



HAL
open science

An update to the Surface Ocean CO₂ Atlas (SOCAT version 2)

Dorothee C. E. Bakker, Benjamin Pfeil, Karl M. Smith, Steven Hankin, Are Olsen, Simone R. Alin, Catherine E. Cosca, Sumiko Harasawa, Alex Kozyr, Yukihiro Nojiri, et al.

► To cite this version:

Dorothee C. E. Bakker, Benjamin Pfeil, Karl M. Smith, Steven Hankin, Are Olsen, et al.. An update to the Surface Ocean CO₂ Atlas (SOCAT version 2). *Earth System Science Data: Papers in open discussion*, 2013, 6, pp.465-512. 10.5194/ESSDD-6-465-2013 . hal-00873454

HAL Id: hal-00873454

<https://hal.science/hal-00873454>

Submitted on 3 Jan 2022

HAL is a multi-disciplinary open access archive for the deposit and dissemination of scientific research documents, whether they are published or not. The documents may come from teaching and research institutions in France or abroad, or from public or private research centers.

L'archive ouverte pluridisciplinaire **HAL**, est destinée au dépôt et à la diffusion de documents scientifiques de niveau recherche, publiés ou non, émanant des établissements d'enseignement et de recherche français ou étrangers, des laboratoires publics ou privés.



Distributed under a Creative Commons Attribution 4.0 International License

An update to the
Surface Ocean CO₂
Atlas

D. C. E. Bakker et al.

An update to the Surface Ocean CO₂ Atlas (SOCAT version 2)

D. C. E. Bakker¹, B. Pfeil^{2,3}, K. Smith^{4,5}, S. Hankin⁴, A. Olsen^{2,3}, S. R. Alin⁴,
C. Cosca⁴, S. Harasawa⁶, A. Kozyr⁷, Y. Nojiri⁶, K. M. O'Brien^{4,5}, U. Schuster^{8,*},
M. Telszewski⁹, B. Tilbrook^{10,11}, C. Wada⁶, J. Aki¹⁰, L. Barbero¹², N. Bates¹³,
J. Boutin¹⁴, W.-J. Cai¹⁵, R. D. Castle¹⁶, F. P. Chavez¹⁷, L. Chen^{18,19},
M. Chierici^{20,21}, K. Currie²², H. J. W. de Baar²³, W. Evans²⁴, R. A. Feely⁴,
A. Fransson²⁵, Z. Gao¹⁸, B. Hales²⁶, N. Hardman-Mountford²⁷, M. Hoppema²⁸,
W.-J. Huang¹⁵, C. W. Hunt²⁹, B. Huss¹⁶, T. Ichikawa³⁰, T. Johannessen^{2,3},
E. M. Jones²⁸, S. D. Jones³¹, S. Jutterström³², V. Kitidis³³, A. Körtzinger³⁴,
P. Landshtzer¹, S. K. Lauvset^{2,3}, N. Lefèvre^{14,35}, A. B. Manke⁴, J. T. Mathis⁴,
L. Merlivat¹⁴, N. Metz¹⁴, A. Murata³⁶, T. Newberger³⁷, T. Ono³⁰, G.-H. Park³⁸,
K. Paterson¹⁰, D. Pierrot¹², A. F. Ríos³⁹, C. L. Sabine⁴, S. Saito⁴⁰, J. Salisbury²⁹,
V. V. S. S. Sarma⁴¹, R. Schlitzer²⁸, R. Sieger²⁸, I. Skjelvan^{2,3}, T. Steinhoff³⁴,
K. Sullivan¹², H. Sun¹⁸, A. J. Sutton^{4,5}, T. Suzuki⁴², C. Sweeney³⁷, T. Takahashi⁴³,
J. Tjiputra⁴⁴, N. Tsurushima⁴⁵, S. M. A. C. van Heuven⁴⁶, D. Vandemark²⁹,
P. Vlahos⁴⁷, D. W. R. Wallace⁴⁸, R. Wanninkhof¹⁶, and A. J. Watson^{8,*}

Title Page

Abstract

Instruments

Data Provenance & Structure

Tables

Figures

◀

▶

◀

▶

Back

Close

Full Screen / Esc

Printer-friendly Version

Interactive Discussion



An update to the Surface Ocean CO₂ Atlas

D. C. E. Bakker et al.

Title Page

Abstract

Instruments

Data Provenance & Structure

Tables

Figures

◀

▶

◀

▶

Back

Close

Full Screen / Esc

Printer-friendly Version

Interactive Discussion



¹School of Environmental Sciences, University of East Anglia, Norwich Research Park, Norwich, UK

²Geophysical Institute, University of Bergen, Bergen, Norway

³Bjerknes Centre for Climate Research, Bergen, Norway

⁴Pacific Marine Environmental Laboratory, National Oceanic and Atmospheric Administration, Seattle, Washington, USA

⁵Joint Institute for the Study of the Atmosphere and Ocean, University of Washington, Seattle, Washington, USA

⁶National Institute for Environmental Studies, Tsukuba, Japan

⁷Carbon Dioxide Information Analysis Center, Oak Ridge National Laboratory, Oak Ridge, Tennessee, USA

⁸College of Life and Environmental Sciences, University of Exeter, Exeter, UK

⁹International Ocean Carbon Coordination Project, Institute of Oceanology of the Polish Academy of Sciences, Sopot, Poland

¹⁰Marine and Atmospheric Research, Hobart, Australia

¹¹Antarctic Climate and Ecosystems Cooperative Research Centre, Hobart, Australia

¹²Cooperative Institute for Marine and Atmospheric Studies, Rosenstiel School for Marine and Atmospheric Science, University of Miami, Miami, Florida, USA

¹³Bermuda Institute of Ocean Sciences, Ferry Reach, Bermuda

¹⁴Laboratoire d'Océanographie et du Climat – Expérimentations et Approches Numériques, Université Pierre et Marie Curie, Paris, France

¹⁵School of Marine Science and Policy, University of Delaware, Newark, Delaware, USA

¹⁶Atlantic Oceanographic and Meteorological Laboratory, National Oceanic and Atmospheric Administration, Miami, Florida, USA

¹⁷Monterey Bay Aquarium Research Institute, Moss Landing, California, USA

¹⁸Key Laboratory of Global Change and Marine-Atmospheric Chemistry, Third Institute of Oceanography, State Oceanic Administration, Xiamen, China

¹⁹Chinese Arctic and Antarctic Administration, Beijing, China

²⁰Institute of Marine Research, Tromsø, Norway

²¹Department of Chemistry and Molecular Biology, University of Gothenburg, Gothenburg, Sweden

²²National Institute of Water and Atmospheric Research, Dunedin, New Zealand

An update to the Surface Ocean CO₂ Atlas

D. C. E. Bakker et al.

Title Page

Abstract

Instruments

Data Provenance & Structure

Tables

Figures

◀

▶

◀

▶

Back

Close

Full Screen / Esc

Printer-friendly Version

Interactive Discussion



²³Royal Netherlands Institute for Sea Research, Texel, the Netherlands

²⁴School of Fisheries and Ocean Sciences, University of Alaska, Fairbanks, Alaska, USA

²⁵Norwegian Polar Institute, Fram Centre, Tromsø, Norway

²⁶College of Earth, Ocean and Atmospheric Sciences, Oregon State University, Corvallis, Oregon, USA

²⁷CSIRO Marine and Atmospheric Research, Floreat, WA, Australia

²⁸Alfred Wegener Institute Helmholtz Centre for Polar and Marine Research, Bremerhaven, Germany

²⁹Ocean Process Analysis Laboratory, University of New Hampshire, Durham, New Hampshire, USA

³⁰National Research Institute for Fisheries Science, Fisheries Research Agency, Yokohama, Japan

³¹Tyndall Centre for Climate Change Research, University of East Anglia, Norwich Research Park, Norwich, UK

³²IVL Swedish Environmental Research Institute, Gothenburg, Sweden

³³Plymouth Marine Laboratory, Plymouth, UK

³⁴GEOMAR, Helmholtz Centre for Ocean Research, Kiel, Germany

³⁵LaboMar, Universidade Federal do Ceará, Fortaleza-Ceará, Brazil

³⁶Japan Agency for Marine-Earth Science and Technology, Yokosuda, Japan

³⁷Cooperative Institute for Research in Environmental Sciences, University of Colorado, Boulder, Colorado, USA

³⁸East Sea Research Institute, Korea Institute of Ocean Science and Technology, Uljin, Korea

³⁹Instituto de Investigaciones Marinas de Vigo, Consejo Superior de Investigaciones Científicas, Vigo, Spain

⁴⁰Marine Division, Global Environment and Marine Department, Japan Meteorological Agency, Tokyo, Japan

⁴¹National Institute of Oceanography, Regional Centre, Visakhapatnam, India

⁴²Marine Information Research Center, Japan Hydrographic Association, Tokyo, Japan

⁴³Lamont Doherty Earth Observatory, Columbia University, Palisades, New York, USA

⁴⁴Uni Climate, Uni Research, Bergen, Norway

⁴⁵National Institute of Advanced Industrial Science and Technology, Tsukuba, Japan

⁴⁶Centre for Isotope Research, University of Groningen, Groningen, the Netherlands

⁴⁷Department of Marine Sciences, University of Connecticut, Groton, Connecticut, USA

⁴⁸Department of Oceanography, Dalhousie University, Halifax, Canada

*formerly at: School of Environmental Sciences, University of East Anglia, Norwich Research Park, Norwich, UK

Received: 25 June 2013 – Accepted: 6 August 2013 – Published: 16 August 2013

Correspondence to: D. C. E. Bakker (d.bakker@uea.ac.uk)

Published by Copernicus Publications.

