The Surface Ocean CO$_2$ Atlas enables quantification of the ocean carbon sink and ocean acidification

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The Global Carbon Budget (2005-2014)

Sources

- Fossil fuel & cement sources
  - $9.0 \pm 0.5$ Pg C yr$^{-1}$ (91%)

- Land-use change (9%)
  - $0.9 \pm 0.5$ Pg C yr$^{-1}$

Sinks

- Atmosphere (44%)
  - $4.4 \pm 0.1$ Pg C yr$^{-1}$

- Ocean sink (26%)
  - $2.6 \pm 0.5$ Pg C yr$^{-1}$

- Land sink (residual)
  - $3.0 \pm 0.8$ Pg C yr$^{-1}$ (30%)

(CDIAC; NOAA-ESRL; Houghton et al 2012; Giglio et al 2013; Le Quéré et al 2015; Global Carbon Budget 2015)
Global synthesis and gridded products of surface ocean fCO$_2$ (fugacity of CO$_2$) in uniform format with quality control;
V4: 18.5 million fCO$_2$ values, accuracy < 5 μatm from 1957-2015 (flags of A-D);
Plus calibrated sensor data (< 10 μatm, flag of E);
Interactive online viewers;
Downloadable (text, NetCDF, ODV, Matlab);
Documented in ESSD articles;
Fair Data Use Statement;
Community activity with >100 contributors worldwide.

Bakker et al. (2016) ESSD in press
Release of SOCAT version 4 – First annual release upon automated data upload

Automation of data upload, initial data checks speeds up data submission and enables annual, public releases of SOCAT.

Online viewers.
SOCAT data is discoverable, accessible and citable.

Future: Automation of metadata upload.

(O’Brien et al., in prep.)
Future SOCAT versions

V5 Data upload ends 15 January 2017;
V5 Quality control ends 31 March 2017;
V5 Release in summer 2017;
V6: V5 dates + 1 year

Sea surface temperature and salinity not QC-ed.
Atmospheric CO₂ measurements accepted (no QC yet);
Extra surface water parameters (DIC, TA, ...) accepted, but no QC planned.
SOCAT-MEMENTO working group on N₂O, CH₄.

(Bakker et al., 2016 ESSD in press)
Surface water $f_{\text{CO}_2}$ per decade (v4)

Increase in $f_{\text{CO}_2}$ data collection from 1990s onwards.

Large regions are not sampled.

(after Bakker et al., 2016 ESSD in press)
Increasing surface water $\text{fCO}_2$ over time (v3)

(Bakker et al., 2016 ESSD in press)
Applications of SOCAT in peer-reviewed articles

SOCAT is named or cited in >>140 peer-reviewed articles:

- Reference to SOCAT,
- Figures or tools,
- Environmental studies,
- Modelling,
- Ocean acidification studies,
- Carbon budgeting.

(Bakker et al., 2016 ESSD in press)

Figure of 22 April 2016
Model evaluation

- Subsampling of 6 ocean-only CMIP5 models to SOCAT v2 fCO₂ values;
- Comparison of annual mean anomalies;
- Models underestimate the variation in surface ocean pCO₂.

- SOCAT in Obs4MIP now a CMIP reference (for next IPCC report).

(Séférian et al., 2014, GRL; Eyring et al., 2016, GMD)
Ocean acidification from SOCAT

Surface ocean pH change for 1991 to 2011 per biome

- Combine SOCAT fCO₂ with salinity-derived alkalinity.
- Mean pH decrease of 0.002 units per year from 1991 to 2011.
- SOCAT enables quantification of regional trends in surface ocean pH.

(Feely et al., 2009; Lauvset et al., 2015, BG)
Mapping (gap filling) of surface ocean pCO$_2$ observations

A synthesis data product (here SOCAT v4)

Mapping technique

Surface water pCO$_2$ (here 1998-2011)

Air-sea CO$_2$ flux (here 1998-2011)

Flux = k * ΔpCO$_2$(w-a)
Gas transfer parameterisation, wind speed product

Talk by Christian Rödenbeck

(Bakker et al., 2016 ESSD in press; Landschützer et al., 2014 GBC; Rödenbeck et al., 2015, BG)
Data-based mapping of the ocean carbon sink provides **priors for atmospheric inversion**, thus aiding quantification of the land sink 

*(Van der Laan et al., 2014; Jones et al., 2015; Rödenbeck et al., 2014, 2015).*
Reinvigoration of the Southern Ocean carbon sink

2 methods using SOCAT v2; ΔpCO$_2$ trends dominate the sink variability; ΔpCO$_2$ trends lead to a sink increase of >0.5 PgC/yr.

