North Atlantic Carbon Observatory

Science Primer

The ocean is the most important global storage depot of mobile carbon on Earth containing 45 times more carbon than the atmosphere and almost 10 times more carbon than in all terrestrial vegetation, soils and permafrost combined. Limiting future atmospheric CO_2 levels and climate change depends critically on future net exchange of CO_2 between the ocean and the atmosphere: the ocean carbon sink.

Canada is well positioned to propose a major new initiative which will link G7 countries in a coordinated approach to measure, or "audit", the ocean carbon sink. Such an effort will support international efforts to bring about greenhouse gas neutrality, as global ambitions for a net-zero-carbon future depend on the ocean's ability to absorb carbon.

The North Atlantic Ocean remains the world's most intense long-term carbon sink, accounting for at least ~30% of the global ocean CO_2 uptake today and during preindustrial times (Ref. 1). It is also particularly vulnerable to the impacts of climate change. However, the North Atlantic's carbon-absorbing function remains critically under-observed. The focus of this effort should therefore be on the North Atlantic. Canada has a unique opportunity to contribute internationally to the urgent global need for monitoring carbon sinks through targeted ocean observation in waters adjacent to Canada's coast. Canada is also well poised to lead in the development and demonstration of the technological and scientific approaches to measuring carbon fluxes in the North Atlantic and globally.

Such an initiative will **connect** and **enhance** existing Canadian and international activities, **develop** and **apply** advanced technology to accurately quantify physically-, biogeochemically-, and biologically-mediated transfers of carbon between the atmosphere and ocean, and ocean interior.

Knowledge of the ocean sink is key to independent, global assessment of carbon mitigation strategies

Over the past 150 years, since the Industrial Revolution, more than one-third of the CO_2 released from burning of fossil fuels and industrial production has dissolved in the ocean. The remainder has accumulated in the atmosphere, while the land biosphere has been, on average, neither a net source nor a sink (Ref. 2).

Our present ability to track the fate of emitted carbon is limited. Over the past decade, estimates of the anthropogenic carbon put into the ocean have varied from one-quarter (based on ocean models) to one third (based on ocean observations (Ref. 3)). There are also currently conflicting views of the net balance of carbon within the global land biosphere.

Model-based estimates of the ocean sink imply that the global land biosphere has been a significant net carbon sink over the past 10 years (Ref. 2). Recent observation-based estimates of

ocean carbon uptake and accumulation (Ref. 3 and Fig. 1) are higher and imply that the land biosphere may have been almost carbon neutral on the global scale.

Direct estimation of sources and sinks of carbon both on land and in the ocean is notoriously difficult and subject to large uncertainties. The discrepancy between the various mass balance approaches demonstrates the importance of high-accuracy, direct measurement of the ocean carbon sink for assessing the effectiveness of future emission reduction policies, including attempts to manage carbon sinks on land. Knowledge of the ocean sink will become more critical as carbon mitigation grows in political and economic importance.