ESSDD

6, 465–512, 2013

An update to the Surface Ocean CO₂ Atlas

D. C. E. Bakker et al.

Title Page

Abstract

Instruments

Data Provenance & Structure

Tables

Figures

⏪

⏩

◀

▶

Back

Close

Full Screen / Esc

Printer-friendly Version

Interactive Discussion



Abstract

The Surface Ocean CO₂ Atlas (SOCAT) is an effort by the international marine carbon research community. It aims to improve access to carbon dioxide measurements in the surface oceans by regular releases of quality controlled and fully documented synthesis and gridded *f*CO₂ (fugacity of carbon dioxide) products. SOCAT version 2 presented here extends the data set for the global oceans and coastal seas by four years and has 10.1 million surface water *f*CO₂ values from 2660 cruises between 1968 and 2011. The procedures for creating version 2 have been comparable to those for version 1. The SOCAT website (<http://www.socat.info/>) provides access to the individual cruise data files, as well as to the synthesis and gridded data products. Interactive online tools allow visitors to explore the richness of the data. Scientific users can also retrieve the data as downloadable files or via Ocean Data View. Version 2 enables carbon specialists to expand their studies until 2011. Applications of SOCAT include process studies, quantification of the ocean carbon sink and its spatial, seasonal, year-to-year and longer-term variation, as well as initialisation or validation of ocean carbon models and coupled-climate carbon models.

Data coverage and parameter measured

Repository-Reference: Individual cruise files and synthesis product:

doi:10.1594/PANGAEA.811776

Gridded products: doi:10.3334/CDIAC/OTG.SOCAT_V2_GRID

Available at: <http://www.socat.info/>

Coverage: 79° S to 90° N; 180° W to 180° E

Location Name: Global Oceans and Coastal Seas

Date/Time Start: 16 November 1968

Date/Time End: 26 December 2011

ESSDD

6, 465–512, 2013

An update to the Surface Ocean CO₂ Atlas

D. C. E. Bakker et al.

Title Page

Abstract

Instruments

Data Provenance & Structure

Tables

Figures

◀

▶

◀

▶

Back

Close

Full Screen / Esc

Printer-friendly Version

Interactive Discussion



1 Introduction

Human activity is releasing large quantities of the greenhouse gas carbon dioxide (CO₂) into the atmosphere. As a result, the atmospheric CO₂ mole fraction has increased from 280 μmol mol⁻¹ in pre-industrial times (Jansen et al., 2007) to 397 μmol mol⁻¹ in April 2013 (Tans and Keeling, 2013). The rapid, ongoing change in the atmospheric composition by greenhouse gas emissions is predicted to increase global mean temperature by 1.5 to 5.0 °C by the end of the century (Peters et al., 2013). Such warming would be accompanied by sea level rise, increased storm frequency, melting of ice caps and sea ice, changes in precipitation patterns and ocean acidification (Solomon et al., 2007) to name only the most prominent examples. Already many changes in the Earth's climate are apparent, such as the decline in Arctic sea ice extent (Stroeve et al., 2007), warming in Alaska, near the Antarctic Peninsula (Vaughan et al., 2003; Mulvaney et al., 2012) and of the upper ocean (Levitus et al., 2005).

The oceans absorb a substantial part of the CO₂ emissions by human activity, thereby mitigating climate change. From pre-industrial times to 1994 the oceans have taken up 118 ± 19 Pg C from the atmosphere (Sabine et al., 2004). This is equivalent to roughly 50 % of CO₂ emissions from fossil fuel burning and cement production or 30 % of the total anthropogenic emissions, if CO₂ emissions from land use change are included. Recent estimates indicate that the oceans are a contemporary sink for roughly 27 % of the annual CO₂ emissions by fossil fuel combustion, cement production and land use change (Le Quéré et al., 2013). Uncertainty in the land use change emissions leads to a large error estimate for the proportion of the anthropogenic emissions taken up by the oceans.

There is uncertainty on how much CO₂ the oceans will absorb in a warming climate of the future (e.g. Jones et al., 2013). Considerable year-to-year, decadal and long-term variation has been demonstrated by CO₂ uptake in the North Atlantic Ocean (Corbière et al., 2007; Schuster and Watson, 2007; Thomas et al., 2008; Schuster et al., 2009;

ESSDD

6, 465–512, 2013

An update to the Surface Ocean CO₂ Atlas

D. C. E. Bakker et al.

Title Page

Abstract

Instruments

Data Provenance & Structure

Tables

Figures

◀

▶

◀

▶

Back

Close

Full Screen / Esc

Printer-friendly Version

Interactive Discussion



McKinley et al., 2011), the North Sea (Thomas et al., 2007), the North Pacific Ocean (Takamura et al., 2010), the Equatorial Pacific Ocean (Ishii et al., 2004, 2009; Feely et al., 2002, 2006; Park et al., 2006, 2012) and the Southern Ocean (Le Quéré et al., 2007; Metzl, 2009) with large differences between ocean regions (Le Quéré et al., 2010; Lenton et al., 2012).

Measurements of CO₂ in the surface oceans (generally as the mole fraction of CO₂ ($x\text{CO}_2$), partial pressure ($p\text{CO}_2$), or fugacity ($f\text{CO}_2$)) enable estimation of CO₂ air-sea fluxes and their variability. Underway measurements of $f\text{CO}_2$ can be made on the surface water supply of ships, including ships of opportunity on commercial routes. The number of CO₂ measurements increased over the past four decades (Fig. 1) (Sabine et al., 2010). Data collection started in the late 1960s and 1970s, increased in the 1980s and intensified from the 1990s onwards. Roughly four times more data were collected during the 2000s than in the 1990s. The growth in data collection partly resulted from large international research programmes, for example JGOFS (Joint Global Ocean Flux Study) and WOCE (World Ocean Circulation Experiment) and regional funding initiatives. The development of autonomous instrumentation for the continuous measurement of surface water $f\text{CO}_2$ (e.g. Körtzinger et al., 1996; Cooper et al., 1998; Pierrot et al., 2009), the intercomparison of such instrumentation at sea (Körtzinger et al., 1996, 2000) and its installation on voluntary observing ships (e.g. Cooper et al., 1998; Lüger et al., 2004; Schuster and Watson, 2007; Watson et al., 2009; Monteiro et al., 2010; Takamura et al., 2010; Lefèvre et al., 2013) and on moorings and drifters (Bakker et al., 2001; Emerson et al., 2011; Wada et al., 2011) have played an important role in the increase in data collection.

Quantification of regional and global annual mean ocean CO₂ uptake requires observations of surface water $f\text{CO}_2$ with adequate spatial and temporal coverage (Sweeney et al., 2000; Lenton et al., 2006). Studies of year-to-year, decadal and longer-term trends in air-sea CO₂ uptake require consistent, multi-decade data records of surface ocean $f\text{CO}_2$ (e.g. Schuster and Watson, 2007; Takamura et al., 2010; Park et al., 2012). Statistical techniques and modelling have been deployed for basin-wide estimation of

An update to the Surface Ocean CO₂ Atlas

D. C. E. Bakker et al.

Title Page

Abstract

Instruments

Data Provenance & Structure

Tables

Figures

◀

▶

◀

▶

Back

Close

Full Screen / Esc

Printer-friendly Version

Interactive Discussion



An update to the Surface Ocean CO₂ Atlas

D. C. E. Bakker et al.

Title Page

Abstract

Instruments

Data Provenance & Structure

Tables

Figures

◀

▶

◀

▶

Back

Close

Full Screen / Esc

Printer-friendly Version

Interactive Discussion



air-sea CO₂ fluxes from surface water *f*CO₂ observations, for example a diffusion-advection based interpolation scheme (Takahashi et al., 1997, 2009), (multiple) linear regression (Boutin et al., 1999; Cosca et al., 2003; Sarma et al., 2006; Olsen et al., 2008; Chen et al., 2011; Chierici et al., 2012), neural network approaches (Lefèvre et al., 2005; Telszewski et al., 2009; Hales et al., 2012; Landschützer et al., 2013; Nakaoka et al., 2013) and a diagnostic model (Rödenbeck et al., 2013a).

Uniform procedures for the collection, reporting, processing and archiving of CO₂ data, as well as public release of data are required for creating global and regional, long-term, consistent surface ocean *f*CO₂ synthesis products. Takahashi and co-workers have constructed an impressive series of surface ocean CO₂ climatologies, the most recent one for the climatological year 2000 (Takahashi et al., 2009), and now provide annual updates to their global surface ocean *p*CO₂ data set (Takahashi et al., 2013). The Surface Ocean CO₂ Atlas (SOCAT) (Bakker et al., 2012; Pfeil et al., 2013; Sabine et al., 2013) complements this work. The SOCAT and Takahashi data sets benefit from standardisation and intercomparison of measurement and reporting protocols, as well as discussions between data providers and quality controllers on reporting standards and data quality (Dickson et al., 2007; IOCCP, 2008, 2012; SOCAT, 2011, 2012a, b; Wanninkhof et al., 2013a). Both data sets have contributed towards more rapid availability of ocean carbon data for synthesis products and policy-related assessments.

SOCAT aims to create, make publicly available and archive (IOCCP, 2007):

- A 2nd level quality-controlled, global surface ocean *f*CO₂ data set following internationally agreed-upon procedures and regional review;
- A gridded data product of mean monthly surface water *f*CO₂ on a 1° latitude by 1° longitude grid with minimal temporal or spatial interpolation using the 2nd level quality-controlled, global surface ocean *f*CO₂ data set.

