Series of Workshops on surface ocean pCO$_2$ observations, synthesis and data products

- Short summary and outcomes -

06. - 09. November (morning to lunch) 2023

Flanders Marine Institute (VLIZ), InnovOcean Campus, Oostende, Belgium

From 6 till 9 November 2023, over a hundred ocean carbon scientists from around the world met at Flanders Marine Institute (VLIZ) in Oostende, Belgium, and online to review the status of the Surface Ocean Carbon Value Chain and discussed specific improvements to the structure, process and resulting delivery of critical information. The community has been ready for an update of its mode of operation for a few years and the recently announced, WMO-led Global Greenhouse Gas Watch (GGGW) initiative served as a direct trigger for this important gathering. GGGW, has the ambition to completely transform our collective ability to deliver a fully transparent, vetted global carbon monitoring system allowing countries to better understand and manage the causes of climate change in a timely and efficient manner. For that ambition to be realized, the ocean carbon community is committed to bringing together existing and future observing efforts into a common framework under the Global Ocean Observing System (GOOS) that can routinely deliver the required information to policy makers. A major outcome of the workshop was [the Oostende Declaration](#), an expression of our collective ambition to completely transform our ability to deliver an integrated global surface ocean carbon monitoring system, helping countries to better understand and manage the causes of climate change in a timely and efficient manner.

About this document:

- **This document summarizes the main discussion points and lists agreed action points to be taken up by the community.**
- **The recordings of the meeting will not be distributed. They were only used to back up the minutes.**
- **The agenda at the end of this document contains links to presentations where the presenters agreed to share their presentation. If we didn't get the agreement, please contact the presenters directly to ask for a copy of their presentation.**
- **If you need access to the original detailed notes that were taken during the sessions, please contact Tobias Steinhoff directly: tost@norceresearch.no**

Day 1 – Summary (SOCOM, Monday 06. November)

Main Discussion points:

1. The current uncertainty estimate used in the GCB - static sources of uncertainty derived from the literature
2. We see a divergence between ocean model fluxes and pCO2-product fluxes that is to-date not explained
3. New methods emerged to quantify errors and uncertainties in pCO2 mapping products
   - The large ensemble testbed
   - The GCB models as testbed
   - Geostatistical approaches
   - Detection and attribution algorithms
4. Thus, it is timely to update the way we quantify biases and uncertainties in the GCB estimate to represent time-varying error sources as good as possible
5. This may help explain some of the divergence in the GCB
6. New methods are available to quantify the added value of measurements on a single platform (e.g. sailboats or saildrones)
7. The above tools thus are not only limited to better represent the uncertainty in the GCB but also to help the measurement community to quantify the impact of their measurements
8. The pCO2 mapping methods and the testbeds above can help design OSSE´s

Action items for the near future and possible contributors

Action item	Possible contributor
Reinvigorate SOCOM (SOCOMv2)	
Introduce regular SOCOM community meetings again	
Link with the SOCONET and SOCAT community and help them design OSSE´s, etc to make a case for each measurement line	
Co-design experiments with common standards to - quantify spatial explicit errors and uncertainties in support of the coming GCB´s - test the effect of data sparsity on the air-sea CO2 flux (influence on trends, variability, mean flux, etc) - test whether sampling and climate variability are linked (i.e. LE testbed vs GCB model testbed)	

Day 2 – Summary (SOCONET, Tuesday 07. November)

Main Discussion points:

1. Are we truly interested building an operational network (from cooperation to operational network)?
2. The community supports the creation of SOCONET (online voting: 95% yes, 0% No, 5% maybe).
3. First Step network design: start with conceptual idea and develop it from there
4. How can the carbon market (carbon credits) help such a network? There is a danger of too close partnerships with industry.
5. We need to work on a Co-Design of an ocean carbon observing system: connecting SOCONET with interior ocean
6. What does 'surface' mean for the ocean? Definition needs to be clear for the WMO.
7. When do we care about surfaces below the surface?
8. Can SOCONET be the ocean part of the WMO GGGW (1° x 1° degree air - sea CO_2 flux estimate on a monthly basis)?
9. What is the scientific purpose of such a network?
10. We need to set up technical and/or regional working groups with a clear training schedule/capacity building
11. Surface ocean pCO_2 data collection in EEZ (Exclusive Economic Zones) and marine parks is and could become problematic.
12. How do we leverage and make sure we are informed by the other members of GOOS?
13. We need to think beyond observations alone. Gather mapping, SOCONET and SOCAT under one umbrella (without giving up individual names: SOCOSYS (or better SOGO? Surface Ocean Greenhouse gas Observations) and describe potential alignment of SOCAT, SOCONET (and SOCOM?). This might be discussed again within the WMO G3W initiative.
14. There is a strong need for fit-for-purpose instrumentation, pCO_2 inter-comparison experiments should be conducted regularly (accepted by the community)
15. When comparing instruments, include the instruments and running costs ($$ per ppm)
16. Need for Coordinated data QA/QC and data management infrastructure
17. Reference sensors to be sent around the globe? SCOR working group for global intercalibration?
18. A global mobile calibration unit would help the community to deliver comparable results.Calibration often not easy for the Global South. We need to investigate in alternative calibration checks, that can be done locally.
19. Availability of necessary tools to run such a network (e.g. reference gases) is crucial
20. SOCONET as reference network: climate vs weather data quality, QC/QA within SOCAT
21. Do we specify an accuracy requirement (for products and measurements)? For about the last 20 years, we used the goal of 0.2 Pg /yr, which needs <2 μatm measurements
22. Create an online support forum
23. SOPs are needed for all steps, from installing onwards. Literature search about what is actually out there

Action items for the near future and possible contributors

Action item	Possible contributor
Create a SOCONET steering committee	Oostende workshop organizers
Write an implementation plan for SOCONET (led by IOCCP), model it like Argo/GO-SHIP?	Oostende workshop organizers
Apply for SOCONET to become an emerging network under GOOS	Oostende workshop organizers
Form a technical working group to identify the SOPs required from start to finish from existing resources	
Create a training sub-committee	
Working group to liaise further with the satellite community	

Day 3 and 4 – Summary (SOCAT, Wednesday 08. November)

Main Discussion points:

1. Alarming decline in the number of data submissions (lines stopped, data not processed, data not submitted to SOCAT)
2. SOCAT is chronically underfunded.
3. SOCAT IT needs modernization.
4. Governance vs. "bottom up community effort".
5. Should SOCAT get involved in mCDR (marine carbon dioxide removal)?
6. Annual ESSD paper highly desirable with lead authorship rotated to ease burden on one person.
7. Regional groups (for quality control) need to be more active and visible
8. Alternative/addition to regional groups (for quality control): topical working groups
9. SOCAT vision should be sold as a part of a larger effort.
10. Data submission to SOCAT should be more closely aligned with National Oceanographic Data Centers.
11. Picture SOCAT as service delivery
12. Starting with SOCAT quality control (QC) is not straightforward, who can new QCers speak to?
13. How much QC should each QCer do? Ideally data providers carry out QC on at least a similar number of data sets as they are submitting. Other QCers are invited to carry out as much QC as they have capacity for. A lower limit of 10 to 20 data sets QCed is used for determining authorship on the SOCAT data products.
14. "High-quality crossover" needs to be determined through manual comparison by the QCer, as the SOCAT system only suggests potential crossovers. Especially in coastal waters and near sea-ice, few high-quality crossovers occur, even though the SOCAT system may suggest a potential crossover
15. 2nd QC should be a check. Main (primary) QC **needs** to happen at PI level, before data submission to SOCAT!
16. Do quality control (QC) efficiently (for example an experienced, confident QCer can assign a global flag for the whole cruise, rather than assigning a regional QC flag).
17. More interactive exchange between QCers (google hangouts,…)
18. Data from networks that do a second QC (e.g. ICOS) could skip the 2nd QC step in SOCAT
19. 2nd QC is an important part of having trust in our data
20. QC should be done by experienced people
21. Checking metadata as part of QC is very time consuming.
22. Records of calibration often not available ⮕ should be in the metadata
23. SOCAT mostly quality controls the instrument
24. Use of SOCAT: start from gridded product and its uncertainty, then go down
25. Takahashi temperature correction of pCO2: should we recheck it?
26. Does the "Law of the Sea" uncrewed vehicles? There seem to be regulatory issues for using uncrewed vehicles both within and outside of EEZs that needs to be addressed to help facilitate broader adoption into observing networks. This should

be discussed with other communities (e.g. air-sea interaction) or organizations (e.g. WMO)

