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A Surface Ocean CO_2 Monitoring Network: Facilitating the development of an internationally-agreed observing strategy and coordination structure for GOOS.

FUTURE OF THE SEAS & OCEANS INITIATIVE

In partnership with the GOOS Biogeochemistry Panel and other international and G7 Member ocean carbon programmes, catalyse and facilitate the development of an internationally-agreed strategy for monitoring surface ocean CO_2 globally, and build on existing observing programmes, data management structures, and coordination bodies to create a global surface monitoring CO_2 network capable of responding to the needs of global and regional policy drivers including the UNFCCC Global Stocktake 2023.

Action Areas 1, 3, and 4.

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1. BACKGROUND INFORMATION

Justification

The ocean currently removes 25-30% of the carbon dioxide (CO_2) emitted to the atmosphere by human activities. Surface ocean measurements of dissolved CO_2 partial pressure enable the calculation of ocean-atmosphere flux. With a suitable coverage of such observations, regional and global uptake of atmospheric CO_2 can be calculated.

The ocean is one of two natural sinks for the CO_2 emitted by humans – the other is land vegetation, especially forests. Together, these sinks have absorbed more than half of the CO_2 we emit. Without these natural sinks, atmospheric CO_2 concentrations would already have reached more than 600 parts per million, would have surpassed 1.5° C warming, and climate change would be much more rapid and disruptive. Ocean uptake of atmospheric CO_2 is also the primary cause of ocean acidification, which has a range of detrimental impacts on marine organisms and ecosystems.

Ocean CO_2 uptake is largely controlled by increasing atmospheric CO_2 levels due to burning of fossil fuels. However, it is not constant regionally or even globally, but changes seasonally, from year to year and from decade to decade. For instance, based on measurements, ocean CO_2 uptake appears surprisingly constant in the 1990s despite the increase in atmospheric CO_2 concentration, but has risen substantially since 2000. The reasons for past variability and thus predictions for the near and long-term future are uncertain. As we aim to stabilize global temperatures through reduction of fossil fuel consumption, the behaviour and quantification of the ocean carbon sink becomes critically important and there are real costs associated with such uncertainty. There is a possibility of the ocean becoming a net source of CO_2 to the atmosphere after emissions peak and atmospheric CO_2 levels decrease. Addressing these societal issues require an operational global monitoring system capable of resolving the temporal and spatial scale changes in ocean CO_2.

Ocean uptake is easier to observe over large regions than is the uptake by land vegetation, because it varies less over short distances and times. Knowledge of ocean uptake also enables calculation of land fluxes at continental and global scales since the total of net land and ocean sinks are determined by the balance of emissions and the atmospheric CO_2 content (which is well observed). A global monitoring system is needed to track where our emitted CO_2 is going so that we know how the ocean and land sinks are changing with time and how the global carbon cycle is responding to global efforts at mitigation. The Global Carbon Project currently uses a blend of models and data-products (for verification where data exist) to estimate ocean uptake.

The specific goal of an observing system for surface ocean CO_2 should be to determine net ocean – atmosphere fluxes to an accuracy of 10% or better regionally and globally on an annual scale *(cf. Global Climate Observing System Implementation Plan).* This will provide powerful constraints on the past, present, and future response of the Earth's carbon cycle to anthropogenic change and on the fate of anthropogenic CO2 and will allow rapid responses to any changes required to alter emission pathways. Observations of surface ocean CO_2 are also needed to accurately monitor ocean acidification and negative impacts on marine biodiversity, climate, and food security.

The first Global Stocktake under the Paris Agreement will take place in 2023, where all Parties under the Convention have committed to conserving and enhancing sinks and reservoirs of greenhouse gases, including oceans and coastal and marine ecosystems. As part of the Global Stocktake exercise, it will be necessary to quantify and assess both carbon emissions and natural sinks. While many elements of a surface ocean CO_2 monitoring system exist, ***there is currently no internationally-agreed strategy that could coordinate national and regional efforts into a global network.***

Existing Networks

The ocean carbon observing community is well organized at the international level through the International Ocean Carbon Coordination Project (IOCCP) which serves as the GOOS Biogeochemistry Panel. Ocean acidification monitoring is coordinated by the Global Ocean Acidification Observation Network (GOA-ON), which liaises closely with IOCCP for carbon system monitoring and supports the ocean acidification observation data collection by IOC-UNESCO in the framework of the 14.3.1 SDG indicator. The UNESCO Intergovernmental Oceanographic Commission's Integrated Ocean Carbon Research Programme (IOC-R) is addressing critical research and monitoring issues such as the changing ocean sink for human-produced CO_2 and its climate change mitigation capacity, the vulnerability of ocean ecosystems to increasing CO_2 levels and our ability and need to adapt to changing ocean conditions. The IOCCP community developed the global strategy for ocean carbon surveys from repeat hydrography (GO-SHIP) and support GLODAP, a data product for interior ocean carbon.