The first SOCAT release was made public as versions 1.4 and 1.5, here jointly referred to as version 1, in September 2011 (Bakker et al., 2012). SOCAT version 1

contains 6.3 million surface $f\text{CO}_2$ data points from 1851 cruises in the global oceans and coastal seas between 1968 and 2007 (Fig. 1; Table 1). This version was documented in two complementary publications (Pfeil et al., 2013; Sabine et al., 2013). Surface water $f\text{CO}_2$ values at sea surface temperature ($f\text{CO}_2_{\text{rec}}$, with “rec” indicating recommended $f\text{CO}_2$) have been (re-)calculated from the original CO_2 values reported by the data provider, following a strict calculation protocol. Pfeil et al. (2013) describe the procedures for putting the data into a uniform format, (re-)calculation of surface water $f\text{CO}_2$ and 2nd level quality control (QC). Sabine et al. (2013) detail the gridding of the $f\text{CO}_2$ values on a 1° latitude by 1° longitude grid with a higher 0.25° latitude by 0.25° longitude resolution product for the coastal seas.

2 SOCAT version 2

2.1 An update of version 1

Version 2 of SOCAT has been made public on 4 June 2013 at the 9th International Carbon Dioxide Conference in Beijing, China (SOCAT, 2013b). SOCAT version 2 contains 10.1 million surface $f\text{CO}_2$ values from 2660 cruises for the global oceans and coastal seas between November 1968 and December 2011 (Figs. 1 and 2; Table 1). Version 2 has an additional 809 cruises relative to version 1, mostly from 2006 to 2011. About 70 cruises contained in version 1 were removed from version 2 upon identification of data quality concerns. The data in version 2 originate from 109 different ships and 4 time series, moorings, and drifters. Figure 3 shows the number of $f\text{CO}_2$ values from the 30 ships and time series with the most intense data collection effort.

The procedures for the retrieval and formatting of these data, for the (re-)calculation of surface water $f\text{CO}_2$, for quality control, and for the creation of data products were analogous to those used in version 1 (see Pfeil et al., 2013; Sabine et al., 2013). During primary quality control basic problems in the data were identified, for example unrealistic positions, times and orders of magnitude. Second level quality control consisted of

An update to the Surface Ocean CO_2 Atlas

D. C. E. Bakker et al.

Title Page

Abstract

Instruments

Data Provenance & Structure

Tables

Figures

◀

▶

◀

▶

Back

Close

Full Screen / Esc

Printer-friendly Version

Interactive Discussion



assigning a quality control flag to each data set and a WOCE flag to individual surface water $f\text{CO}_2$ values (see Sect. 2.3.2).

Version 2 has three different data products (Table 2):

1. Individual cruise files of surface water $f\text{CO}_2$ in a uniform format which have been subject of 2nd level quality control;
2. A synthesis data set of surface water $f\text{CO}_2$ for the global oceans and coastal seas;
3. Global gridded products of surface water $f\text{CO}_2$ means.

These data products are much the same as products reported with version 1 (Pfeil et al., 2013; Sabine et al., 2013).

SOCAT is a community effort of seagoing ocean carbon scientists and data managers without central funding. SOCAT is supported by the International Ocean Carbon Coordination Project (IOCCP), the Surface Ocean Lower Atmosphere Study (SOLAS), and the Integrated Marine Biogeochemistry and Ecosystem Research program (IMBER). The numerous SOCAT contributors have donated their time and data to this effort (Figs. 3 and 4; Tables 3, 4 and 5).

Users of the SOCAT data products are requested to (SOCAT, 2013a, b):

1. Recognise the contribution of SOCAT scientists, data contributors and quality controllers in the form of invitation to co-authorship, or citation of relevant scientific articles by data contributors;
2. Cite all SOCAT data products by reference to publications documenting SOCAT;
3. Send references of publications using SOCAT products to submit@socat.info.

Regular updates of the SOCAT products are planned (IOCCP, 2007; Bakker et al., 2012; Pfeil et al., 2013). The SOCAT website (<http://www.socat.info/>) provides access

An update to the Surface Ocean CO_2 Atlas

D. C. E. Bakker et al.

Title Page

Abstract

Instruments

Data Provenance & Structure

Tables

Figures

⏪

⏩

◀

▶

Back

Close

Full Screen / Esc

Printer-friendly Version

Interactive Discussion



to the data products together with online visualisation tools, data documentation, meeting reports, publications and a list of contributors. This publication documents SOCAT version 2, in particular differences relative to version 1. Section 2.2 highlights where version 2 differs from version 1 (Table 1) and Sect. 2.3 provides a summary of the procedures followed for creating version 2. Section 2.4 describes the data products and tools available for version 2 (Table 2).

2.2 Key differences between versions 1 and 2

2.2.1 Time stamp and version numbering

The time stamp for SOCAT version 1 products did not contain seconds (Table 1) (Pfeil et al., 2013). In some cases this resulted in multiple entries for a given time stamp. Such multiple entries were averaged in the global and regional synthesis data files (version 1.5), but not in the individual cruise files (version 1.4). Two version numbers (version 1.4 and 1.5) highlight the different treatment of multiple entries for the same time stamp in these version 1 data products.

SOCAT version 2 products include seconds, as reported by the data contributor, in the time stamp for all newly added and updated cruises (Table 1). However, a time stamp including seconds is still not available most of the version 1 cruises. For these cruises seconds were added artificially to the time stamp to avoid the problem of multiple entries. The next version of SOCAT will include seconds, as reported by the data contributor, for all cruises.

The CO₂ measurements for a dozen historical cruises are listed as taken at midnight or their time stamp in fractional days contains insufficient decimals for retrieving minutes and seconds. Artificial seconds, in some cases including tenths or hundreds of a second, were generated for these valuable data, such that they can remain in SOCAT version 2. Every effort will be made to retrieve a more adequate time stamp for these cruises for future versions. Unlike version 1, which has version 1.4 and 1.5 data products, version 2 data products have a single version number.

An update to the Surface Ocean CO₂ Atlas

D. C. E. Bakker et al.

Title Page

Abstract

Instruments

Data Provenance & Structure

Tables

Figures

⏪

⏩

◀

▶

Back

Close

Full Screen / Esc

Printer-friendly Version

Interactive Discussion



2.2.2 Expocodes

SOCAT uses twelve character expocodes (Swift, 2008) as stable and unique data set identifiers. For example, 49P120101218 indicates a cruise on the Japanese (49) ship of opportunity Pyxis (P1) with the first day of the cruise on 18 December 2010. In contrast to version 1, expocodes have also been assigned for moorings and drifters in version 2, by registering a “vessel code” at International Council for the Exploration of the Sea (ICES) in collaboration with the National Oceanographic Data Center (NODC) and the British Oceanographic Data Centre (BODC) (Table 1).

2.2.3 Creation of an Arctic regional designation

Quality control in SOCAT is carried out by groups organised according to region. Figure 5 shows the regions for SOCAT version 2 (Table 4). These regions have been operationally defined and do not necessarily follow common oceanographic definitions. Version 1 had regions for the coastal seas, the North Atlantic, Tropical Atlantic, North Pacific, Tropical Pacific, Indian Ocean and Southern Ocean (Pfeil et al., 2013). Arctic data were part of the North Pacific and North Atlantic Oceans and the coastal region. Given the importance of Arctic research and the rapid increase in the quantity of Arctic $f\text{CO}_2$ values, an Arctic region has been defined for version 2 (Figs. 1b, 5 and 6; Table 1) (SOCAT, 2012b). The Arctic region includes both shelf seas and the deep ocean. It encompasses all waters north of 70°N for 100°W to 43°E (Atlantic sector) and north of 66°N elsewhere.

2.2.4 WOCE flags for individual $f\text{CO}_2$ values

During quality control individual $f\text{CO}_2$ values are assigned WOCE flags: 2 (good), 3 (questionable) or 4 (bad) with 2 (good) being the default setting (Pfeil et al., 2013). Flags 3 and 4 might indicate an erroneous time or position stamp, an unrealistic sea-water temperature, strong warming of the water between intake and equilibrator or a

ESSDD

6, 465–512, 2013

An update to the Surface Ocean CO_2 Atlas

D. C. E. Bakker et al.

Title Page

Abstract

Instruments

Data Provenance & Structure

Tables

Figures

◀

▶

◀

▶

Back

Close

Full Screen / Esc

Printer-friendly Version

Interactive Discussion



$f\text{CO}_2$ measurements. SOCAT products do not include $f\text{CO}_2$ calculated from other carbon parameters, such as pH, alkalinity or dissolved inorganic carbon. A small number of $f\text{CO}_2$ observations (0.08 % in version 2) are from measurements by a spectrophotometric method using a pH-sensitive dye.

As in version 1, all data were assembled in a uniform file format (Pfeil et al., 2013). Primary quality control was carried out at this stage. Surface water $f\text{CO}_2$ values at sea surface temperature, also known as recommended $f\text{CO}_2$ ($f\text{CO}_2\text{-rec}$), were recalculated following a single set of equations and an order of preference for the CO_2 input parameter (Pfeil et al., 2013). Climatological values of salinity and atmospheric pressure from re-analysis were used in the calculation of recommended $f\text{CO}_2$, if the data contributor did not report in situ salinity and pressure (Pfeil et al., 2013).

2.3.2 Secondary quality control

Secondary quality control of the version 2 data was carried out by 24 marine carbon scientists from eight countries (Fig. 4). Procedures for 2nd level quality control were defined in a series of workshops (IOCCP, 2008, 2009, 2010; Pfeil et al., 2013). The regional group members assigned data set quality control flags and WOCE flags. All new and updated data sets were subject to this quality control. The criteria and procedures for quality control were identical between versions 1 and 2 (Pfeil et al., 2013). Each data set was assigned a separate data set flag A, B, C, D, S (Suspend) or X (Exclude) for each region it crossed. As a final step in the quality control process the quality controllers needed to resolve any “conflicting” data set flags between regions and decide on the “agreed” flag for a data set. Only data sets with a flag A, B, C or D are included in SOCAT version 2 products, as was also the case for version 1.

