The Surface Ocean CO_2 Mapping intercomparison initiative: Phase 2 (SOCOMv2)

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1. Summary

In recent years, a large number of surface ocean partial pressure of carbon dioxide (pCO_2) studies emerged, taking advantage of novel statistical and machine-learning methods together with the increasing number of available observations in continuously growing databases. These studies led to the discovery that the oceanic sink for carbon dioxide (CO_2) from the atmosphere is much more variable than previously recognised, challenging on the one hand our mechanistic understanding of the oceanic carbon cycle and on the other hand our ability to project the future evolution of the oceanic carbon sink. These methods, however, rely on extensive interpolation of the available observations and it is unclear how reliable these estimates are in data-sparse regions or seasons. The Surface Ocean pCO_2 Mapping intercomparison initiative (SOCOM), a voluntary project established in 2013 during the 9th International Carbon Dioxide Conference (ICDC9) in Beijing, China, gathered more than a dozen diverse methods developed by various groups. Its phase 2 (SOCOMv2) now sets out to quantify the uncertainty in air-sea CO_2 flux estimates, integrate novel data and coastal ocean estimates and help design future observing networks. The results of this project will form a valuable asset to the global carbon community and help to improve data-anchored state estimates spanning decades. This group will thereby provide an essential resource in response to broad demand from within the modeling community, including with efforts focused on projections of ocean carbon uptake, as well as a critical component of efforts towards limiting temperature perturbation by 2100 to 2°C.

2. Scientific Background and Rationale

2.1 Increase in data availability – increasing number CO_2 flux estimates

Over the past decade, the number of publicly available surface ocean CO_2 observations has increased rapidly from 6 million in the first release of the Surface Ocean CO2 Atlas (SOCAT) database (Pfeil et al 2013, Bakker et al 2014, Bakker et al 2016) in 2011 to 22 million data in 2017. This rich abundance of information has enabled scientists around the world to create a variety of new observation-based estimates of the ocean carbon sink, taking advantage of novel data-interpolation techniques based on statistics and machine-learning to fill observational gaps.

While previous data-based estimates were limited to climatologies, the increase in available observations, both in space and time, has opened new research avenues, such as studies of the variability in the air-sea exchange of CO_2 on interannual to decadal time scales (Landschützer et al 2015, Rödenbeck et al 2015, Ritter et al 2017). These studies suggest much stronger variability on interannual to decadal timescales than earlier model estimates (Rödenbeck et al 2015, Landschützer et al 2016, Gregor et al 2018), calling into question the mechanistic understanding gained from ocean models and challenging our ability to predict the future ocean carbon sink on decadal timescales.

New measurements will be made public through SOCAT in annual releases and in addition, carbon estimates based on observations from autonomous floats are complementing the shipboard data. Hence, improved observation-based studies of the ocean carbon sink will emerge. This development, however, is uncoordinated and lacking in institutional or funding support needed for a careful weighing of priorities moving forward.

2.2 Why is this an important development?

Global assessments suggest that, in recent decades, the ocean has annually taken up about 25% of the CO_2 emitted by human activities (Le Quéré et al 2018). This assessment is based on ocean forward models with a variety of observational approaches for estimating mean ocean CO_2 uptake in the 1990s and cumulative uptake over the full industrial period. Thus, the year-to-year variability, as well as the integrated CO_2 uptake that has occurred since the 1990s is constrained by ocean forward models – the same models with a pronounced bias in variability relative to recent observationally-based estimates.

In light of the Paris climate agreement, it is essential to better understand the mechanisms behind the variability in oceanic CO_2 uptake and to improve ocean models and their near-term projection of the ocean CO_2 uptake in order to test whether we are on the right track towards the 2°C (or 1.5°C) target (Peters et al 2017). The novel observation-based ocean sink estimates can help to achieve these goals, yet without a coordinated effort this opportunity might be lost.

2.3 Why is there a need for an intercomparison project?

Despite the strong increase in available surface ocean pCO_2 observations, shipboard measurements and mooring data are still heterogeneously distributed and thus CO_2 flux estimates based on these data must rely heavily on data interpolation. The resulting estimates are therefore limited by this as well as other sources of uncertainty. However, it is still common practice that a single observation-based estimate, made available via institute websites or various databases, is selected for model comparison ignoring all possible uncertainties and shortcomings of the observation-based data product itself.