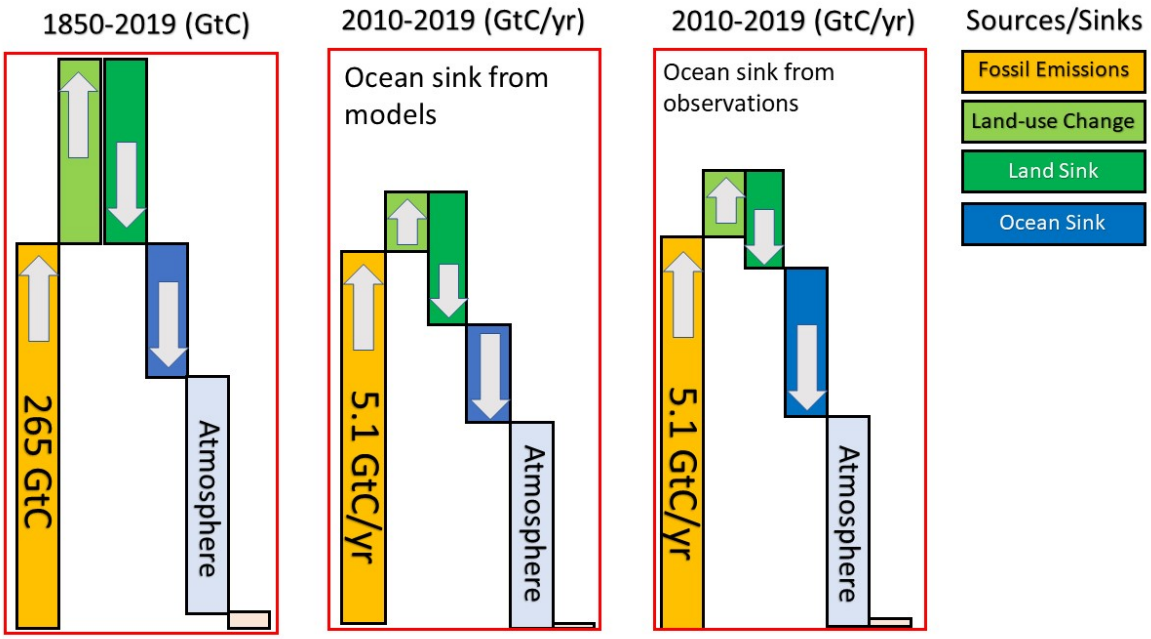

Figure 1. Cumulative changes in the carbon sink between 1850 and 2019, and mean fluxes 2010-2019 for the anthropogenic perturbation. Pale pink boxes represent the budgetary imbalance within each method – note these are cumulative when comparing between methods. Modified from Friedlingstein et al (Global Carbon Project) and data from Watson et al., 2020.

The ocean carbon sink is large, variable and vulnerable to both climate change and emission reductions

The net transfer of CO_2 from the atmosphere to the ocean across the sea-surface depends on the rate at which CO_2 is added to the atmosphere through emissions. The strength of the ocean carbon sink then critically depends on the rate at which carbon is transported from the sea surface into the vast, deep ocean. This transfer is mediated by a complex set of physical, chemical and biological processes which sequester carbon deep into the ocean.

Climate-change impacts such as near-surface warming and the addition of freshwater, and melting glaciers and ice-caps, can reduce the rate at which deep ocean waters are exchanged with near-surface layers. The result is a slowing of the rate of CO_2 transfer into the deep ocean,

thereby reducing the carbon sink. Changes to the biologically-mediated, downward transport of carbon can also be forced by these climate-related changes, impacting not only CO_2 sequestration but also the food supply of deep ocean ecosystems.

Coupling between climate forcing and within-ocean transfers of carbon caused the major glacial-interglacial changes in atmospheric CO_2 associated with the recurring ice-ages of the past 1 million years of Earth history (Fig. 2). Sustainment

There is every reason to expect that climate change will impact the ocean carbon sink in the future. The changes in ocean carbon storage will not be as visible and dramatic as their counterparts on land, which can involve forest fires, industrial-scale agriculture or land clearance. **Equivalent critical climate-related changes in carbon transport in the ocean will be missed unless they are being rigorously measured**.

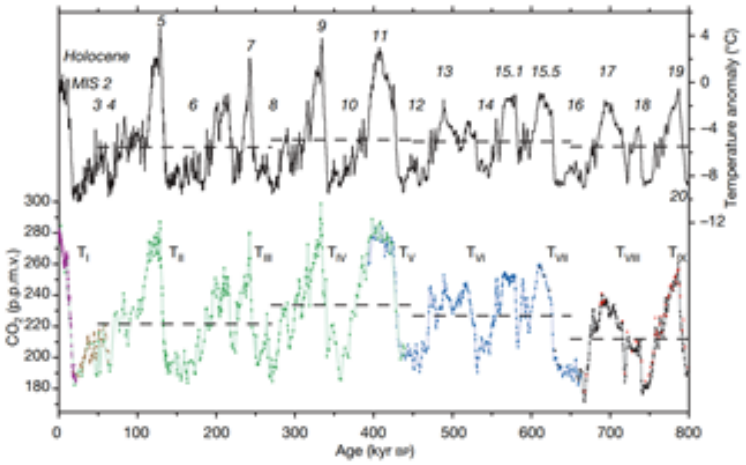

Figure 2. Ice-core records of temperature anomalies and atmospheric CO_2 over the past 800,000 years, as recorded in the DOME-C ice core. (Luethi et al., Nature, 2008) (Ref. 4).