The data set quality control flags in SOCAT versions 1 and 2 were developed for automated shipboard measurement of surface water $f\text{CO}_2$, mainly by infrared detection and at sea standardisation using compressed calibration gases with a range of CO_2 concentrations (IOCCP, 2008; Pfeil et al., 2013). Much weight is put on whether approved methods or standard operating procedures (AOML, 2002; Dickson et al., 2007;

An update to the Surface Ocean CO_2 Atlas

D. C. E. Bakker et al.

Title Page

Abstract

Instruments

Data Provenance & Structure

Tables

Figures

◀

▶

◀

▶

Back

Close

Full Screen / Esc

Printer-friendly Version

Interactive Discussion



Pierrot et al., 2009) were followed by making this a pre-requisite for flags A and B (Pfeil et al., 2013). Frequent calibration of shipboard $f\text{CO}_2$ measurements is undertaken with three or more non-zero calibration gases, e.g. every 2.5–3 h (Pierrot et al., 2009), to characterise the non-linearity in detector response. The $f\text{CO}_2$ values from cruises with flags of A and B are judged to have an accuracy of $\pm 2 \mu\text{atm}$ or better.

Complete metadata documentation is required for data set quality control flags of A, B and C. Comparison to other data is carried out, if possible. The overall quality of the data needs to be deemed acceptable for flags of A, B, C and D (Pfeil et al., 2013). Surface water $f\text{CO}_2$ measurements from moorings and drifters were quality controlled for versions 1 and 2 using the existing data quality control criteria.

Overall data quality and reporting of metadata has improved from version 1 to version 2 which we attribute to the SOCAT effort. In the first version, 41 % of cruises were assigned a flag of A or B, 22 % obtained a flag of C and 37 % received a flag of D. Version 2 has a larger proportion of cruises with flags of A or B (48 %) and smaller proportions of cruises with a flag of C (18 %) and D (33 %).

2.4 Version 2 data products and tools

2.4.1 Surface water $f\text{CO}_2$ in the SOCAT data products

The SOCAT data products provide access to recommended surface ocean $f\text{CO}_2$ values in a uniform format for the global oceans and coastal seas. Three different SOCAT data products are available: individual cruise files, synthesis files and gridded files. All data products can be accessed via the SOCAT website (<http://www.SOCAT.info/>) or via the web-links provided below and in Table 2. The version 2 data products resemble those for version 1 (Pfeil et al., 2013; Sabine et al., 2013). The key differences between the version 1 and 2 products have been discussed in Sect. 2.2 and are listed in Table 1.

Two interactive online tools, the Cruise Data Viewer and the Gridded Data Viewer, facilitate interrogation of the global synthesis product and the gridded data products, respectively. These data products and tools are discussed below.

An update to the Surface Ocean CO_2 Atlas

D. C. E. Bakker et al.

Title Page

Abstract

Instruments

Data Provenance & Structure

Tables

Figures

◀

▶

◀

▶

Back

Close

Full Screen / Esc

Printer-friendly Version

Interactive Discussion



2.4.2 Individual cruise files

Individual cruise files provide surface water $f\text{CO}_2$, the parameters used to (re-)calculate $f\text{CO}_2$ and the original CO_2 parameter(s) reported by the data contributor (Table 6). The files for data sets with flags A, B, C and D include all surface water $f\text{CO}_2$ values with WOCE flags of 2, 3 and 4. Individual cruise data files are archived at PANGAEA[®] (<http://doi.pangaea.de/10.1594/PANGAEA.811776>) (Table 2). Each cruise has a digital object identifier (doi). Metadata provided by the data contributor accompany the cruise files.

As in version 1, the individual cruise and synthesis files include the climatological values of salinity and atmospheric pressure from re-analysis (Table 6). The files also contain values for the water depth, the distance to a major land mass and the atmospheric CO_2 mole fraction interpolated from GLOBALVIEW-CO2 (2012). Version 2 is made available via PANGAEA[®] to the World Data System (WDS) of the International Council for Science (ICSU), to the Group of Earth Observations (GEO) Portal and to the Global Earth Observation System of Systems (GEOSS).

2.4.3 Global synthesis product

A global synthesis product of surface ocean $f\text{CO}_2$ values has been created by merging the individual cruise files. The product is available as a global file or as regional files for the various SOCAT regions (Tables 2 and 4). The synthesis files only contain cruise files with flags A, B, C and D and surface water $f\text{CO}_2$ values with WOCE flag 2 (Table 6). The synthesis files do not contain the original CO_2 values. Each line in the files lists the doi-number of the corresponding individual cruise file at PANGAEA[®], thus giving access to the metadata and the original CO_2 values (Sect. 2.4.1). The global and regional files are publicly available as compressed zip text files via CDIAC (<http://cdiac.ornl.gov/ftp/oceans/SOCATv2/>). The regional files contain only data from within that region, so that data from most cruises are split between several regional files. The global synthesis

ESSDD

6, 465–512, 2013

An update to the Surface Ocean CO_2 Atlas

D. C. E. Bakker et al.

Title Page

Abstract

Instruments

Data Provenance & Structure

Tables

Figures

◀

▶

◀

▶

Back

Close

Full Screen / Esc

Printer-friendly Version

Interactive Discussion



product is also available in Ocean Data View format (http://odv.awi.de/en/data/ocean/socat_fCO2_data).

The Cruise Data Viewer (http://ferret.pmel.noaa.gov/SOCAT2_Cruise_Viewer/), an interactive tool on a Live Access Server, enables interrogation of the global synthesis product. The user can search and subset the global SOCAT data set by year, month, day, region, parameter, expocode, cruise name, vessel, and data set quality control flag. One may define search limits, for example salinity below 30 or sea surface temperature above 10 °C. The user can include data with a WOCE flag of 3 (questionable) and 4 (bad), find metadata, read quality control comments, create property-property plots and download data. Figures 2 and 7 have been made with the Cruise Data Viewer.

2.4.4 Gridded products

Several gridded products of surface ocean $f\text{CO}_2$ means with minimal interpolation are available (doi:10.3334/CDIAC/OTG.SOCAT_V2_GRID). Surface water $f\text{CO}_2$ values with a flag of 2 have been put on a 1° latitude by 1° longitude grid in four ways: per year, monthly per year, monthly per decade, and per climatological month from 1970 to 2011 (Table 2). A higher resolution of 0.25° latitude by 0.25° longitude is available as monthly means per year for the coastal region (Fig. 5; Table 4). The procedures for gridding the data are similar between versions 1 and 2 (Sabine et al., 2013).

Gridded $f\text{CO}_2$ values are reported as unweighted means and as cruise-weighted means (Sabine et al., 2013). In an unweighted mean all the $f\text{CO}_2$ _rec values in a grid cell have been given equal weight in calculating the mean. In a cruise-weighted mean, first averages of the $f\text{CO}_2$ _rec data per cruise have been calculated within a grid cell, before averages of the cruise means have been determined. Grid cells without $f\text{CO}_2$ values are empty. No correction has been made for the expected long-term increase in surface water $f\text{CO}_2$, thus care should be taken in use of the decadal and climatological gridded products. Furthermore, the gridded products may have a temporal bias in grid cells with uneven temporal data coverage. For example, an annual gridded product will have a strong seasonal bias, if only summertime $f\text{CO}_2$ values are available.

An update to the Surface Ocean CO₂ Atlas

D. C. E. Bakker et al.

Title Page

Abstract

Instruments

Data Provenance & Structure

Tables

Figures

◀

▶

◀

▶

Back

Close

Full Screen / Esc

Printer-friendly Version

Interactive Discussion



Gridded $f\text{CO}_2$ products can be accessed as NetCDF files from CDIAC (http://cdiac.ornl.gov/ftp/oceans/SOCATv2/SOCATv2_Gridded_Dat/), in Ocean Data View format (http://odv.awi.de/en/data/ocean/socat_fCO2_data) and via the Gridded Data Viewer (http://ferret.pmel.noaa.gov/SOCAT_gridded_viewer/) (Table 2).

5 Several new gridded products and variables are available via the Gridded Data Viewer for version 2. The number of different years has been added as a variable in the monthly climatological gridded dataset. Data sets now show the 400 km continental margin mask at 1 min resolution, as used in SOCAT, and the distance to the nearest major land mass from 0 to 1000 km at 20 min resolution. The Gridded Data Viewer has
10 an option for animation of gridded products. The visualisation tools of the Gridded Data Viewer have been expanded. The interface now includes a comparison capability for up to four gridded data sets. This enables the user to visualise, for example, gridded data products in SOCAT versions 1 and 2 in a multiple-plot view.

3 Spatial and temporal data coverage

15 SOCAT version 2 includes surface ocean $f\text{CO}_2$ values collected between 1968 and 2011 for the global oceans and coastal seas (Figs. 1 and 2). Data availability has increased over time for most ocean regions (Figs. 1b and 6). A notable exception is the Indian Ocean north of 20°S , for which data are available from the 1990s, but where few subsequent observations have been made. Marked increases in data collection are
20 apparent in the Arctic Ocean and the Gulf of Mexico (Fig. 1b). For example, version 2 has a total of 40 cruises in the Arctic Ocean, of which 10 cruises were conducted in 2011 alone. Data coverage remains sparse south of 30°S (Fig. 2). The seasonal data distribution of $f\text{CO}_2$ for the period 2000 to 2009 is shown in Fig. 7. The maps demonstrate the near-absence of wintertime data from the high-latitude regions. The southwest Ross Sea (Southern Ocean) has about 20 months of observations spanning
25 five months from austral spring to autumn (Fig. 8).