This approach is less the result of bad practice than the result of uninformed decision making due to the lack easily interpretable uncertainty estimates. Given the increasing number of data-based estimates available from various sources, the situation has become confusing and resembles a “buffet” of estimates. Furthermore, there is a lack of well-defined, widely agreed-upon criteria for assessing the uncertainty of individual mapping methods. We therefore propose to coordinate with the data providers, SOCAT and Biogeochemical Argo communities, to foster the continuation of observation-based estimates and assess their uncertainty.

The ensemble of estimates offers a variety of possibilities, such as the evaluation of its uncertainty based on the ensemble spread. This can perhaps be understood as the surface ocean observation-based analogue to model intercomparison projects such as C4MIP and atmospheric inversion intercomparison projects such as TransCom. There is a wide range of beneficiaries for such an exercise, e.g. the large modelling groups around the globe that need to evaluate Earth System Model simulations and improve decadal CO_2 prediction systems as well as future projections.

There is further a lack of coordinated studies using the observation-based CO_2 flux ensemble on a number of spatial scales, from regional to global, concluding with the combination of open ocean mapping efforts with novel coastal ocean mapping efforts (Laruelle et al. 2017, Gruber 2015). Besides SOCAT, there is the potential to complement the ensemble with other measurements, such as measurements from the Global Ocean Data Analysis Project version 2 (GLODAPv2, Olsen et al 2016), and measurements made by vertically profiling floats (Williams et al 2017). This will enable us to study the variability of data-sparse regions such as the Southern Ocean, i.e. the ocean basin responsible for the uptake of the majority of human-emitted CO_2, but also previously largely unexplored basins, e.g. the Arctic Ocean (Yasunaka et al 2018).

Finally, the observation-based air-sea CO_2 flux ensemble and all documentation as well as publications will be publicly available to allow the wider community to advance their own experiments and studies.

2.4 Why is this best organized under the SCOR umbrella?

Many institutes around the globe, have benefitted from the availability of the increasing amount of ocean CO_2 measurements, and have developed their own observation-based air-sea CO_2 flux products (see e.g. Rödenbeck et al 2015). Traditional funding sources have helped these groups to develop new techniques and publish the results. This is, however, where the traditional support stops. No traditional funding source is prepared to fund the global community to take the necessary next step, namely global coordination that benefits other communities, global carbon cycle assessment studies, near-term predictions, future projections, and ultimately society itself. Therefore, today we turn to SCOR to ask exactly for that help.

At the 9th International Carbon Dioxide Conference (ICDC9) in Beijing, China, the idea of a pilot intercomparison project was born and SOCOM was initiated. By 2015, a total of 14 groups had contributed their estimates to this bottom-up air-sea flux assessment project and since then 2 studies emerged (Rödenbeck et al 2015, Ritter et al 2017), highlighting common features and differences between these estimates. Other studies, focusing on specific regions such as the Southern Ocean, used part of the ensemble (Landschützer et al 2015). The value of the emerging observational CO_2 flux constraints has since then continuously been highlighted (e.g. Gruber 2015, Mikaloff-Fletcher 2015, 2017, Ilyina 2017). However, a clear understanding of the robust features and the uncertainties is still lacking, indicating the need to pursue further analysis.

While the first phase of SOCOM has added valuable initial insights, the coordinated design of experiments planned in phase two will benefit the wider scientific community and will inform climate science policy. This can only be established from a generalized approach, i.e. when integrating the project in Earth System Modelling and global carbon budget analysis efforts. We therefore propose the establishment of a SCOR working group that combines the expertise of both the measurement community as well as the modelling community, together with SOCOM scientists, to tailor studies that provide (a) realistic uncertainty estimates alongside the flux estimates, (b) provide the baseline to improve global carbon budget analyses, decadal CO_2 predictions and future carbon cycle projections and (c) feed back to the measurement community where we lack valuable measurements.

3. Terms of Reference

There will be several objectives to the SCOR group. Firstly, we propose to develop a best data-based uncertainty estimate. Secondly, will propose to the carbon and climate modelling communities a set of recommendations for improved process-representation needed to improve simulations of carbon cycle variations. Thirdly, we use both the observational and modelling framework and test the current limits of the data-based CO_2 estimates.