The strength of the ocean carbon sink will likely decrease with future reductions in emissions of CO_2 as well as changes in the chemical buffering capacity of surface seawater. If the atmospheric CO_2 increases do slow as intended, the ocean carbon sink will shrink, and the flux could even reverse sign in some regions, with some previously sequestered CO_2 out-gassing back to the atmosphere (Ref. 5).

While the potential changing role of the ocean is represented in most models of future emissions scenarios, the details and magnitude of the response to emission reduction are highly uncertain. We lack the data to determine whether the models are correct. Further, the effect is not broadly appreciated in full by policymakers or the general public. This could complicate assessment of the effectiveness or legitimacy of mitigation measures.

The North Atlantic Ocean is a major contributor to the global ocean sink and is especially vulnerable to change.

Several features of the ocean carbon sink differ from sinks on land and must be taken into account in any assessment or auditing process. In contrast to most land carbon sinks, carbon in the ocean moves around, vertically and horizontally, transported by ocean circulation and biological processes. This means that atmospheric carbon deposited in the ocean can accumulate far from where it entered.

For example, fossil-fuel derived CO_2 taken up by surface waters off eastern Canada is now found at depths below 1500 m, in the far-distant South Atlantic Ocean. In contrast to the atmosphere, the accumulation is non-uniform because downward mixing and horizontal transport in the ocean are comparatively slow and vary with geographic location. The complexity and geographic variability of ocean carbon transport processes implies that wherever we initiate assessment of the ocean carbon sink, the work must ultimately be global in scope.

Why, then, must we start with the North Atlantic Ocean? In fact, the North Atlantic is a critical first focus for this effort. It plays a key role in the global carbon uptake and transport. It is the most intense sink for carbon. Its particular features make it an immediate priority for tracking the magnitude and variability of the carbon sink. Deep water formation in the North Atlantic causes its overall carbon sink strength to be twice that of the global average. The average depth to which carbon is sequestered is highest in the North Atlantic.

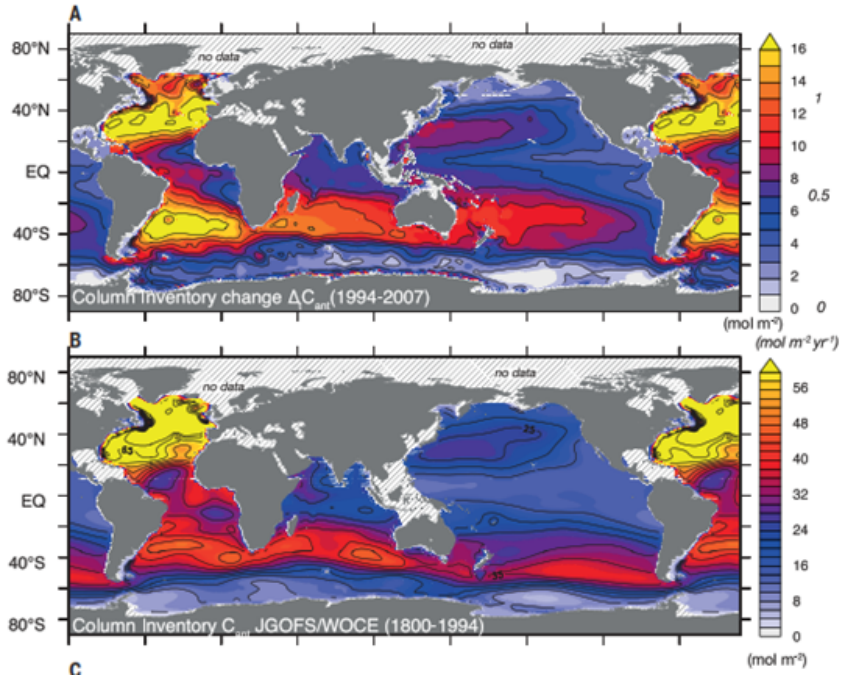

Figure 3. Accumulation of anthropogenic carbon in the global ocean over a) the time-period 1994 to 2007; and b) since the Industrial Revolution. Both estimates are based directly on ocean observations (from Ref. 6).