An update to the Surface Ocean CO_2 Atlas

D. C. E. Bakker et al.

Title Page

Abstract

Instruments

Data Provenance & Structure

Tables

Figures

◀

▶

◀

▶

Back

Close

Full Screen / Esc

Printer-friendly Version

Interactive Discussion



An update to the Surface Ocean CO₂ Atlas

D. C. E. Bakker et al.

Title Page

Abstract

Instruments

Data Provenance & Structure

Tables

Figures

⏪

⏩

◀

▶

Back

Close

Full Screen / Esc

Printer-friendly Version

Interactive Discussion



The installation of automated $f\text{CO}_2$ systems on voluntary observing ships and Antarctic supply ships has greatly improved the data availability for coastal regions along shipping routes (Fig. 9). For example, between 2000 and 2009 more than 40 individual cruises have crossed the 1° latitude by 1° longitude grid boxes in the Florida Straits, the English Channel, off the coast of Japan and close to the Antarctic Peninsula.

The number of months of the year and total months with $f\text{CO}_2$ values per 1° by 1° grid cell shed light on data collection activities for 1970 to 2011 (Fig. 8). High data density along shipping routes highlights the repeat $f\text{CO}_2$ observations. For example, numerous grid boxes east of Japan have observations in all months of the year for more than 50 months in total, reflecting an intense CO_2 observational effort over a large number of years. This on-going data collection effort is critical for the quantification of the variability and trends in CO_2 air-sea exchange.

4 Future plans

4.1 Progress towards version 3

Surface water CO_2 values and accompanying metadata can be submitted to CDIAC in the IOCCP-recommended formats (<http://cdiac.ornl.gov/oceans/submit.html>) at all times. Ideally data are submitted as they become available. The SOCAT global group sets deadlines for consideration of data in specific SOCAT versions, for example the deadline for submission to SOCAT version 3 is 31 December 2013. Version 3 quality control is scheduled to take place during the summer and autumn of 2014 with the release of version 3 planned for mid-2015.

4.2 Quality control flags for new instrumentation and alternative sensors

The SOCAT data quality control flags have been primarily designed for shipboard, continuous surface water CO_2 measurements by gas chromatography or infrared detection (Pfeil et al., 2013). Since the definition of these flags, high-precision and stable cavity

ring-down spectroscopy (CRDS) has become available for surface water CO₂ measurements (Friedrichs et al., 2010; Becker et al., 2012). The quality control criteria in SOCAT are deemed adequate for the measurements by CRDS. Measurements made by CRDS will be included in future SOCAT versions, provided calibrations have been carried out at least daily (SOCAT, 2012b).

The quality control criteria need revision for *f*CO₂ values from sensors on surface moorings and drifters (SOCAT, 2012b). These measurements do not follow all the standard operation procedures and at-sea calibration of such *f*CO₂ measurements is often infrequent or non-existent. Also the sensors tend to use fewer gas standards than on ships, due to logistical and power constraints. A working group on alternative sensors (Table 3) has developed a vision on how to include such *f*CO₂ values, as measured for example by infrared analysis and spectrometry, in future SOCAT versions (Waninkhof et al., 2013a). The working group has recommended which quality control criteria should apply to these data.

4.3 Automation

The large effort for data entry and quality control is a major obstacle for regular and prompt SOCAT updates, especially with more data becoming available each year. The need for automating SOCAT was formally recognised in September 2011 (SOCAT, 2011) and an automation team was created (Table 3). The automation vision was accepted by regional and global group leads (SOCAT, 2012a, b). The automation system will allow the data provider to upload, review and submit data and metadata. It will calculate surface water *f*CO₂. The automation system will provide a single portal for data providers, data managers and quality controllers. Manual data entry by the SOCAT data managers will be reduced. Regular, prompt releases of SOCAT will be more straightforward, once the automation system is fully operational. The automation system is expected to become the primary mode of data submission from version 4 onwards.

An update to the Surface Ocean CO₂ Atlas

D. C. E. Bakker et al.

Title Page

Abstract

Instruments

Data Provenance & Structure

Tables

Figures

◀

▶

◀

▶

Back

Close

Full Screen / Esc

Printer-friendly Version

Interactive Discussion



5 Scientific applications of SOCAT

Several scientific studies have already used SOCAT data products. The global synthesis product is the most commonly used SOCAT product in scientific publications. Files in zipped text format (Lourantou and Metzl, 2011; Tjiputra et al., 2012; Nakaoka et al., 2013; Rödenbeck et al., 2013a, b; Wanninkhof et al., 2013b) and the Ocean Data View collection (Chierici et al., 2012) are most commonly used for data access. Two studies use the global gridded products (Landschützer et al., 2013; Schuster et al., 2013).

Scientific applications of SOCAT include:

- Visualisation of surface ocean $f\text{CO}_2$ data coverage (Chierici et al., 2012) and data requirements (Wanninkhof et al., 2013b);
- Use of the SOCAT continental margin mask (Evans and Mathis, 2013);
- Process studies (Lourantou and Metzl, 2011);
- Creation and validation of surface water $f\text{CO}_2$ and CO_2 air-sea flux maps by a variety of techniques, including multiple linear regression (Schuster et al., 2013), neural network approaches (Landschützer et al., 2013; Nakaoka et al., 2013) and an ocean mixed layer model (Rödenbeck et al., 2013a, b);
- Quantification of the annual mean ocean carbon sink (Schuster et al., 2013);
- Studies of variation in the ocean carbon sink on seasonal (Rödenbeck et al., 2013a), year-to-year (Rödenbeck et al., 2013b) and decadal time-scales (Lourantou and Metzl, 2011);
- Initialisation and validation fields for ocean carbon cycle models (Tjiputra et al., 2012).

These applications highlight the utility of SOCAT for regional and global air-sea CO_2 flux assessments, process studies and ocean carbon modelling.

ESSDD

6, 465–512, 2013

An update to the Surface Ocean CO_2 Atlas

D. C. E. Bakker et al.

Title Page

Abstract

Instruments

Data Provenance & Structure

Tables

Figures

⏪

⏩

◀

▶

Back

Close

Full Screen / Esc

Printer-friendly Version

Interactive Discussion



6 Conclusions

SOCAT version 2 represents a 44 yr record of surface water $f\text{CO}_2$ values from 1968 to 2011 for the global oceans and coastal seas (Figs. 1 and 2). Version 2 extends version 1 by four years to 2011, while also adding more $f\text{CO}_2$ values for the years 2006 and 2007.

The data are in a uniform format and have been subject to fully documented quality control. The quality of data and of data reporting has improved in version 2 relative to version 1. The temporal data distribution at least partly reflects activities in large international research programmes. Over time, data coverage in all ocean regions has increased, with the exception of the Indian Ocean north of 20° S. Data coverage has increased four-fold from the 1990s to the 2000s, thus providing much better seasonal and spatial coverage for large parts of the northern hemisphere oceans and coastal seas. Data coverage remains sparse in large parts of the Southern Hemisphere and the Indian Ocean.

The international importance of SOCAT is evident from recent scientific articles using SOCAT data products for quantification of the ocean carbon sink, process studies and ocean carbon modelling. Regular updates to SOCAT will extend the SOCAT data record and ensure that new data are promptly made available for flux assessments and modelling. Future plans include automation and a revision of the quality control criteria for $f\text{CO}_2$ values from alternative sensors.

Acknowledgements. SOCAT is promoted by the International Ocean Carbon Coordination Project, the Surface Ocean Lower Atmosphere Study, and the Integrated Marine Biogeochemistry and Ecosystem Research program. Support for SOCAT has been received from the University of East Anglia (UK), the Bjerknes Centre for Climate Research, the Geophysical Institute at the University of Bergen (Norway), the Climate Observation Division of the Climate Program Office of the US National Oceanic and Atmospheric Administration, the University of Washington, Oak Ridge National Laboratory (US), PANGAEA[®] Data Publisher for Earth and Environmental Data (Germany), the Alfred Wegener Institute Helmholtz Centre for Polar and Marine Research (Germany), the National Institute for Environmental Studies (Japan), the Korean Institute of Ocean Science and Technology, the European Union projects CarboChange (FP7

An update to the Surface Ocean CO_2 Atlas

D. C. E. Bakker et al.

Title Page

Abstract

Instruments

Data Provenance & Structure

Tables

Figures



Back

Close

Full Screen / Esc

Printer-friendly Version

Interactive Discussion



264879) and GEOCARBON (FP7 283080), the UK Ocean Acidification Research Programme (NE/H017046/1; funded by the Natural Environment Research Council, the Department for Energy and Climate Change and the Department for Environment, Food and Rural Affairs), the Research Council of Norway (CARBON-HEAT), the Scientific Committee on Oceanic Research (SCOR, US, OCE-0938349), the US National Science Foundation (OCE-1068958) and the Swedish National Space Board (Remote Sensing Carbon UptakE).

References

Antonov, J. I., Locarnini, R. A., Boyer, T. P., Mishonov, A. V., and Garcia, H. E.: World Ocean Atlas 2005, in: Volume 2: Salinity, NOAA Atlas NESDIS 62, edited by: Levitus, S., US Government Printing Office, Washington, DC, 182 pp., 2006.

AOML: Underway $p\text{CO}_2$ Systems workshop, Atlantic Oceanographic and Meteorological Laboratory (AOML) National Oceanic and Atmospheric Administration, Miami, 2–3 October 2002, <http://www.aoml.noaa.gov/ocd/gcc/uwpcoc2/workshops/> (last access: 13 March 2012), 2002.