27. Regular QC meetings (3-6 months)
28. Clarify in the QC cookbook: Quality control should be carried out on the whole cruise, even if a regional cruise flag is assigned.
29. Clarify in the QC cookbook: An experienced, confident quality controller can assign a global QC flag, rather than a regional QC flag.
30. Clarify in the QC cookbook: An automatically found crossover by the QC system just shows a possible high-quality crossover → The QCer needs to check whether this is a high-quality crossover.
31. Clarify in the QC cookbook: What happens to a data set with an accuracy of 2.3 µatm? Flag B or C?
32. Clarify in the QC cookbook that there is no expectation that QCers will revisit data sets from previous SOCAT versions, e.g. to find crossovers. However, QCers are welcome to revisit data sets to check for possible crossovers.
33. The QC tools on socat.info are ONLY tools. QCers need knowledge of surface ocean pCO_2 data collection!
34. The main, primary QC happens at PI level, before data submission to SOCAT.
35. Where to find expocode? Information on how to find the expocode should be sufficiently clear to SOCAT data providers.
36. Links to satellite images would be helpful for QC.
37. A suggestion is to add predicted pCO_2 data as a QC tool.

Action items for the near future and possible contributors

Action item	Possible contributor
Write a governance and Terms of Reference for SOCAT (see Siv below)	Global Group
Update QC cookbook (see comments in discussion)	Global Group
Discuss with users whether higher resolution ¼ degree by ¼ degree monthly gridded product would be useful	Global Group
Ensure that information on determining the expocode is available for SOCAT data providers	Global Group
Virtual Training sessions for QC (Webinar) in early 2024, and organize a Hackathon to QC data	Global Group with help from regional leads
Test group for new Metadata editor	Tobias Steinhoff, Ute Schuster, Dennis Pierrot, Meike Becker, Steve Jones, Yuanxu Dong, Hannelore Theetaert
Suggest guidelines for point-by-point uncertainty	Tobias Steinhoff, Yuanxu Dong
Longer term action: ESSD paper (rotate responsibility through regional groups)	Global Group

Outcome of polls during the sessions:

What form(s) of SOCAT data do you use?	
Monthly Gridded NetCDF - Monthly, Annual, Decadal	17
Global synthesis (text)	13
Regional Synthesis (text)	13
LAS - Synthesis	11
Coastal Gridded NetCDF	9
Copernicus	6
ERDDAP	4
Flag E	3
LAS - Gridded	2
Other	2

Are there any other formats you would like to see (e.g. cloud services)?
It is already perfect!!   (7x)
Cloud (3x)
matlab files
ODV format (2x)
search data tool (pCO2>500 µa)
FOS
download subset with code
grided but higher resolution, e.g. 0.1 deg x 0.1 deg x 1 w
Sort by instrument type
region
Machine 2 machine download
nope, ERDDAP is key for us
netcdf

Which parts of the SOCAT Website do you use?	
Current version	35
Data submission info	29
SOCAT Publications	27
Data products based on SOCAT	26
Presentations	16
Release Posters	16
Publications mentioning SOCAT	14
Group Members	11
Previous versions	9
FAQ	9

News (rarely updated)	4
X (Twitter) Feed	3

What is missing from the website/you can never find it?
None (5x)
setting colorbar (4x)
exact # of pts on plot
A fast way to database/ user friendly interface
Specific cruise
The current version!
an easy way to submit data (2x)
Exam. for QCer
Platform statistics
subsetting-direct download
By cruise data
Need to know expocode
SOPs
new publications
Jupyter notebooks
integration of github???
ready-to-use basic plots
An easy video tutorial
discussion/support forum
Newer QC instruc. videos
Scripts for gridding
Funding info
Links to data products
DOI of previous versions