Objective 1: Gather the up-to-date publicly available and best estimates of the global ocean carbon sink based on surface ocean CO_2 observations, in collaboration with data providers. Use the ensemble of data-based pCO_2 estimates and quantify the oceanic uptake of carbon dioxide and its uncertainty based upon the ensemble spread.

Objective 2: Provide best observation-based constraints of the marine CO_2 uptake, including known processes driving its variability, for global carbon budget analysis,

ocean model validation and carbon cycle projections, including a well-founded representation of the uncertainty derived from the ensemble. This objective aims to (a) provide a baseline for model validation studies, (b) foster research regarding the source of the variability mismatch between observations and models and (c) provide guidance on the integration of observation-based estimates into global carbon budget analyses.

Objective 3: Combine open ocean air-sea CO_2 flux estimates with high-resolution coastal ocean estimates and to help design future sampling strategies. The working group will integrate new data streams (shipboard and float-based) as well as unique coastal ocean estimates, and further perform optimal observing system simulations using state-of-the-art ocean biogeochemical models.

4. Working Plan

Month 1 until month 6: In order to deliver the 3 objectives, a set of basic rules will be established. Participating data-mapping methods will need to be (a) publicly available and (b) well documented. Once these criteria are met, the set of data-based estimates will be collected and the scientists responsible for the method will be invited to contribute to the further analysis. Since we already have a good overview from the SOCOM pilot project, we do not expect this step to take longer than 6 months. As the project continues, however, we will be open to additional contributions as they emerge.

During the data gathering phase, we propose to host the first coordination meeting, bringing together representatives from the measurement, modelling, and global carbon budget analysis communities as well as the data providers. We propose to organize this meeting alongside the SOLAS open science conference in Sapporo, Japan from 21-25 April 2019. The aim of this meeting is to design the following main analyses:

- The first analysis will prioritise the ensemble-based air-sea CO_2 flux variability and uncertainty estimate. A sustainable goal arising from this analysis will be the development and publication of an uncertainty metric based upon the spread across the ensemble. This metric will serve as standard for future studies of similar scope.

- A second analysis will focus on the limitations posed by the observing network. Global model output will be selected to perform optimal observing system simulations to investigate the robustness of current estimates based on the observation platforms (ship, mooring, float, etc.) and the frequency and resolution of measurements used by the various methods. The analysis will define key regions of high CO_2 sampling priority.

- A third analysis will expand the open ocean estimates with newly emerging high-resolution coastal ocean pCO_2 estimates. The integration of estimates will provide a more complete picture of the ocean carbon cycle. Furthermore, it will focus on the coastal-to-open-ocean aquatic continuum and identify regions where we lack essential observations.

Lead scientists will be identified to coordinate each analysis. In addition, all other meeting participants and also scientists from various communities will be encouraged to actively contribute to the analysis. The existing resources, such as the SOCOM website, will be updated. The website will include all necessary information regarding participating methods and working groups and links to all publicly available data.

Following the first coordination workshop in Sapporo, key conferences will be selected that the majority of participants are planning to travel and side events as well as workshops will be organised during these meetings. Proposed upcoming conferences for the remaining annual meetings and workshops organised by the working group are the Ocean Sciences Conference in February 2020 in San Diego, California, USA and the 11th International Carbon Dioxide Conference (ICDC11), which will take place in late 2021. Combining the meetings with conferences will on the one hand provide the opportunity to immediately communicate results to the wider community, and on the other hand reduce the global travelling efforts and further help to reduce the environmental impact of the proposed SCOR working group. Furthermore, combining the working group meetings with bigger conferences will allow us to organise one hands-on training event for Early Career Scientists on data-mapping and uncertainty evaluation.

Month 6 until month 18: Suitable data-based estimates for each analysis will be selected based on analysis length, spatial extent and other criteria. For each study, a protocol will be created and published on the project website. Preliminary analysis will be performed in each task group and discussed at the second working group meeting, proposed during the Ocean Sciences meeting in 2020 in San Diego, California. Furthermore, we plan to interact with other projects, such as the Global Carbon Project, and the planned continuation of the Regional Carbon Cycle Assessment Project (RECCAP II) effort, which is currently in preparation, as well as modelling groups for an exchange of data and knowledge.