Bakker, D. C. E., Etcheto, J., Boutin, J., Dandonneau, Y., and Merlivat, L.: Variability of surface water $f\text{CO}_2$ during seasonal upwelling in the equatorial Atlantic Ocean as observed by a drifting buoy, *J. Geophys. Res.*, 106, 9241–9253, doi:10.1029/1999JC000275, 2001.

Bakker, D. C. E., Pfeil, B., Olsen, A., Sabine, C., Metzl, N., Hankin, S., Koyuk, H., Kozyr, A., Malczyk, J., Manke, A., and Telszewski, M.: Global data products help assess changes to the ocean carbon sink, *Eos, Transactions American Geophysical Union*, 93, 125–126, doi:10.1029/2012EO120001, 2012.

Becker, M., Andersen, N., Fiedler, B., Fietzek, P., Körtzinger, A., Steinhoff, T., and Friedrichs, G.: Using cavity ringdown spectroscopy for continuous monitoring of $\delta^{13}\text{C}(\text{CO}_2)$ and $f\text{CO}_2$ in the surface ocean, *Limnol. Oceanogr.-Meth.*, 10, 752–766, doi:10.4319/lom.2012.10.752, 2012.

Boutin, J., Etcheto, J., Dandonneau, Y., Bakker, D. C. E., Feely, R. A., Inoue, H. Y., Ishii, M., Ling, R. D., Nightingale, P. D., Metzl, N., and Wanninkhof, R.: Satellite sea surface temperature: a powerful tool for interpreting in situ $p\text{CO}_2$ measurements in the equatorial Pacific Ocean, *Tellus*, 51B, 490–508, 1999.

An update to the Surface Ocean CO_2 Atlas

D. C. E. Bakker et al.

Title Page

Abstract

Instruments

Data Provenance & Structure

Tables

Figures

◀

▶

◀

▶

Back

Close

Full Screen / Esc

Printer-friendly Version

Interactive Discussion



An update to the Surface Ocean CO₂ Atlas

D. C. E. Bakker et al.

Title Page

Abstract

Instruments

Data Provenance & Structure

Tables

Figures

◀

▶

◀

▶

Back

Close

Full Screen / Esc

Printer-friendly Version

Interactive Discussion



- Chen, L., Xu, S., Gao, Z., Chen, H., Zhang, Y., Zhan, J., and Li, W.: Estimation of monthly air-sea CO₂ flux in the Southern Atlantic and Indian Ocean using in-situ and remotely sensed data, *Remote Sens. Environ.*, 115, 1935–1941, doi:10.1016/j.rse.2011.03.016, 2011.
- 5 Chierici, M., Signorini, S. R., Mattsdotter-Björk, M., Fransson, A., and Olsen, A.: Surface water *f*CO₂ algorithms for the high-latitude Pacific sector of the Southern Ocean, *Remote Sens. Environ.*, 119, 184–196, doi:10.1016/j.rse.2011.12.020, 2012.
- Cooper, D. J., Watson, A. J., and Ling, R. D.: Variations of *p*CO₂ along a North Atlantic shipping route (UK to the Caribbean): A year of automated observations, *Mar. Chem.*, 60, 147–164, 1998.
- 10 Corbière, A., Metzl, N., Reverdin, G., Brunet, C., and Takahashi, T.: Interannual and decadal variability of the carbon dioxide sink in the North Atlantic subpolar gyre, *Tellus*, 59B, 168–178, doi:10.1111/j.1600-0889.2006.00232.x, 2007.
- Cosca, C. E., Feely, R. A., Boutin, J., Etcheto, J., McPhaden, M. J., Chavez, F. P., and Strutton, P. G.: Seasonal and interannual CO₂ fluxes for the central and eastern equatorial Pacific Ocean as determined from *f*CO₂-SST relationships, *J. Geophys. Res.*, 108, 3278, doi:10.1029/2000JC000677, 2003.
- 15 Dickson, A. G., Sabine, C. L., and Christian, J. R. (Eds.): Guide to best practices for ocean CO₂ measurements, PICES Special Publication 3, IOCCP Report 8, 191 pp., 2007.
- Emerson, S., Sabine, C., Cronin, M. F., Feely, R., Cullison Gray, S. E., and DeGrandpré, M.: Quantifying the flux of CaCO₃ and organic carbon from the surface ocean using in situ measurements of O₂, N₂, *p*CO₂, and pH, *Global Biogeochem. Cy.*, 25, GB3008, doi:10.1029/2010GB003924, 2011.
- 20 ETOPO2: 2-minute Gridded Global Relief Data (ETOPO2v2), National Geophysical Data Center, National Oceanic and Atmospheric Administration, US Dept. of Commerce, available at: <http://www.ngdc.noaa.gov/mgg/global/etopo2.html> (last access: 1 May 2013), 2006.
- 25 Evans, W. and Mathis, J. T.: The Gulf of Alaska coastal ocean as an atmospheric CO₂ sink, *Cont. Shelf Res.*, 65, 52–63, doi:10.1016/j.csr.2013.06.013, 2013.
- Feely, R. A., Boutin, J., Cosca, C. E., Dandonneau, Y., Etcheto, J., Inoue, H. Y., Ishii, M., Le Quéré, C., Mackey, D. J., McPhaden, M., Metzl, N., Poisson, A., and Wanninkhof, R.: Seasonal and interannual variability of CO₂ in the equatorial Pacific, *Deep-Sea Res. Pt. II*, 49, 2442–2469, 2002.
- 30

An update to the Surface Ocean CO₂ Atlas

D. C. E. Bakker et al.

Title Page

Abstract

Instruments

Data Provenance & Structure

Tables

Figures

◀

▶

◀

▶

Back

Close

Full Screen / Esc

Printer-friendly Version

Interactive Discussion



- Feely, R. A., Takahashi, T., Wanninkhof, R., McPhaden, M. J., Cosca, C. E., and Sutherland, S. C.: Decadal variability of the air-sea CO₂ fluxes in the Equatorial Pacific Ocean, *J. Geophys. Res.*, 111, CO8S90, doi:10.1029/2005JC003129, 2006.
- Friedrichs, G., Bock, J., Temps, F., Fietzek, P., Körtzinger, A., and Wallace, D. W. R.: Toward
5 continuous monitoring of seawater ¹³CO₂/¹²CO₂ isotope ratio and *p*CO₂: Performance of cavity ringdown spectroscopy and gas matrix effects, *Limnol. Oceanogr.-Meth.*, 8, 539–551, doi:10.4319/lom.2010.8.539, 2010.
- GLOBALVIEW-CO2: Cooperative Atmospheric Data Integration Project – Carbon Dioxide, 2008 version, Earth System Research Laboratory, National Oceanic and Atmospheric Administration, Boulder, Colorado, USA, available at: <http://www.esrl.noaa.gov/gmd/ccgg/globalview/>
10 (last access: 26 June 2013), 2008.
- GLOBALVIEW-CO2: Cooperative Atmospheric Data Integration Project – Carbon Dioxide, 2012 version, Earth System Research Laboratory, National Oceanic and Atmospheric Administration, Boulder, Colorado, USA, available at: <http://www.esrl.noaa.gov/gmd/ccgg/globalview/>
15 (last access: 26 June 2013), 2012.
- Hales, B., Strutton, P. G., Saraceno, M., Letelier, R., Takahashi, T., Feely, R., Sabine, C., and Chavez, F.: Satellite-based prediction of *p*CO₂ in coastal waters of the eastern North Pacific, *Prog. Oceanogr.*, 103, 1–15, doi:10.1016/j.pocean.2012.03.001, 2012.
- Ishii, M., Saito, S., Tokieda, T., Kawano, T., Matsumoto, K., and Inoue, H. Y.: Variability of surface
20 layer CO₂ parameters in the Western and Central Equatorial Pacific, in: *Global environmental change in the ocean and on land*, edited by: Shiyomi, M., Kawahata, H., Koizumi, H., Tsuda, A., and Awaya, Y., TERRAPUB, Tokyo, Japan, 2004.
- Ishii, M., Inoue, H. Y., Midorikawa, T., Saito, S., Tokieda, T., Sasano, D., Nakadate, A., Nemoto, K., Metzl, N., Wong, C. S., and Feely, R. A.: Spatial variability and decadal trend of the
25 oceanic CO₂ in the western equatorial Pacific warm/fresh water, *Deep-Sea Res. Pt. II*, 56, 591–606, 2009.
- IOCCP: Surface Ocean CO₂ Variability and Vulnerabilities Workshop. UNESCO, Paris, France, 11–14 April 2007, IOCCP Report 7, available at: <http://www.ioccp.org/> (last access: 1 May 2013), 2007.
- 30 IOCCP: Surface Ocean CO₂ Atlas Project, UNESCO, Paris, France, IOCCP Report 9, available at: <http://www.ioccp.org/> (last access: 1 May 2013), 2008.

An update to the Surface Ocean CO₂ Atlas

D. C. E. Bakker et al.

Title Page

Abstract

Instruments

Data Provenance & Structure

Tables

Figures

◀

▶

◀

▶

Back

Close

Full Screen / Esc

Printer-friendly Version

Interactive Discussion



IOCCP: SOCAT Atlantic and Southern Oceans Regional Meeting, University of East Anglia, Norwich, UK, 25–26 June 2009, IOCCP Report 13, available at: <http://www.ioccp.org/> (last access: 1 May 2013), 2009.

IOCCP: Southern and Indian Ocean SOCAT Workshop. CSIRO Marine Laboratories, Hobart, Tasmania, Australia, 16–18 June 2010, IOC Workshop Report 234, IOCCP Report 21, available at: <http://www.ioccp.org/> (last access: 1 May 2013), 2010.