The North Atlantic carbon sink is also particularly sensitive to climate change, being located downstream of the Arctic Ocean and the Greenland Ice Cap, both of which are experiencing extreme impacts resulting from climate change. The Canadian Arctic Gateway, where Arctic-derived waters enter the Atlantic Ocean, is one of only a few regions worldwide where the surface layer of the ocean can communicate directly and rapidly with the deep ocean interior via mixing. This process is linked to the Atlantic Meridional Overturning Circulation (AMOC) and is highly vulnerable to climate change (Ref. 7).

The carbon sink of the North Atlantic is also sensitive to the strength and location of the Gulf Stream, another key, climate-sensitive component of the AMOC. The carbon sink in the region offshore eastern Canada (the Labrador Sea and the northern "edge" of the Gulf Stream) is particularly vulnerable and major decade-timescale variations in carbon accumulation have already been observed there (Refs. 6, 8).

A Sentinel Region for a Vulnerable Ocean Carbon Sink

The magnitude and vulnerability of the North Atlantic sink, including in the key region adjacent to north-eastern and eastern Canada, make it a "sentinel region" where observations of the ocean sink strength will provide major value for large scale assessments. Comprehensive ocean observations of the ocean sink in a sentinel region of the world ocean, will be key to measuring progress towards greenhouse gas neutrality.

Partners in a North Atlantic Carbon Observatory (NACO)

The focus of the measurement program will be in two key regions: (i) The sub-polar gyre off Newfoundland and Labrador - the Labrador Sea and (ii) the sub-tropical gyre southeast of Nova Scotia. There is already ocean observation activity upon which to build a North Atlantic Carbon Observatory program. The key gaps to fill are in these two crucial gyres, and the need is for more and better biogeochemical measurements.

There are several current initiatives doing useful and relevant work; however, there are also critical gaps. The Integrated Carbon Observation System (ICOS) - a European initiative with a geographic focus on the Northeast Atlantic - offers some of the data and technical services that are required. NOAA in the USA has an active carbon measurement program. The US Ocean Observatory Initiative (OOI) has two relevant moorings arrays, one east of Greenalnd, the other off New England in sub-tropical waters. There is a critical monitoring station at Bermuda. Many other existing ocean observation networks are focused on making physical measurements, such as temperature and salinity, but it is essential to develop initiatives like the biogeochemical Argo float program (BGC Argo) initiative which can provide some of the critically needed measurements of biogeochemical variables, including carbon. There is a need for new, autonomous platforms and sensors to measure ocean carbon: both are areas where Canada's ocean tech sector excels and which will bring innovation outcomes to market, aligning well with Canada's focus on a future, holistic Blue Economy approach.

Missing across the entire system is an integrated, coordinated international observing supporting a North Atlantic Carbon Observatory (NACO) across North American, European, and other international efforts. Scientists are increasingly recognizing the global risk of ocean carbon work happening in silos. Repeatedly, work is focused on individual researcher programs, or national programs, rather than a global, integrated approach that is required to provide scientific outcomes and critical information for policymakers.

Canada is well positioned to lead global work in the North Atlantic, and to establish Canadian G7 leadership in the North Atlantic Carbon Observatory (NACO).