Measurements of CO_2 in the surface ocean were initiated in the late 1950s and have grown over time through international collaborations and partnerships with shipping companies and research ship operators. The observations from moorings and ships-of-opportunity have been collated into a comprehensive data holding in the Surface Ocean CO_2 Atlas (SOCAT), a volunteer effort initiated in 2007 that has pulled together 28 million quality-controlled surface water CO_2 observations spanning 50 years (2020 version). The SOCAT database serves as the global basis for evaluating monthly fields of air-sea CO_2 flux. However, systematic surface CO_2 measurements have mainly been restricted to the major sea lanes of developed countries, and there remain large data gaps in the vast ocean, particularly for coastal and marginal seas and in the Southern Hemisphere (see IOC-R report).

In 2018, the community came together to develop the Surface Ocean CO_2 Reference Observing Network (SOCONET), a volunteer collaboration of established operators who have developed a pilot surface water and atmospheric CO_2 reference network that focuses on providing high-quality automated surface CO_2 measurements from multiple platforms from which global air-sea CO_2 fluxes and trends in surface water CO_2 levels may be determined. Ultimately, the SOCONET vision is that this reference network will expand from its existing pilot stations to support a much wider global surface CO_2 monitoring array.

Most of the global observing networks that currently contribute to the global ocean observing system are platform-based, bringing together scientists and funding agencies around implementation of a single platform, such as Argo, where the coordination challenges and implementation strategies are relatively straightforward. Surface Ocean CO_2 observations come from a combination of trans-ocean shipping routes using automated instruments on commercial and private vessels, instruments on research ships, fixed moorings - in particular, observations in the equatorial Pacific and Atlantic and at a few other open ocean sites, and recently, from new designs of autonomous surface vehicles. ***Development of an implementation strategy will therefore require an integrated system-design approach using the Essential Ocean Variables across multiple platforms, combined with satellite data and modelling / data-assimilating models / AI techniques.*** The coverage of observations made over the last 30 years has varied substantially, but it has never been sufficient to define the flux of CO_2 into the global ocean to the required accuracy of 10% (e.g., GCOS Implementation Plan). However, recent studies indicate that, at its best ***(from about 2005 to 2015), the coverage in the North and Equatorial Atlantic and Pacific, when combined with satellite and Argo float measurements of wind, temperature, and salinity, was sufficient to define the flux in those regions to the required accuracy.*** Since that time, the density of coverage has decreased and is no longer adequate even in those regions.

In recent years, serious gaps have developed in surface CO_2 data coverage owing to funding cuts in some key underway pCO_2 programmes that had been operating for decades, highlighting the fragility of the network and the global volunteer efforts that have built it. These programmes, and the international ocean and climate science communities they serve, suffer from the lack of an internationally-agreed strategy that recognizes individual programmes as essential elements of a coordinated global network.

This activity proposes to develop an international strategy and implementation plan that would enable G7 members and other nations to coordinate investments in a sustained, fit-for-purpose surface CO_2 monitoring network as part of GOOS. This network would build on and enhance existing global activities, principally by expanding the pilot reference network of SOCONET, in partnership with GOA-ON and the SOCAT database project and evolve with relevant Decade programmes. Global coordination for the network would be provided by an enhanced IOCCP and GOA-ON secretariat, with strong links to the IOC-WMO OceanOPS Centre.