IOCCP: Coastal and Arctic Surface Ocean CO₂ Atlas (SOCAT) Quality Control Workshop, NOAA-PMEL, Seattle, USA, 2–4 October 2012, IOCCP Report 4/2012, available at: <http://www.ioccp.org/> (last access: 1 May 2013), 2012.

Jansen, E., Overpeck, J., Briffa, K. R., Duplessy, J.-C., Joos, F., Masson-Delmotte, V., Olago, D., Otto-Bliesner, B., Peltier, W. R., Rahmstorf, S., Ramesh, R., Raynaud, D., Rind, D., Solomina, O., Villalba, R., and Zhang, D.: Palaeoclimate, in: *Climate Change 2007: The Physical Science Basis. Contribution of Working Group I to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change*, edited by: Solomon, S., Qin, D., Manning, M., Chen, Z., Marquis, M., Averyt, K. B., Tignor, M., and Miller, H. L., Cambridge University Press, Cambridge, United Kingdom and New York, NY, USA, 2007.

Jones, C., Robertson, E., Arora, V., Friedlingstein, P., Shevliakova, E., Bopp, L., Brovkin, V., Hajima, T., Kato, E., Kawamiya, M., Liddicoat, S., Lindsay, K., Reick, C. H., Roelandt, C., Segschneider, J., and Tjiputra, J.: 21st Century compatible CO₂ emissions and airborne fraction simulated by CMIP5 Earth System models under 4 Representative Concentration Pathways, *J. Climate*, 26, 4398–4413, doi:10.1175/JCLI-D-12-00554.1, 2013.

Kalnay, E., Kanamitsu, M., Kistler, R., Collins, W., Deaven, D., Gandin, L., Iredell, M., Saha, S., White, G., Woollen, J., Zhu, Y., Chelliah, M., Ebisuzaki, W., Higgins, W., Janowiak, J., Mo, K. C., Ropelewski, C., Wang, J., Leetmaa, A., Reynolds, R., Jenne, R., and Joseph, D.: The NCEP/NCAR 40-year reanalysis project, *B. Am. Meteorol. Soc.*, 77, 437–470, 1996.

Körtzinger, A., Thomas, H., Schneider, B., Gronau, N., Mintrop, L., and Duinker, J. C.: At-sea intercomparison of two newly designed underway *p*CO₂ systems – Encouraging results, *Mar. Chem.*, 52, 133–145, 1996.

Körtzinger, A., Mintrop, L., Wallace, D. W. R., Johnson, K. M., Neill, C., Tilbrook, B., Towler, P., Inoue, H., Ishii, M., Shaffer, G., Torres, R. F., Ohtaki, E., Yamashita, E., Poisson, A., Brunet, C., Schauer, B., Goyet, C., and Eiseheid, G.: The international at-sea intercomparison of *f*CO₂ systems during the R/V Meteor cruise 36/1 in the North Atlantic Ocean, *Mar. Chem.*, 72, 171–192, 2000.

An update to the Surface Ocean CO₂ Atlas

D. C. E. Bakker et al.

Title Page

Abstract

Instruments

Data Provenance & Structure

Tables

Figures

◀

▶

◀

▶

Back

Close

Full Screen / Esc

Printer-friendly Version

Interactive Discussion



- 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 Discuss.*, 10, 8799–8849, doi:10.5194/bgd-10-8799-2013, 2013.
- 5 Lefèvre, N., Watson, A. J., and Watson, A. R.: A comparison of multiple regression and neural network techniques for mapping in situ $p\text{CO}_2$ data, *Tellus*, 57B, 375–384, 2005.
- Lefèvre, N., Caniaux, G., Janicot, S., and Gueye, A. K.: Increased CO_2 outgassing in February–May 2010 in the tropical Atlantic following the 2009 Pacific El Niño, *J. Geophys. Res. Oceans*, 118, 1645–1657, doi:10.1002/jgrc.20107, 2013.
- 10 Lenton, A., Matear, R. J., and Tilbrook, B.: Design of an observational strategy for quantifying the Southern Ocean uptake of CO_2 , *Global Biogeochem. Cy.*, 20, GB4010, doi:10.1029/2005GB002620, 2006.
- Lenton, A., Metzl, N., Takahashi, T., Kuchinke, M., Matear, R. J., Roy, T., Sutherland, S. C., Sweeney, C., and Tilbrook, B.: The observed evolution of oceanic $p\text{CO}_2$ and its drivers over the last two decades, *Global Biogeochem. Cy.*, 26, GB2021, doi:10.1029/2011GB004095, 2012.
- 15 Le Quéré, C., Rödenbeck, C., Buitenhuis, E. T., Conway, T. J., Lagenfelds, R., Gomez, A., Labuschagne, C., Ramonet, M., Nakazawa, T., Metzl, N., Gillett, N., and Heimann, M.: Saturation of the Southern Ocean CO_2 sink due to recent climate change, *Science*, 316, 1735–1738, 2007.
- 20 Le Quéré, C., Takahashi, T., Buitenhuis, E., Rödenbeck, C., and Sutherland, S. C.: Impact of climate change and variability on the global oceanic sink of CO_2 , *Global Biogeochem. Cy.*, 24, GB4007, doi:doi:10.1029/2009GB003599, 2010.
- Le Quéré, C., Andres, R. J., Boden, T., Conway, T., Houghton, R. A., House, J. I., Marland, G., Peters, G. P., van der Werf, G. R., Ahlström, A., Andrew, R. M., Bopp, L., Canadell, J. G., Ciais, P., Doney, S. C., Enright, C., Friedlingstein, P., Huntingford, C., Jain, A. K., Jourdain, C., Kato, E., Keeling, R. F., Klein Goldewijk, K., Levis, S., Levy, P., Lomas, M., Poulter, B., Raupach, M. R., Schwinger, J., Sitch, S., Stocker, B. D., Viovy, N., Zaehle, S., and Zeng, N.: The global carbon budget 1959–2011, *Earth Syst. Sci. Data*, 5, 165–185, doi:10.5194/essd-5-165-2013, 2013.
- 25 Levitus, S., Antonov, J., and Boyer, T.: Warming of the world ocean, 1955–2003, *Geophys. Res. Lett.*, 32, L02604, doi:10.1029/2004GL021592, 2005.
- 30

An update to the Surface Ocean CO₂ Atlas

D. C. E. Bakker et al.

Title Page

Abstract

Instruments

Data Provenance & Structure

Tables

Figures

◀

▶

◀

▶

Back

Close

Full Screen / Esc

Printer-friendly Version

Interactive Discussion



- Lourantou, A. and Metzl, N.: Decadal evolution of carbon sink within a strong bloom area in the subantarctic zone, *Geophys. Res. Lett.*, 38, L23608, doi:10.1029/2011GL049614, 2011.
- Lüger, H., Wallace, D. W. R., Körtzinger, A., and Nojiri, Y.: The $p\text{CO}_2$ variability in the midlatitude North Atlantic Ocean during a full annual cycle, *Global Biogeochem. Cy.*, 18, GB3023, doi:10.1029/2003GB002200, 2004.
- 5 McKinley, G. A., Fay, A. R., Takahashi, T., and Metzl, N.: Convergence of atmospheric and North Atlantic carbon dioxide trends on multidecadal timescales, *Nat. Geosci.*, 4, 606–610, doi:10.1038/NGEO1193, 2011.
- Metzl, N.: Decadal increase of oceanic carbon dioxide in Southern Indian Ocean surface waters (1991–2007), *Deep-Sea Res. Pt. II*, 56, 607–619, 2009.
- 10 Monteiro, P. M. S., Schuster, U., Hood, M., Lenton, A., Metzl, N., Olsen, A., Rogers, K., Sabine, C. L., Takahashi, T., Tilbrook, B., Yoder, J., Wanninkhof, R., and Watson, A. J.: Community White Paper. A global sea surface carbon observing system: Assessment of changing sea surface CO₂ and air-sea CO₂ fluxes, in: *Proceedings of OceanObs'09: Sustained Ocean Observations and Information for Society*, Vol. 2, edited by: Hall, J., Harrison, D. E., and Stammer, D., Venice, Italy, 21–25 September 2009, ESA Publication WPP-306, doi:10.5270/OceanObs09.cwp.64, 2010.
- 15 Mulvaney, R., Abram, N. J., Hindmarsh, R. C. A., Arrowsmith, C., Fleet, L., Triest, J., Sime, L. C., Alemany, O., and Foord, S.: Recent Antarctic Peninsula warming relative to Holocene climate and ice-shelf history, *Nature*, 489, 141–145, doi:10.1038/nature11391, 2012.
- Nakaoka, S., Telszewski, M., Nojiri, Y., Yasunaka, S., Miyazaki, C., Mukai, H., and Usui, N.: Estimating temporal and spatial variation of ocean surface $p\text{CO}_2$ in the North Pacific using a Self Organizing Map neural network technique, *Biogeosciences Discuss.*, 10, 4575–4610, doi:10.5194/bgd-10-4575-2013, 2013.
- 20 Olsen, A., Brown, K. R., Chierici, M., Johannessen, T., and Neill, C.: Sea-surface CO₂ fugacity in the subpolar North Atlantic, *Biogeosciences*, 5, 535–547, doi:10.5194/bg-5-535-2008, 2008.
- Park, G.-H. and Wanninkhof, R.: A large increase of the CO₂ sink in the western tropical North Atlantic from 2002 to 2009, *J. Geophys. Res.*, 117, C08029, doi:10.1029/2011JC007803, 2012.
- 30 Park, G.-H., Lee, K., Wanninkhof, R., and Feely, R. A.: Empirical temperature-based estimates of variability in the oceanic uptake of CO₂ over the past 2 decades, *J. Geophys. Res.*, 111, C07S07, doi:10.1029/2005JC003090, 2006.