Month 18 until month 30: Analyses will be performed. Results will be gathered and study protocols will be updated with the analysis methods used. During this period, additional coordination teleconferences will be held.

Month 30 until Month 42: The analyses will be revised according to the feedback received at the 2nd annual meeting and the study protocols will be finalized. Studies will be completed and manuscripts will be drafted including the results of each analysis. The chairs and working group members will organize a special issue in the open-access journal *Biogeosciences* where the manuscripts describing each analysis will be submitted.

A side-event will be organized at the 11th International Carbon Dioxide Conference meeting in late 2021 for the third working group meeting, where the final results including the uncertainty estimates will be presented. We further plan to organize a hands-on workshop for Early Career Scientists in large data handling and estimating uncertainties from observation-based CO_2 flux estimates. Additionally, to advance the long-term planning of oceanic CO_2 research, we propose to provide a statement for the ocean observing community that identifies regions in both space and time where additional measurements will have the largest impact on reducing uncertainties in CO_2 flux estimates. During the side-event, outreach activities as well as press releases will be discussed and drafted. Furthermore, possible follow-up side-events during one major international conference (European Geoscientific Union (EGU) general assembly in April 2022, the American Geoscientific Union (AGU) annual meeting in December 2021, or the Ocean Sciences meeting in February 2022) will be discussed and organised to best communicate the results to the science community. Furthermore, necessary follow-up studies will be discussed and continuation of the project beyond the life of the SCOR working group – should it be desired – will be planned.

Month 42 until month 48: Outreach activities will take place, to communicate our work and results to the non-specialist public, highlighting its significance. Results will be presented at international conferences and final published papers will be highlighted on the project website.

5. Deliverables

Month 6: Project website with all required information regarding the open-access data products, including their documentation, will be updated. A detailed outline plus study protocol of each task group will be made public.

Month 18: Updates made to the methods will be made public on the project website

Month 30: Final study protocols will be published

Month 30-42: A special issue in *Biogeosciences* will be launched and a training event for Early Career Scientists on data-mapping, uncertainty estimation and model evaluation will be held.

Month 42: Publications (resulting from the proposed analysis) will be submitted to the special issue. The uncertainty metric and ensemble uncertainty estimate will be made public and the results will be provided to the Global Carbon Project and the modelling groups. Furthermore, a statement will be provided to the ocean observation communities (SOCAT, BGC Argo), highlighting where SOCOMv2 would benefit most from future measurements.

Month 42-48: Press releases will be created and a side event at one of the major international ocean conference will be planned to present the results.

6. Capacity Building

The project will collect a unique ensemble of observation-based datasets of air-sea CO_2 fluxes and will make it easily accessible. This will help to better understand and quantify the uncertainty of the observation-based products and provide valuable information on where new field campaigns are required to further reduce the methods' uncertainty. A particular focus will be set on regions, where we currently face strong data limitation. While autonomous floats now measure valuable information on the carbonate system, particularly in the Southern Ocean, this working group is the only proposed effort to coordinate the integration of both shipboard and float estimates using state-of-the-art CO_2 mapping strategies.

Additionally, the project will develop a standard uncertainty metric applicable to future observation-based intercomparison projects, also for applications beyond ocean CO_2 research. All research items – from the data-products to the study protocols to the final publications – will be open access to increase visibility and reproducibility. For the first time, the working group will thoroughly assess the uncertainty of data-based surface pCO_2 estimates - and consequently the exchange of CO_2 with the atmosphere. This advance will not only shed new light on the existing knowledge gaps, but also provide a pathway for closing it.

This uncertainty information is further a critical asset for global carbon budget analyses, ocean model evaluation and decadal biogeochemical projections and will help to monitor future carbon inventories in the future. The latter is a necessary requirement for determining if we are on target to meet the 2°C (1.5°C) goal for a maximum temperature increase over the 2100 baseline.

Furthermore, the working group will coordinate the integration between open ocean and coastal ocean CO_2 mapping efforts to provide a more complete picture of the global ocean carbon cycle.

During the proposed annual meeting events, which will take place alongside major conferences to reduce the travel efforts of the members, the working group will additionally organize a training workshop for Early Career Scientists. During these training workshop, Early Career Scientists will learn how to find and use the observation-based CO_2 estimates and how the methods used within SOCOMv2 can be applied to their own scientific research.