Network Requirements

While defining the observation requirements for the core global surface CO_2 monitoring network would be the main objective of a G7 FSOI Task Team, we can already identify past and current essential contributions that constitute the building blocks of the global network. For example:

1 NOAA in the US, JMA and JAMSTEC in Japan and CNRS in France provide essential and ongoing support for fixed stations and research vessel observations in the Equatorial Pacific and Atlantic, and the Western Pacific. Canada provides support for a key time series station in the North East Pacific. Automated instruments on research and supply vessels in the Antarctic operated by the US, UK, France, Germany, and Australia (among other nations) provide important observations in the Southern Ocean. Italy contributes crucial observatories in the Adriatic and Mediterranean focussed on understanding marginal sea contributions to the global carbon cycle ***These ongoing efforts are essential and must be continued.***

2 In the period of 2005-2015, coverage in northern and equatorial region Atlantic and Pacific *was* adequate to define the net CO_2 sink these regions to the required accuracy. At that time, there were about ***five trans-ocean shipping routes operated by commercial vessels in both the North Pacific and North Atlantic, as well as routes in the Caribbean***. These were operated by various nations (US, Japan (NIES), France, UK, Germany, Norway, Spain). These

complemented the coverage by NOAA, JMA, JAMSTEC, and CNRS time series stations, moorings and research vessel observations. Several of the trans-ocean routes have now ceased operation or become much more intermittent due to short-term nature of their funding support, and these regions are no longer adequately covered. ***Automated instrumentation on trans-ocean commercial shipping routes is a cost-effective way of observing large regions. In ocean basins covered by regular shipping routes (North Pacific and North and South Atlantic, Indian) these need to be restored and maintained.***

3 In the South Pacific and the Southern Ocean, observations are far less numerous and have mostly been provided by research vessels. Historically, these regions have never been observed with sufficient density. Since 2014, the US Southern Ocean Carbon and Climate Observations and Modelling (SOCCOM) program launched a substantial number of biogeochemical (BGC) Argo floats in the Southern Ocean, and this approach, along with new G7-led international commitments to implementing approximately 70% of the global biogeochemical Argo array in the coming years, may provide adequate surface observations to provide the required coverage here and in other data-sparse areas. ***However, the BGC Argo floats measure pH, not dissolved CO_2 partial pressure,*** and there remain large uncertainties in estimating pCO_2 from a combination of these pH measurements and estimates of alkalinity measured by decadal repeat hydrographic surveys. Furthermore, calibration and interpretation of BGC Argo pH measurements can only be resolved through independent pH measurements (especially from deep pH observations where variability is low) and through surface CO_2 observations using research vessels and /or autonomous surface vehicles. ***Ongoing and increased pH reference observations and sustained direct surface pCO_2 observations from research vessels, autonomous vehicles, and moorings, coupled with continued development of the BGC Argo float observations, are required in these under-sampled regions.***

4 For a global network, resources to observe coastal areas and shelf seas are also required. The status of surface CO_2 and pH observations in coastal zones is varied with GOA-ON providing a coordination role. Major capacity building activities by GOA-ON and its regional hubs, with support from sponsoring agencies IOC-UNESCO and the Ocean Acidification International Coordination Centre of the IAEA, have helped to expand the network and have increased the number of ocean acidification measurements, partly provided by surface ocean measurements. For reasons of carbon accounting as well as protection of biodiversity and food security, nations with significant coastal seas will require a monitoring network in place to allow for the observation of carbon uptake and acidification in those waters. Additionally, monitoring the effects of restoration, blue carbon sinks, and other negative emission technologies (e.g., alkalinization) will require targeted ocean CO_2 monitoring. The proposed activity would catalyse a stronger coordination of coastal programmes at the regional level and globally.

2. DESCRIPTION OF THE ACTIVITY AND NEXT STEPS

The proposed G7 FSOI activity would work with international partners (not limited to G7 members) to catalyse and facilitate the development of an internationally-agreed strategy for a global surface CO_2 monitoring network, with a focus on the open ocean and marginal seas. This would permit G7 members to identify priority observing system investments to meet data needs, develop the foundations of a sustained surface ocean carbon monitoring system, and respond to international / intergovernmental policy drivers and commitments to UN agreements.