What can SOCAT improve for its contributors and users?
have a map with country contributions
When I compare the several distribution maps, the color bar in each figure is fixed and is not able to be changed. I'm glad to improve it.
Better zoom function for crossover
a way to control the size of the points on the plot
The depths at which measurements are made
Revision of qc procedures, including providing metadata on frequency of gas calibrations along with sensor type
QC guidance material updated; and reviewed including new Qc'ers
Video step through with commentary explaining the qc process, qc season zoom session to remind everyone of the process.
How about a kind of regular meetings (zoom) of primary and secondary QC people?
Regularly training for QC-ers

Capacity building
"Engagement of more Volunteers and training"
Incentives for contributors?
Credits top X (5 or 10 or more) QCer list on SOCAT HP OR nominate QCers as co-authors on GCB annual report.
A big font text added to any file whenever someone downloads SOCAT data that once more details the proper way to acknowledge data contributors
Email addresses for QC group leads need to be on the website
Is it possible to make it visible if some other QCer is already working on a data set (and not finished the QC, yet).
More strict requirement for citing individual data providers. Especially when one particular cruise data is used, simply citing SOCAT as a whole is not enough credit given to the PIs.
Help with data upload
Automated metadata. User guide for LAS server
Update of documentation considering issues with new sensor types and issues that might occur with these. E.g. how is pressure measured behind membrane systems, and where is intake temperature sensor located (after or before pump)
WMO G3W requieres monthly 1X1 maps. We should move to that.
There is code available on the website to load SOCAT (gridded or raw data) into Matlab, but as far as I have seen, no sample code to bring it into python. That would be helpful to users who are newer to coding and working with the data.
SOCAT is great, amazing effort. I strongly encourage the expanding of the tent in how we think about this community to go all the way from data to products useful to policy/public. We should identify ourselves as part of a bigger whole, but what the outside world sees is just one acronym, one organization. Below this, we have working groups on data collection and QC, on mapping, on dissemination, etc. The satellite community does this, and we can learn how they do it.
Show its value in the larger value chain to groups like the Science Based Target Initiative (SBTi) and Task Force on Climate Related Financial Disclosures (TCFD) to tap into private sector financing driven riven by the need to align the use of capital with the goals of the Paris Climate Agreement
Ability to summarise data in socat e.g. number of data points or hours of data by country over a year range. Also what percentage good quality data for dataset or country/ship.
The Jan 15 data submission deadline in January is tied up with S hemisphere summer holidays. I realise data can be submitted anytime, but it's a mental shift.
I'd like more reminders to submit data. Help with submitting the data (I don't have a dedicated person to do that)
send general e mail with deadlines of submission 2 months in advance
Already paying for socat via ICOS subscription
Ability to calculate lag between intake and equilibrator using temperature

Participants

88 in-person participants on Monday (40-60 participants online)

40 Female
48 Male

Europe: 49
N. America:16
S. America: 2
Africa: 7
Asia: 12
Oceania:2

Agenda

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<tr><td style="background-color:#8BC58B; color:white">

DAY 1 – Monday 6 November 09:00 - 18:00 CET
Global Carbon Budget
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Aims:
- The aim of the first day is to identify and develop ways to implement time-varying (e.g. through changing pCO_2 data availability) and regional uncertainty into the GCB pCO_2-uncertainty
- Identify common needs and experimental designs between SOCAT, SOCONET and SOCOM communities
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09:00 – 09:15	Welcome at VLIZ	Jan Mees
09:15 – 09:45	Importance of the ocean carbon observing system in the context of high level intergovernmental requirements	Joanna Post

Session 1
Uncertainty from sparse observations in pCO_2-products
Chair: Peter Landschützer

09:45 – 10:00	The current GCB uncertainty method	Peter Landschützer
10:00 – 10:15	Impacts of sampling patterns and observational uncertainties on surface ocean pCO_2 reconstructions	Thea Heimdahl
10:15 – 10:30	A detectable change in the air-sea CO_2 flux estimate from sailboat measurements	Jacqueline Behncke
10:30 – 11:00	**Coffee break**	
11:00 – 11:15	A flexible approach for quantifying spatially and temporally varying uncertainties within $fCO_{2(sw)}$ and air-sea gas flux data	Daniel Ford
11:15 – 12:30	Plenary discussion	Chair: Peter/Judith Rapporteur: tbc
12:30 – 14:30	**Lunch break**	

Session 2
How can we make use of the pCO_2 mapping infrastructure to quantify the added value of pCO_2 measurements?