7. Working Group Composition

7.1 Full Members (chairs are highlighted in bold letters)

Name	Gender	Place of Work	Expertise
1 Peter Landschützer	**M**	**Max Planck Institute for Meteorology, Hamburg, Germany**	**Chair, Surface Ocean CO_2 mapping member and data contributor**
2 Christian Rödenbeck	**M**	**Max Planck Institute for Biogechemistry, Jena, Germany**	**Chair, Surface Ocean CO_2 mapping lead-scientist and data contributor**
3 Dorothee C. E. Bakker	F	UEA, Norwich, United Kingdom	Lead-scientist in the Surface Ocean CO_2 Atlas data synthesis effort
4 Are Olsen	M	University of Bergen, Bergen, Norway	Lead-scientist in the Surface Ocean CO_2 Atlas and GLODAPv2 data synthesis effort
5 Luke Gregor	M	CSIR and UCT, Cape Town, South Africa	Surface Ocean CO_2 mapping member and data contributor, Southern Ocean expert
6 Galen A. McKinley	F	LDEO and Columbia University, New York, USA	Data-based and model based estimates of CO_2 flux variability and its mechanisms
7 Alison R. Gray	F	University of Washington, Seattle, USA	Expert in BGC float data, scientist in the Southern Ocean Carbon and Climate Observations and Modeling (SOCCOM) project
8 Goulven G. Laruelle	M	Sorbonne Universities, Paris, France	Expert in observation-based coastal ocean CO_2 mapping and the coastal ocean carbon cycle

9 Keith B. Rodgers	M	IBS Center for Climate Physics (ICCP), Busan, South Korea*	Expert in Ocean Modelling and Surface Ocean CO_2 mapping member
10 Vinu Valsala	M	Indian Institute of Tropical Meteorology, Pune, India	Surface Ocean CO_2 mapping member, Expert in ocean modelling and data assimilation

*Will be affiliated in Busan at the start of the SCOR working group. Currently, the member is affiliated with Princeton University in the United States of America.

7.2 Associate Member

Name	Gender	Place of Work	Expertise
1 Marion Gehlen	F	LSCE, Paris, France	CO_2 mapping and marine carbon cycle
2 Geun-Ha Park	F	East Sea Research Institute, Korea Institute of Ocean Science and Technology, Uljin, Korea	CO_2 mapping and marine carbon cycle
3 Yosuke Iida	M	JMA, Tokyo, Japan	CO_2 mapping
4 Ute Schuster	F	University of Exeter, UK	CO_2 observations, marine carbon cycle and CO_2 mapping
5 Steve Jones	M	University of Bergen, Norway	CO_2 mapping and marine carbon cycle
6 Shin-ichiro Nakaoka	M	NIES, Tsukuba, Japan	CO_2 observations, CO_2 mapping and marine carbon cycle
7 Tatiana Ilyina	F	Max Planck Institute for Meteorology	Ocean modelling CO_2 projections and decadal CO_2 predictions
8 Corinne Le Quéré	F	University of East Anglia, Norwich, United Kingdom	Global Carbon Project, Ocean Modelling, Southern Ocean
9 Nicolas Gruber	M	ETH, Zürich, Switzerland	Observation based CO_2 estimates from surface and interior, Ocean Modelling
10 Nicole Lovenduski	F	University of Boulder, Colorado, USA	Ocean Modelling, CO_2 projections

8. Working Group Contributions

The working group will:

- Combine and compare novel data interpolation and machine learning techniques used to map the surface ocean pCO_2 content spatially and temporally
- Provide an open and transparent platform where the data products, reference publications and study protocols can be accessed
- Set out new metrics and standards for observation-based pCO_2 data as well as data-model intercomparison studies
- Combine open ocean with coastal ocean estimates and provide a more complete estimate of the marine CO_2 uptake
- Identify key ocean areas where data collection is a high priority and future field campaigns should set their focus
- Provide a baseline for model validation, e.g. within the CMIP6 effort
- Contribute towards a data-driven global carbon budget
- Provide a realistic “ground truth” for the projection of the oceanic uptake of CO_2 in order to monitor the 2°C climate target
- Advance future observation-based research activities, such as ocean acidification studies
- Reduce the working group’s carbon footprint by planning working group meetings in combination with conferences
- Combine these meetings with Early Career Scientist training events to pass on the SOCOMv2 knowledge and advance the careers of the next generation of scientists
- Publish the results in open-access journals and provide press releases to make the results available to a wider audience

9. Expertise

Christian Rödenbeck established and led the SOCOM effort and is an expert in ocean pCO_2 mapping and the air-sea exchange of CO_2.