(Landschützer et al., 2015, Science 349 (6253): 1221-1224)
Ocean carbon observations for:

- Quantification of trends in the ocean carbon sink and ocean acidification,
- Quantification of the land carbon sink,
- Evaluation of ocean carbon models (Obs4MIP for CMIP),
- Large year-to-year variation in the ocean carbon sink,
- Models underestimate the variation in the ocean carbon sink.

(Landschützer et al., 2014; Rödenbeck et al., 2014, 2015; Le Quéré et al., 2015)
‘No substitute exists for adequate observations.’

‘Models will evolve and improve, but, without data, will be untestable, and observations not taken today will be lost forever.’

‘Today’s climate models will likely prove of little interest in 100 years. But adequately sampled, carefully quality controlled and archived data for key elements of the climate system will be useful indefinitely.’

Wunsch et al. (2013) PNAS 110 (12) 4435-4436; Bryden, H., 2014 Challenger Medal Lecture; Bakker et al., 2016 in press; Le Quéré et al., 2015.
Acknowledgements

SOCAT has >> 100 contributors and numerous funding agencies. Contribute to and/or use these products.

Acknowledge the contribution of the data providers, e.g. by invitation to co-authorship, notably in regional studies, and by citation of relevant scientific publications.

SOCAT needs quality controllers!
User feedback essential.
Sustained funding for data collection and synthesis is key.

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Surface Ocean pCO$_2$ Mapping intercomparison (SOCOM)

- 14 data-based mapping methods, incl. 10 using SOCAT.
- Methods differ in forcing and driver data sets.
- SOCOM welcomes new methods.
- http://www.bgc-jena.mpg.de/SOCOM/

(Rödenbeck et al., BG, 2015)
Global ocean carbon sink in 10 mapping methods

- Differences between 10 methods (7 using SOCAT);
- Low decadal change before 2000, increasing sink after 2000;
- Year-to-year variation (σ of 0.31 Pg C yr⁻¹, 1992-2009);
- Models underestimate variation in the ocean carbon sink.

(Rödenbeck et al., 2015, BG)
Accuracy of fCO$_2$ (versions 3, 4)

Accuracy criteria for all fCO$_2$ values:
- $<2$ µatm for data set flags A & B
- $<5$ µatm for data set flags C & D
- $<10$ µatm for data set flag E

Typical data set flags, if data set QC was acceptable:
- A-C: Shipboard IR/GC/CRDS systems with an equilibrator;
- D: Above, for incomplete metadata;
- C, E: Some alternative sensors or platforms with in situ, documented calibration.

_Wanninkhof, R. et al. (2013) Recommendationnewsensors.pdf._

_doi: 10.3334/CDIAC/OTG.SOCAT_ADQCF._
Δ$pCO_2$ trend components (2002-2011)

Overall trend 2002-2011

thermal trend component

non-thermal trend component

Increasing sink  Decreasing sink

-3  0  3 \mu atm yr^{-1}

(Landschützer et al., 2015, Science 349 (6253): 1221-1224)
Processes governing $\Delta p\text{CO}_2$ trends (2002-2011)

(Landschützer et al., 2015, Science 349 (6253): 1221-1224)
**pCO₂ residuals (independent)**

Figure S2: Residuals between the LDEOv2013 gridded observations, that are not included in SOCATv2 and the neural network pCO₂ estimates for the area south of 35°S.

*(Landschützer et al., 2015, Science 349 (6253): 1221-1224)*
Coastal sink estimates of $0.19 \pm 0.05 \text{ Pg C yr}^{-1}$ and $0.4 \text{ Pg C yr}^{-1}$.

(Chen et al., 2013; Laruelle et al., 2014 GBC; Gruber, 2015 Nature)