australia shown in red (~40% of all observations), contributions from other nations are shown in grey, with flags scaled proportionally. **Source:** SOCAT (https://socat.info), B. Tilbrook.

Our ability to observe the vast and remote Southern Ocean has long been inconsistent with its importance. While Australia has provided global leadership in acquiring ship-board observations, the Southern Ocean remains persistently under-sampled, contributing up to 0.4 gigatons CO_2 per year of the uncertainty in estimates of the ocean carbon sink – roughly equal to Australia's net annual emissions.



(left) Deployment of the surface float for one of the SOTS moorings in May 2025; (centre) the SOTS site is located southwest of Tasmania, south of the Subtropical Front and in the Subantarctic Zone; (right) the air-sea flux and biogeochemistry mooring carries both in-water oceanographic sensors and a suite of meteorological instrumentation.

Taking the pulse of the Southern Ocean

Now in its 28th year, the Southern Ocean Time Series (SOTS) observatory, located 500km southwest of Tasmania and currently sustained by CSIRO research vessel (RV) *Investigator*, is the longest-running observation program of its kind in the open Southern Ocean.

Using two deep-water moorings anchored to the seafloor at a depth of 4600m, the SOTS program acquires observations of the lower atmosphere, upper ocean, and ocean interior, using a combination of sensors and automated samplers.

The SOTS program provides a critical baseline of oceanographic conditions, allowing natural variations to be distinguished from human-caused changes.

Observations collected at fixed locations like the SOTS site are expanded to the broader Southern Ocean by underway sensors that measure ocean properties continuously from research vessels (e.g., *RV Investigator* and *RSV Nuyina*). Southern Ocean observations from both moorings and ships are contributed annually to the Surface Ocean Carbon Atlas (SOCAT, see map above) and used to refine estimates of the Ocean Carbon Sink in the Global Carbon Budget.

Both the SOTS observatory and the shipboard CO_2 measurements are part of Australia's Integrated Marine Observing System (IMOS), and are operated in partnership with the CSIRO Marine National Facility and the Australian Antarctic Program Partnership.

The IMOS and the CSIRO Marine National Facility are national research infrastructure supported by the Australian Government's National Collaborative Research Infrastructure Strategy (NCRIS).

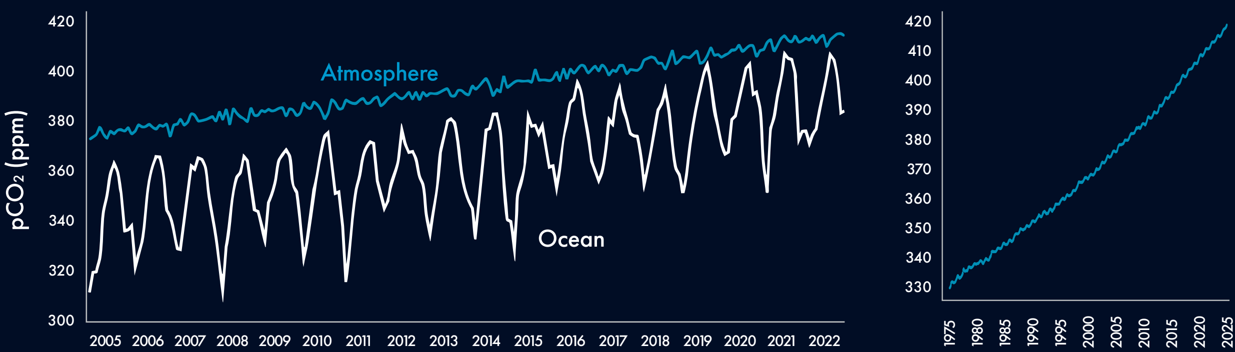
What must we do?

The world has a carbon problem – rising greenhouse gas emissions induce dangerous climate change and associated extreme weather. Ocean warming and acidification, ice loss, and sea-level rise are direct consequences.

Australia has committed to addressing this problem, which requires documenting and verifying emissions, as well as natural CO_2 sink pathways and marine CO_2 removal measures, to support national and international policies to limit the impacts of climate change. Observing the Southern Ocean is central to this effort because it plays a dominant role in the uptake of human-made CO_2.

Specifically, quantifying Southern Ocean CO_2 uptake is required to reliably forecast decadal and centennial climate change, because CO_2 has been – and will continue to be – the largest driver of climate over the past and coming centuries.

As the impacts of climate change are accelerating, immediate and significant emissions reductions are required. Closing gaps in knowledge of the ocean carbon cycle is no longer optional, but essential, to support effective climate action.



The Kennaook/Cape Grim Baseline Air Pollution Station in north-west Tasmania (jointly operated by CSIRO and the Bureau of Meteorology) provides observations of atmospheric CO_2 concentration extending back to 1975 (right panel). Together with surface water CO_2 estimated from observations collected at the Southern Ocean Time Series since 2005 (Yang et al., 2024) it has been shown that the subantarctic Southern Ocean is tracking, or potentially exceeding, the rate of human-caused increase in atmospheric CO_2 (Shadwick et al., 2023).

References cited: Friedlingstein, P., et al (2026) *Global Carbon Budget 2025*, Earth Syst. Sci. Data, 18, 3211–3288. Shadwick, EH, et al. (2023) *Observed amplification of the seasonal CO_2 cycle at the Southern Ocean Time Series*. Front. Mar. Sci., 10. Yang, X., et al. (2024). *Carbon export in the subantarctic zone revealed by multi-year observations from biogeochemical-Argo floats and sediment traps*. Global Biogeochemical Cycles, 38, e2024GB008135.

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