Chair:		
14:30 – 14:40	Introduction to the session	Peter Landschützer
14:40 – 15:00	The mapping/modeling infrastructure	Galen McKinley
15:00 – 16:00	Open community input/discussion on community requirements and opportunities	Chair: tbc Rapporteur: tbc
16:00 – 16:30	**Coffee break**	
16:30 – 17:30	**Wrap up of the day**	

17:30 – 19:00
The Director of Flanders Marine Institute (VLIZ) invites to a small reception at the venue.

DAY 2 – Tuesday, 7 November 09:00 – 18:00 CET
SOCONET

Aims:
- Identify science and policy and key stakeholders for a Surface Ocean CO_2 Observing Network (SOCONET) of global reference measurements
- Establish connections/interaction with other networks through, for example, the GOOS Observations coordination group (OCG) and GOOS operations group (OceanOPS)
- Requirements for a reference network including training and support function governance

Identify path forward for developing an observing network design (building on day 1 outcomes)

Session 1
To identify key policy drivers, science challenges and stakeholders for a Surface Ocean CO_2 Observing Network (SOCONET) of global reference measurements
Chair: Rik Wanninkhof

09:00 – 09:20	Introduction to SOCONET concept including history and the place of surface Ocean Carbon Observations in the value chain (pyramid) including science objectives	Rik Wanninkhof
09:20 – 09:35	What does a GOOS Network look like, what features would SOCONET need including governance and links to external programmes	Kevin O´Brien
09:35 – 09:50	What is a reference network?	Adrienne Sutton
09:50 – 10:30	**Discussion**: - Does creating SOCONET have broad community support - What are the key issues that need to be addressed to bring it to life. Have we addressed the earlier barriers?	Chair: Ute Schuster Rapporteur: Rik Wanninkhof
10:30 – 11:00	**Coffee break**	

Session 2		
Developing a pathway for regional networks to contribute to SOCONET		
Chair: Bronte Tilbrook		
11.00 - 11:40	Examples of regional networks that could contribute/identifying key challenges they face in delivery: Tilbrook Pierrot Becker	Bronte Tilbrook, Denis Pierrot, Meike Becker, Siyabulela Hamnca, Shin-ichiro Nakaoka
11.40 - 12.30	Discussion: Key Question is how do we want to organise ourselves within GOOS	Chair: Bronte Tilbrook Rapporteur: Leticia Barbero
12:30 – 14:00	**Lunch Break**	

Session 3		
To determine key organizational and scientific operating principles for SOCONET, including governance, data, training and support functions		
Chair: Kim Currie		
14:00- 14.15	Report from WMO GGGW meeting in Geneva	Maciej Telszewski
14:15 – 14:30	Co-Design of ocean carbon observing system connecting SOCONET with interior ocean	Anya Waite
14:30 – 15:00	Discussion: How do we want to organise ourselves within WMO GGGW	Chair: Adrienne Sutton Rapporteur: tba
15.00 -15.20	Training and Capacity building: What is most needed to support new entrants to SOCONET	Dariia Atamanchuk
15:20 - 16:00	Discussion	Chair: Kim Currie Rapporteur: Simone Alin

16:00 – 16:30	**Coffee Break**

Session 4		
Towards a SOCONET strategy and implementation plan		
Chair: Richard Sanders		
16:30 - 16:50	Key actions gathered during the day to build SOCONET Implementation Plan: ● Governing structure (SC, regional nodes/networks, confirmed ToRs) ● Specific personnel needs for SOCONET Office ● GANTT Chart ● Training (technical capacity building) Requirements ● Data Structures and Management ● Operating model for USVs in SOCONET ● Milestones for all the above	Richard Sanders
16:50 - 17:30	Discussion and creation of action list in two tiers: 1. practical 2. visionary	Chair: Richard Sanders Rapporteur: Vlad Macovei
17:30 – 18:00	Wrap Up	Chair: Rik Wanninkhof