The Ocean Frontier Institute (OFI) is a partnership initiative between Canadian and international ocean research universities and institutions with a transboundary mandate focusing on the North Atlantic. The researchers associated with the Institute have the expertise, the leadership capabilities and credibility, and the international stature, to lead a transnational North Atlantic Carbon Observatory initiative supporting Canadian leadership. OFI is also focused on the technological solution space producing market opportunities for Canada:

- Anya Waite is the Scientific Director of the OFI and co-chairs the Global Ocean Observing System (GOOS) Steering Committee.
- Katja Fennel chairs the Biogeochemical Argo Canada Program.
- Doug Wallace is co-chair of the ICES-PICES Working Group on Ocean Negative Carbon Emissions.
- Daria Atamanchuk leads the instruments group of the International Ocean Carbon Coordination Project (IOCCP).
- Brad deYoung leads the AtlantOS Basin-Scale Program, co-chairs Ocean Gliders and has been on the Steering Committee of the OSNAP AMOC program from its inception.
- DFO would be an important partner, with Dr. Kumiko Azetsu-Scott being a member of the international GO-SHIP Science Committee and with key contributions to carbon monitoring from the Atlantic Zonal Monitoring and Atlantic Zonal Monitoring and Ocean Programs (AZMP and AZOMP).

Framework for a Phased Scientific Approach

1. Formation of a G7 International Steering/Advisory Group
2. Assessment of current resources and carbon-flow gaps
3. Observatory Design
    a. In situ measurements
        i. Argo
        ii. Gliders
        iii. Moorings
        iv. Autonomous vehicles
        v. Carbon sensors
    b. Satellite observations
    c. Ship-based measurements
    d. Data flows and Management
    e. Dashboard design
4. Observatory Planning
5. Observatory Execution

References:

1. Yu et al., Nature Communications, 2019
2. Friedlingstein et al, GCP, ESSD, 2020
3. Watson et al., Nature Communications, 2020
4. Luethi et al., Nature, 2008
5. Ridge and McKinley, Biogeosciences, 2021
6. Gruber et al., Science, 2020
7. Caesar et al., Nature Geoscience, 2021

8. Raimondi et al., JGR Oceans, 2021

Proposed Action

Strong Canadian leadership in a G7 North Atlantic Carbon Observatory would audaciously match Canada's leadership ambition on carbon emission reductions, with a visible international profile. Important carbon sink regions such as the North Atlantic remain under- observed and in urgent need of a state-of-the-art ocean observation system supporting deployment of new Canadian and international instrumentation technologies on floats and moorings across critical ocean gateways between the Arctic and the Atlantic, and within regions where the carbon sink is most dynamic, in the two key gyres – the sub-polar and sub-tropical.

Data flows could be curated and shared in real time, linking and consolidating information from Canada's recent investments in BGC Argo and the Canadian Integrated Ocean Observing System (CIOOS) to service an enhanced carbon observation program that could contribute to the Global Ocean Observation System (GOOS).

In Canada, the OFI is spearheading the conversation on the ocean's role in reaching net zero carbon emissions. OFI partners with six international institutes in G7 countries with key expertise in the physics, chemistry and biology of ocean carbon absorption. With our G7 colleagues, we commit to building an international research alliance to develop ocean solutions to meet the carbon challenge.

In early spring 2021, the Ocean Frontier Institute held its inaugural International Science Policy Workshop. International scientists (German, French, UK and Canadian) and policy influencers - UNFCCC, IUCN, IOC UNESCO, Ocean Unite, NOAA, Envoy Kerry's Office and a private foundation attended. Fisheries and Oceans Canada and Environment and Climate Change Canada also participated.

The Workshop yielded two clear outcomes: compelling evidence that mechanisms supporting the North Atlantic carbon sink are undergoing dramatic change, and concern from the policy cadre that climate targets may not be valid if they do not incorporate or reflect the changing carbon absorption effort of the ocean.

The April 2021 Workshop also sparked a number of conversations which signaled the likely breadth of international interest in a path forward. NOAA and other US colleagues indicated they would like to work more closely on this. There is an appetite with philanthropic coalitions focused on the innovation/solution space, and UN and non-governmental actors signalled their interest in remaining involved.

International Climate Policy Arc

Concurrent with the need to urgently address the critical scientific knowledge gap, 2021 also represents the year which sees the international community focused on addressing global climate change policy.

Without robust understanding of our capacity to quantify the impact of the ocean carbon cycle on atmospheric conditions, current (and future) climate targets will not be judged credible by the international community.