Peter Landschützer is an expert in ocean pCO_2 mapping using machine learning algorithms and is an expert in the analysis of the decadal variability of the global ocean uptake of CO_2.

Dorothee C. E. Bakker is expert in the collection and synthesis of CO_2 observations and she is carrying a lead role in the SOCAT effort.

Are Olsen is an expert in the collection and synthesis of both surface and interior CO_2 data and carries leading roles in the SOCAT and GLODAPv2 efforts.

Luke Gregor is an expert in ocean pCO_2 mapping based on novel statistical techniques. He is further an expert in the Southern Ocean.

Galen A. McKinley is an expert in assessment of the mechanisms of variability and long-term change of CO_2 fluxes using pCO_2 observations and models. She is a member of the Global Carbon Project Scientific Steering Committee.

Alison R. Gray is an expert in the collection and analysis of Biogeochemical-Argo float data, particularly float-derived pCO_2 data. She is a member of the Southern Ocean Carbon and Climate Observations and Modeling (SOCCOM) project and an expert in the Southern Ocean.

Goulven G. Laruelle is expert in coastal ocean biogeochemistry and in mapping the exchange of CO_2 in coastal regions based on observations and models.

Keith B. Rodgers is an expert in the analysis of the ocean carbon cycle based on models and observations.

Vinu Valsala is an expert in modelling and assimilating the global ocean carbon cycle.

10. Relationship to other International Programs

SOCOMv2 will interact with many international projects, analysis and synthesis efforts. In particular, the working group sets out to provide air-se CO_2 flux estimates including uncertainty for the global carbon budget analysis of the **Global Carbon Project**. The Global Carbon Project provides annual updates of the global sources and sinks of carbon and the results of the working group will help to provide an observation-based estimate of the global oceanic uptake of CO_2 and its variability in time.

SOCOMv2 also sets out to provide observation-based estimates of the ocean uptake of CO_2 for phase 2 of the **Regional Carbon Cycle Assessment Project (RECCAP II)** and actively contribute to the analysis of the state-of-the-art knowledge.

Furthermore, SOCOMv2 will closely collaborate with the existing surface ocean CO_2 data collection efforts, in particular the **Surface Ocean CO_2 Atlas (SOCAT)** and the **Southern Ocean Carbon and Climate Observations and Modeling (SOCCOM)** projects.

SOCOMv2 will collaborate with the **International Ocean Carbon Coordination Project (IOCCP)**, in particular relaying information on critical gaps in the existing pCO_2 network, to ensure that appropriate actions can be taken to improve this.

Finally, SOCOMv2 will work closely with global modelling groups to help improve future carbon cycle projections and decadal CO_2 predictions by adding the observation-based uncertainty, but also by providing an observation-based reference for model intercomparison projects such as **C4MIP**.

11. Key References

The selected key references on the on hand highlight the past achivements of the observation-based CO_2 estimates, and on the other hand highlight emerging research questions that the SOCOMv2 ensemble has the potential to resolve.

Both the Rödenbeck et al 2015 and Ritter et al 2017 publications highlight a stronger marine carbon sink variability on decadal timescales, yet strong differences exist between the various estimates:

1. Ritter, R., Landschützer, P., Gruber, N., Fay, A. R., Iida, Y., Jones, S., Nakaoka, S., Park, G.-H., Peylin, P., Rödenbeck, C., Rodgers, K. B., Shutler, J. D. and Zeng, J.: Observation-based trends of the Southern Ocean carbon sink. Geophysical Research Letters, 44, doi:10.1002/2017GL074837, 2017