DAY 3 – Wednesday, 8 November 09:00 – 18:00 CET
SOCAT

Aims:
- Identify SOCAT Needs and Ways forward
- Consider the SOCAT organization and governance
- Consider feedback from the user (GCB) and SOCONET/observational communities
- Consider data submission and quality control
- Discuss emerging issues

Consult the SOCAT community

Session 1		
Surface Ocean CO$_2$ (SOCAT) Achievements, Vision on Structure, Governance and Funding		
Chair: Kim Currie		
09:00 - 09:20	Welcome, Aims, Achievements, Needs	Dorothee Bakker
09:20 - 09:30	The value chain of surface ocean pCO$_2$ measurements, illustrated with current activities in Japan	Masao Ishii
09:30 - 09:45	Vision on Structure, Governance and Funding 1 (short-term 2024-25, medium-term 2026-28, long-term, 2029-33)	Richard Sanders
09:45 - 10:30	Discussion: Can we agree on a vision for the future structure and governance for SOCAT? How do we secure at least one additional regional support hub for SOCAT with long-term funding?	Chairs: Siv Lauvset & Dorothee Bakker Rapporteur: Dariia Atamanchuk
10:30 – 11:00	**Coffee Break**	

11:00 - 11:10	Governance (Terms of Reference)	Siv Lauvset
11:10 - 11:20	Quality control by region	Simone Alin
11:20 - 11:30	Collaboration with the Global Carbon Project, users (communication, citations), website, X	Dorothee Bakker & Steve Jones
11:30 - 12:30	Discussion: What governance structure would work best for SOCAT? How can SOCAT improve the organisation of its expert quality control?	Chairs: Thanos Gkritzalis & Meike Becker Rapporteur: Léa Olivier

	What can SOCAT improve in its collaboration with the GCP and for its users?	
12:30 – 14:30	**Lunch Break**	

Session 2 SOCAT Data submission and quality control **Chair: Shin-ichiro Nakaoka**		
14:30 - 14:50	Live Access Server for data submission and quality control, doi-numbers, automation, ERDDAP (incl. for SDG14.3.1), innovation (m2m data harvesting)	Kevin O'Brien
14:50 - 15:00	Point-by-point uncertainty	Tobias Steinhoff
15:00 - 15:10	QC cookbook revision	Thanos Gkritzalis
15:10 – 16:00	Discussion: Identify priorities for SOCAT (software) innovation Views on point-by-point uncertainty QC cookbook revision	Chair: Kevin O'Brien & Ute Schuster Rapporteur: Steve Jones
16:00 – 16:30	**Coffee break**	

SOCAT innovation **Chair: Ingunn Skjelvan**		
16:30 – 16:40	VLIZ intercomparison	Tobias Steinhoff
16:40 - 16:50	New sensors and technologies	Adrienne Sutton
16:50 - 17:30	Discussion: Lessons from intercomparison Promising sensors and technologies	Chair: Tobias Steinhoff & Adrienne Sutton Rapporteur: Matthew Humphreys
17:30 – 18:00	Wrap up	Chair: Ingunn Skjelvan

18:30 – 21:00 **Food and drinks at the venue sponsored by the ICOS group at VLIZ and the EU project GEORGE (Next generation of scientific instrumentation, tools and methods)**

DAY 4 – Thursday, 9 November 09:00 – 112:30 CET
SOCAT - Hands-on data submission training

Aims:

- Hands-on training for SOCAT data submission and quality control

- Introduce the enhanced metadata submission for SOCAT

Identify desired enhancements and improvements

Session 1		
SOCAT data submission system		
Chair: Kevin O´Brien		
9:00 - 9:30	Introduction and Overview of SOCAT data submission and QC	Kevin O'Brien
9:30 - 9:45	Towards a More Uniform SOCAT QC Process	Thanos Gkritzalis
9:45 - 10:30	Discussion	
10:30 – 11:00	**Coffee Break**	

11:00 - 11:45	Introduction to enhanced SOCAT metadata submission and handling	Linus Kamb
11:45 - 12:30	Discussion/hands-on training	
12:30 – 14:30	**Lunch Break**	