Leadership of the North Atlantic Carbon Observatory would position Canada to fill a critical knowledge gap to address the global climate emergency that humanity faces.

The Paris Agreement text and subsequent policy documents about carbon sinks barely mention the "big" open/ deep ocean sink. It is unclear whether the policy discussion of greenhouse gas neutrality presently include any consideration of this "big" ocean sink. The current global discussion of ocean sinks tends to focus on seagrass, mangroves, which are important for conservation/ biodiversity, but play only a small role in terms of the oceans' carbon sink contributions.

It appears that the "big" part of the ocean sink is not discussed explicitly; even the global stock-take process is almost silent about the ocean sink and it appears to be left to IPCC to assess it. In contrast, land biosphere sinks are likely to be looked at in great detail, including via the Nationally Determined Contributions process. Given that ocean sinks are far offshore in the deep ocean, out of sight, they may not be addressed by NDCs and may simply fall through the cracks.

This gap represents potentially the most significant miscalculation of climate change policy by the numbers. Citing insufficient data will harm the credibility of national and global policy positions.

In an open letter to the UNFCCC in advance of CoP 26, Peter Thomson, UN Secretary General's Special Envoy for the Ocean set out some of the challenges relating to the ocean. In the excerpt below, he touches on the oceanic carbon pump, which is precisely the system the North Atlantic initiative would examine with a view to being able to quantify those limits.

> "The hope of all those consulted is that the ocean's critical role in climate change mitigation and adaptation will be integral to COP26 considerations, and that the conference's outcomes will include greatly enhanced commitments and resources to meet the challenges presented within the ocean-climate nexus. The challenges are summarised in the following points.
>
> (i) The ocean is the great regulator of climate, through the water cycle, oceanic circulation and the oceanic [carbon] pump. It absorbs around 23% of annual emissions into the atmosphere of anthropogenic carbon dioxide (CO_2). .. ***It must be understood by all that the constancy of these contributions and capacities has its limits.*** ..Many thresholds and tipping points are becoming apparent, with concurrent negative impacts on marine biodiversity and ecosystem services."

Canada has a unique international leadership opportunity coming out of the Cornwall G7 meetings to redress the science and policy gap. As the 2021 G7 leader, the UK has built into the G7 Future of the Seas and Oceans Initiative a new spotlight on net-zero ocean capabilities for G7 nations, in the context of increasing recognition of the ocean's role in controlling climate change.

From the G7, to the G20 and finally to CoP-26 there is an opportunity for Canada to convene international science and policy experts to discuss the value add of a North Atlantic initiative. Should Canada be a first mover post-Cornwall, it would be on the way to leading to a substantive element in the Glasgow 'protocol' that is expected out of CoP 26 in Glasgow.

US Special Envoy John Kerry has indicated his desire for an Ocean 'outcome' at CoP 26. He has referenced the North Atlantic specifically in the context the climate – ocean nexus, and the changing chemistry of the ocean. The CoP Presidency is encouraging all countries to submit ambitious NDCs *and* net-zero strategies ahead of the Summit.

Canada could step forward before November with an approach and solution to fill the essential missing piece in the framework for international climate policy. Starting in the North Atlantic, this initiative would build scientific knowledge, apply real time outcomes to climate policy and spurr innovation in a critical area.

Key Dates

- September 3-11, 2021 International Union for the Conservation of Nature (IUCN). The Conference has 7 themes, including oceans and climate change
- September 14-30, 2021 United Nations 76th General Assembly.
- September 20, 2021 – New York Climate Week
- September 28-30 – Youth4Climate Summit
- September/October 30-2 – Preparatory meeting ahead of the 26th Session of the Conference of the Parties to the UN Framework Convention on Climate Change. (Pre-CoP 26)
- October 11-24 15th Session of the Conference of the Parties to the UN Convention on Biodiversity (CBD CoP15)
- October 30-31, 2021 – G-20
- November 1-12, 2021 - 26th Session of the Conference of the Parties to the UN Framework Convention on Climate Change (UNFCCC CoP26). *The Presidency is encouraging all countries to submit ambitious NDC's AND net-zero strategies ahead of the Summit.*