Irreversible near-term consequences of Southern Ocean acidification with current CO2 emissions pathways

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**Information Paper submitted by ASOC**

Summary

CO2 levels in the atmosphere have exceeded 423 ppm several times in 2023, exhibiting the same year-on-year increase of ≈2.5ppm that began in the early 2000s. Should this current rate continue, atmospheric concentrations of CO2 will reach the 450ppm critical level, established by the National Academies, in just eleven years. Shell damage due to acidification has already been observed in samples taken from the Ross Sea in 2006. Only the lowest IPCC Sixth Assessment (AR6) emissions pathways, in which emissions decrease by 43% in the next eight years, will prevent widespread shell damage throughout the Southern Ocean, in long-tail ocean chemistry processes that will persist for 30-70,000 years.

Recent Research of Concern

* Mounting research indicates that that a high emissions scenario would lead to catastrophic Southern Ocean marine species loss by 2100, at a scale on par with the five mass ocean extinction events in Earth’s past.1, 2
* Exposure to new stressors such as nanoplastics could worsen the effects of acidification for Southern Ocean marine species.3
* Westerly winds have shifted closer to the Antarctic continent, causing water eddies to erode the base of ice sheets and increase meltwater input into the ocean. This shift may have negative impacts on Southern Ocean ecosystems and species, and underscores the influence this ice sheet holds over local ecosystems, as well as the global climate system.4
* Sea ice loss is increasing the uptake of atmospheric carbon dioxide by surface water and driving rapid acidification of the western Arctic Ocean at a rate three to four times higher than that of the other ocean basins; as sea ice is lost around Antarctica, portions of the Southern Ocean may soon see similar dynamics.5 A decline in plankton diversity and carbon flux has already been observed in the waters off the West Antarctic Peninsula, where ice-free conditions occurred during the past austral summer.6

Background

Increasing CO2 concentration leads not only to climate change, but also to increasing rates of acidification of the world’s oceans.7 Oceans provide a vital service to the global climate system by absorbing CO2; limiting global warming, despite sharp increases in human carbon emissions. However, such ocean carbon absorption comes with a price: when dissolved into seawater, CO2 forms carbonic acid (H₂CO₃). This phenomenon is known as ocean acidification; and rates of acidification today are faster than at any point in the past 300 million years.8

The Southern and Arctic Oceans have absorbed the lion’s share of this dissolved CO2, mostly because colder and fresher waters can hold more carbon, which gets transferred to deep waters allowing more CO2 to be taken up at the surface. By some estimates, Antarctic waters have absorbed up to 40% of the total carbon taken up by the world’s oceans thus far.9 This makes it an important carbon sink, helping to hold down global heating. This “sink” harms polar marine environments, however, because it also results in higher rates of acidification than anywhere else on Earth.

Acidification makes it more difficult for Southern Ocean shell-building animals to build and maintain their structures; while in all water-dwelling organisms, ocean acidification increases the energy costs to maintain pH in the cells and tissues. In this way, ocean acidification harms key organisms such as marine gastropods and pteropods, sea urchins, clams, and crabs.10 Polar species of the Southern Ocean are adapted to the stable pH, temperature and saltwater conditions that have existed for several million years. They are sensitive to even small changes in seawater chemistry. 11

There is currently no practical way for humans to reverse ocean acidification. The only way to slow and eventually, halt the acidification process is through rapid CO2 emissions reductions and future carbon dioxide removal (CDR). If emissions continue to rise, these more acidic conditions will persist for tens of thousands of years. This is because processes that buffer the acidity from the ocean occur very slowly, over nearly geologic time scales. Although CO2 “only” lasts for 800-1000 years in the atmosphere, ocean processes are much slower. It will take some 50-70,000 years to bring acidification and its impacts back to pre-industrial levels, following the weathering of rocks on land into the ocean.12 This very long lifetime of acidification in the oceans is one reason why mitigation efforts focused on “solar-radiation management,” as opposed to decreasing atmospheric CO2 represent a special threat to the health of the Southern Ocean environment.

In the Southern Ocean, the ability of some vulnerable organisms to build shells declined by around 4% between 1998 and 2014. Pteropods – tiny marine snails known as “sea butterflies” – are particularly susceptible to these expanding corrosive waters, with shell damage documented in several Southern Ocean regions.13 Pteropods are important in the polar food web, serving as a key source of food for the young of many marine species.

Global temperatures peaking at 1.5°C will occur at atmospheric CO2 levels of around 450 ppm, which scientists of the Inter-academy Panel (a consortium of national Academies of Sciences) identified in 2008 as an important threshold for serious global ocean acidification.14 However, current pledges (even if completely fulfilled) will result in CO2 levels above 500 ppm, and temperatures of around 2.1°C.15 At that point, acidity will have more than doubled in the Southern Ocean, projected to cause widespread areas of corrosive waters.

Global ocean acidity has been relatively stable over the past several million years. Today’s rate of change is unprecedented, however, in at least the past 300 million years, when severe changes in ocean conditions, including high rates of acidification resulted in the mass extinction of many organisms. The speed of today’s acidification is therefore a key part of its threat: it is occurring far too quickly to allow species of today to evolve and survive.20

The Southern Ocean around Antarctica also has warmed more than other ocean regions, in particular the western Antarctic Peninsula, placing additional stress on ecosystems and species.19  The Bellingshausen Sea was completely ice-free in 2023, which will increase both acidification and warming in this region. Southern Ocean warming also seems increasingly important in overall global ocean heat increase. Ocean pollution, particularly that from plastics, add another layer of stress to Southern Ocean species.3

Southern Ocean waters contain some of the world’s richest fisheries and most diverse marine ecosystems. At 2°C or higher, the combination of sea ice loss for several months of the year, ocean warming, freshening and acidification will alter this marine ecosystem beyond our recognition. A world kept close to 1.5°C or lower can limit these irreversible effects on Southern Ocean ecosystems and fisheries, though some losses unfortunately are now inevitable.12 The projected effects of climate-induced stressors on this marine ecosystem will have negative implications for the global economy.3,12

Increased run-off from glaciers and the Antarctic ice sheet is also freshening surface waters. This colder, fresher water sits like a lid on top of the deeper, warmer and saltier levels below, preventing nutrients from reaching the surface where most species live.10,18 This phenomenon of a freshwater “lid” can also impact ocean currents, including the Global Meridional Ocean Circulation (GMOC). Freshwater incursion from the Antarctic ice sheet therefore has consequences for global circulation of important nutrients, gases and heat.

These impacts above 2°C are essentially irreversible, and will occur with all but the very lowest emissions pathways. These require a 50% reduction in CO2 emissions by 2030, motivated by high ambition and commitment toward global decarbonization; with essentially zero emissions by 2050, and negative emissions (removing carbon from the atmosphere) thereafter.15 Until, and unless, human-caused CO2 levels begin to fall sharply, there is high likelihood that the damage to Southern Ocean species observed thus far are a harbinger of much worse to come.

Input from ATCM

While global oceans have received increasing attention through a variety of forums, including the annual UNFCCC Oceans and Climate Dialogues, the closeness of the Southern Ocean to serious and irreversible acidification thresholds remains virtually unaddressed in these forums. Parties and Stakeholders should consider ways to raise this serious threat to marine ecosystems and fisheries from CO2 levels that continue to rise toward the critical 450ppm threshold identified by the research community fifteen years ago.

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