The Coordination Centre proposes to work directly with experts from (*inter alia)* G7 national programmes, the IOCCP (GOOS Biogeochemistry Panel), SOCONET, SOCAT, GOA-ON, the EU Research Infrastructure Integrated Carbon Observing System (ICOS) Ocean Thematic Center, the EU Joint Programming Initiative Healthy and Productive Seas and Oceans (JPI Oceans) programme, the IOC Integrated Ocean Carbon Research (IOC-R) Working Group, the Global Carbon Project, OceanPredict, relevant UN Ocean Decade programmes (e.g., Observing Air-Sea Interactions Strategy (OASIS), CoastPredict, the Ocean Acidification Research for Sustainability (OARS) programme of GOA-ON and the IOC), and the World Meteorological Organization's Global Atmosphere Watch to develop this strategy and the community of practice and coordination structure to manage this global network, building on SOCONET (observations) and SOCAT (quality-controlled dataset in uniform format).

Specific Tasks include to:

1. Develop an internationally-agreed observing strategy required to determine net ocean-atmosphere fluxes to an accuracy of 10% or better regionally and globally, and to monitor global ocean acidification, building on existing infrastructures and making best use of the combination of *in situ* observing platforms, satellite data, and models to fill gaps.
2. Develop international agreements on the system components required to support the observing network, including data management and global coordination support.
3. Develop a roadmap, phased-implementation plan, and budget requirements by the end of 2022 for a sustained surface ocean CO_2 monitoring system, with the goal of establishing a fully-functional system for the 2nd Global Stocktake of the UNFCCC in 2028, where all Parties under the Convention have committed to conserving and enhancing sinks and reservoirs of greenhouse gases, including oceans and coastal and marine ecosystems. Additionally, this Task Team should provide comprehensive information on ocean carbon system monitoring to assist G7 Members in their reporting on the SDG ocean acidification target (14.3 SDG target and the indicator 14.3.1) and to assist other countries with the goal of establishing global representative coverage of all open ocean areas.
4. Work with international partners to reach agreements on coordinated contributions and investments to implement the full fit-for-purpose observing system, including coastal areas, regional seas, and regional hubs (e.g., GOA-ON) and coordination support, by 2028.

Developing the necessary strategy and roadmap by building on existing networks and infrastructure should be achievable within a 1-year period. Discussions and consultations across the G7 members and other countries about the roadmap, and initial commitments to implement the system, could be carried out within the following 1-year period.

Phase 1: Strategy Development (mid-2021 to mid-2022)

Develop a G7 FSOI Task Team with partners to address Tasks 1 – 3 through an international workshop (virtual or mixed) and through regular writing team meetings to draft and circulate for extensive international review a strategy for a global surface CO_2 monitoring network, including a phased implementation plan (roadmap) and budget requirements.

Deliverables:

Workshop report of the Strategy Development meeting.

Draft strategy, phased-implementation plan, and roadmap for the development of a sustained global surface ocean CO_2 monitoring network.

Phase 2: Establishment of the Global Network and Implementation agreements (mid-2022 to early-2023)

Using the Draft strategy and roadmap developed by the Task Team in Phase 1, host a stakeholders forum and global workshop for government agencies and ministries (G7 FSOI and GOOS) to address Task 4; namely, identify existing national programmes that are elements of the global surface ocean CO_2 monitoring network, identify critical gaps in the observing system (including global coordination structures and data management activities), and reach agreements on priorities for coordinated investment to establish the global network.

Deliverables:

Report from the stakeholder's forum.

Statement or communique from the G7 FSOI (e.g., released for the first UNFCCC 2023 Global Stocktake Process) highlighting achievements in agreements and commitments for implementation of the global surface CO_2 monitoring network.

Establishment of the global coordination structures for links with GOOS and other observing, modelling and data management networks.

Regular comprehensive information on surface ocean carbon levels and fluxes and ocean acidification to assist G7 Members in their reporting on the SDG ocean acidification target (14.3 SDG target and the indicator 14.3.1) and other global and regional policy drivers.

3. RESOURCING FOR THE G7 FSOI TASK TEAM

Estimate 20% FTE support by G7 FSOI Coordination Centre to establish the Task Team, guide and facilitate its work, and communicate regularly with G7 members and stakeholders.

Estimate < 2% FTE in-kind support from each G7 Member to ensure engagement and communications with respective national and regional experts and programmes.

Estimate $30K USD for an initial start-up planning workshop if in-person (phase 1); funds requested for invited experts with additional G7 member support for the participation of their own experts and representatives.

Estimate $50K USD for the Stakeholder's forum (phase 2); funds requested for invited experts with additional G7 member support for the participation of their own experts and representatives.