2. Rödenbeck, C., Bakker, D. C. E., Gruber, N., Iida, Y., Jacobson, A. R., Jones, S., Landschützer, P., Metzl, N., Nakaoka, S., Olsen, A., Park, G.-H., Peylin, P., Rodgers, K. B., Sasse, T. P., Schuster, U., Shutler, J. D., Valsala, V., Wanninkhof, R.,

and Zeng, J.: Data-based estimates of the ocean carbon sink variability – The Surface Ocean pCO2 Mapping intercomparison (SOCOM), Biogeosciences, 12, 7251-7278, doi:10.5194/bg-12-7251-2015, 2015

Several recent journals articles have highlighted scientific challenges, all in fields SOCOM methods have already left their impact:

3. Gruber, N.: Ocean biogeochemistry: Carbon at the coastal interface. Nature 517, 148–149, 2015

4. Ilyina, T.: Hidden trends in the ocean carbon sink. Nature, 530, 426-427, 2017

5. Peters, G. P., Le Quéré, C., Andrew R. M., Canadell J.G., Friedlingstein, P., Ilyina, T., Jackson, R.B., Joos, F., Korsbakken, J.A., McKinley, G. A., Sitch, S. and Tans, P. Towards real-time verification of CO2 emissions. Nature Climate Change 7, 848–850 2017.

6. Mikaloff-Fletcher S.E.: An increasing carbon sink? Science, 349, 6253, 1165, 2015

7. Mikaloff-Fletcher S.E.: Climate Science: Ocean Circulation drove increase in CO2 uptake, Nature, 542, 169-170, 2017

8. Li H. and Ilyina T.: Current and future decadal trends in the oceanic carbon uptake are dominated by internal variability. Geophysical Research Letters, doi:10.1002/2017GL075370, 2018.

9. Hauck, J.: Unsteady seasons in the sea, Nature Climate Change, 8, 2, 97-98, 2018

12. Appendix

Full Member Key Publications:

Peter Landschützer:

Landschützer, P., Gruber, N., Bakker, D. C. E., Stemmler, I. and Six. K. D.: Strengthening seasonal marine CO_2 variations due to increasing atmospheric CO_2. Nature Climate Change, 8, 146–150, doi: 10.1038/s41558-017-0057-x, 2018

Landschützer, P., Gruber, N. and Bakker, D. C. E.: Decadal variations and trends of the global ocean carbon sink, Global Biogeochemical Cycles, 30, 1396-1417, doi:10.1002/2015GB005359, 2016

Landschützer, P., Gruber, N., Haumann, F. A. Rödenbeck, C. Bakker, D. C. E., van Heuven, S. Hoppema, M., Metzl, N., Sweeney, C., Takahashi, T., Tilbrook, B. and Wanninkhof, R: The reinvigoration of the Southern Ocean carbon sink, Science, 349, 1221-1224. doi: 10.1126/science.aab2620, 2015

Landschützer, P., Gruber, N., Bakker, D. C. E. and Schuster, U.: Recent variability of the global ocean carbon sink, Global Biogeochemical Cycles, 28, 927-949, doi: 10.1002/2014GB004853, 2014

Landschützer, P., Gruber, N., Bakker, D. C. E., Schuster, U., Nakaoka, S., Payne, M. R., Sasse, T., and Zeng, J.: A neural network-based estimate of the seasonal to inter-annual variability of the Atlantic Ocean carbon sink, Biogeosciences, 10, 7793-7815, doi:10.5194/bg-10-7793-2013, 2013

Christian Rödenbeck:

Rödenbeck, C., Bakker, D. C. E., Gruber, N., Iida, Y., Jacobson, A. R., Jones, S., Landschützer, P., Metzl, N., Nakaoka, S., Olsen, A., Park, G.-H., Peylin, P., Rodgers, K. B., Sasse, T. P., Schuster, U., Shutler, J. D., Valsala, V., Wanninkhof, R., and Zeng, J.: Data-based estimates of the ocean carbon sink variability – The Surface Ocean pCO_2 Mapping intercomparison (SOCOM), Biogeosciences, 12, 7251-7278, doi:10.5194/bg-12-7251-2015, 2015

Rödenbeck, C., Bakker, D.C.E., Metzl, N., Olsen, A., Sabine, C., Cassar, N., Reum, F., Keeling, R.F. and Heimann, M.: Interannual sea-air CO_2 flux variability from an observation-driven ocean mixed-layer scheme. Biogeosciences 11, 4599-4613, doi:10.5194/bg-11-4599-2014, 2014

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