An update to the Surface Ocean CO₂ Atlas

D. C. E. Bakker et al.

Title Page

Abstract

Instruments

Data Provenance & Structure

Tables

Figures

◀

▶

◀

▶

Back

Close

Full Screen / Esc

Printer-friendly Version

Interactive Discussion



Peters, G. P., Andrew, R. M., Boden, T., Canadell, J. G., Ciais, P., Le Quéré, C., Marland, G., Raupach, M. R., and Wilson, C.: The challenge to keep global warming below 2 °C, *Nature Climate Change*, 3, 4–6, doi:10.1038/nclimate1783, 2013.

Pfeil, B., Olsen, A., Bakker, D. C. E., Hankin, S., Koyuk, H., Kozyr, A., Malczyk, J., Manke, A., Metzl, N., Sabine, C. L., Akl, J., Alin, S. R., Bates, N., Bellerby, R. G. J., Borges, A., Boutin, J., Brown, P. J., Cai, W.-J., Chavez, F. P., Chen, A., Cosca, C., Fassbender, A. J., Feely, R. A., González-Dávila, M., Goyet, C., Hales, B., Hardman-Mountford, N., Heinze, C., Hood, M., Hoppema, M., Hunt, C. W., Hydes, D., Ishii, M., Johannessen, T., Jones, S. D., Key, R. M., Körtzinger, A., Landschützer, P., Lauvset, S. K., Lefèvre, N., Lenton, A., Lourantou, A., Merlivat, L., Midorikawa, T., Mintrop, L., Miyazaki, C., Murata, A., Nakadate, A., Nakano, Y., Nakaoka, S., Nojiri, Y., Omar, A. M., Padin, X. A., Park, G.-H., Paterson, K., Perez, F. F., Pierrot, D., Poisson, A., Ríos, A. F., Santana-Casiano, J. M., Salisbury, J., Sarma, V. V. S. S., Schlitzer, R., Schneider, B., Schuster, U., Sieger, R., Skjelvan, I., Steinhoff, T., Suzuki, T., Takahashi, T., Tedesco, K., Telszewski, M., Thomas, H., Tilbrook, B., Tjiputra, J., Vandemark, D., Veness, T., Wanninkhof, R., Watson, A. J., Weiss, R., Wong, C. S., and Yoshikawa-Inoue, H.: A uniform, quality controlled Surface Ocean CO₂ Atlas (SOCAT), *Earth Syst. Sci. Data*, 5, 125–143, doi:10.5194/essd-5-125-2013, 2013.

Pierrot, D., Neill, C., Sullivan, K., Castle, R., Wanninkhof, R., Lüger, H., Johannessen, T., Olsen, A., Feely, R. A., and Cosca, C. E.: Recommendations for autonomous underway pCO₂ measuring systems and data reduction routines, *Deep-Sea Res. Pt. II*, 56, 512–522, doi:10.1016/j.dsr2.2008.12.005, 2009.

Rödenbeck, C., Keeling, R. F., Bakker, D. C. E., Metzl, N., Olsen, A., Sabine, C., and Heimann, M.: Global surface-ocean p^{CO₂} and sea–air CO₂ flux variability from an observation-driven ocean mixed-layer scheme, *Ocean Sci.*, 9, 193–216, doi:10.5194/os-9-193-2013, 2013a.

Rödenbeck, C., Olsen, A., Bakker, D. C. E., Metzl, N., Sabine, C. L., Cassar, N., Keeling, R. F., and Heimann, M.: Interannual sea–air CO₂ flux variability from an observation-driven ocean mixed-layer scheme, *Ocean Sci.*, in preparation, 2013b.

Sabine, C. L., Feely, R. A., Gruber, N., Key, R. M., Lee, K., Bullister, J. L., Wanninkhof, R., Wong, C. S., Wallace, D. W. R., Tilbrook, B., Millero, F. J., Peng, T. H., Kozyr, A., Ono, T., and Rios, A. F.: The oceanic sink for anthropogenic CO₂, *Science*, 305, 367–371, 2004.

Sabine, C. L., Ducklow, H., and Hood, M.: International carbon coordination. Roger Revelle’s legacy in the Intergovernmental Oceanographic Commission, *Oceanography*, 23, 48–61, 2010.

An update to the Surface Ocean CO₂ Atlas

D. C. E. Bakker et al.

Title Page

Abstract

Instruments

Data Provenance & Structure

Tables

Figures

◀

▶

◀

▶

Back

Close

Full Screen / Esc

Printer-friendly Version

Interactive Discussion



Sabine, C. L., Hankin, S., Koyuk, H., Bakker, D. C. E., Pfeil, B., Olsen, A., Metzl, N., Kozyr, A., Fassbender, A., Manke, A., Malczyk, J., Akl, J., Alin, S. R., Bellerby, R. G. J., Borges, A., Boutin, J., Brown, P. J., Cai, W.-J., Chavez, F. P., Chen, A., Cosca, C., Feely, R. A., González-Dávila, M., Goyet, C., Hardman-Mountford, N., Heinze, C., Hoppema, M., Hunt, C. W., Hydes, D., Ishii, M., Johannessen, T., Key, R. M., Körtzinger, A., Landschützer, P., Lauvset, S. K., Lefèvre, N., Lenton, A., Lourantou, A., Merlivat, L., Midorikawa, T., Mintrop, L., Miyazaki, C., Murata, A., Nakadate, A., Nakano, Y., Nakaoka, S., Nojiri, Y., Omar, A. M., Padin, X. A., Park, G.-H., Paterson, K., Perez, F. F., Pierrot, D., Poisson, A., Ríos, A. F., Salisbury, J., Santana-Casiano, J. M., Sarma, V. V. S. S., Schlitzer, R., Schneider, B., Schuster, U., Sieger, R., Skjelvan, I., Steinhoff, T., Suzuki, T., Takahashi, T., Tedesco, K., Telszewski, M., Thomas, H., Tilbrook, B., Vandemark, D., Veness, T., Watson, A. J., Weiss, R., Wong, C. S., and Yoshikawa-Inoue, H.: Surface Ocean CO₂ Atlas (SOCAT) gridded data products, Earth Syst. Sci. Data, 5, 145–153, doi:10.5194/essd-5-145-2013, 2013.

Sarma, V. V. S. S., Saino, T., Sasaoka, K., Nojiri, Y., Ono, T., Ishii, M., Inoue, H. Y., and Matsumoto, K.: Basin-scale $p\text{CO}_2$ distribution using satellite sea surface temperature, Chl *a*, and climatological salinity in the North Pacific in spring and summer, Global Biogeochem. Cy., 20, GB3005, doi:10.1029/2005GB002594, 2006.

Schuster, U. and Watson, A. J.: 2007, A variable and decreasing sink for atmospheric CO₂ in the North Atlantic, J. Geophys. Res., 112, C11006, doi:10.1029/2006JC003941, 2007.

Schuster, U., Watson, A. J., Bates, N. R., Corbière, A., González-Dávila, M., Metzl, N., Pierrot, D., and Santana-Casiano, M.: Trends in North Atlantic sea-surface $f\text{CO}_2$ from 1990 to 2006, Deep-Sea Res. Pt. II, 56, 8–10, 620–629, 2009.

Schuster, U., McKinley, G. A., Bates, N., Chevallier, F., Doney, S. C., Fay, A. R., González-Dávila, M., Gruber, N., Jones, S., Krijnen, J., Landschützer, P., Lefèvre, N., Manizza, M., Mathis, J., Metzl, N., Olsen, A., Rios, A. F., Rödenbeck, C., Santana-Casiano, J. M., Takahashi, T., Wanninkhof, R., and Watson, A. J.: An assessment of the Atlantic and Arctic sea-air CO₂ fluxes, 1990–2009, Biogeosciences, 10, 607–627, doi:10.5194/bg-10-607-2013, 2013.

SOCAT: Future for the Surface Ocean CO₂ Atlas: Data quality, management and products, Data2Flux Workshop, Unesco, Paris, 12 and 13 September 2011, SOCAT Report, available at: <http://www.socat.info/meetings.html> (last access: 24 June 2013), 2011.

SOCAT: Surface Ocean CO₂ Atlas (SOCAT) Automation Planning Meeting, NOAA-PMEL, Seattle, USA, 10 and 11 May 2012, SOCAT Report, available at: <http://www.socat.info/meetings.html> (last access: 1 May 2013), 2012a.

An update to the Surface Ocean CO₂ Atlas

D. C. E. Bakker et al.

Title Page

Abstract

Instruments

Data Provenance & Structure

Tables

Figures

◀

▶

◀

▶

Back

Close

Full Screen / Esc

Printer-friendly Version

Interactive Discussion



SOCAT: Surface Ocean CO₂ Atlas (SOCAT) Progress Meeting, Epochal Tsukuba, Tsukuba, Japan, 3–5 July 2012, SOCAT Report, available at: <http://www.socat.info/meetings.html> (last access: 1 May 2013), 2012b.

SOCAT: Data policy for the SOCAT public release, available at: http://www.socat.info/SOCAT_data_policy_public_release_v2.htm, last access: 1 May 2013a.

SOCAT: Surface Ocean CO₂ Atlas (SOCAT) side event: Release of version 2 and science highlights, SOCAT side event during the 9th International Carbon Dioxide Conference, Beijing International Convention Center, Beijing, China, 4 June 2013, SOCAT Report, available at: <http://www.socat.info/meetings.html>, in preparation, 2013b.

Solomon, S., Qin, D., Manning, M., Chen, Z., Marquis, M., Averyt, K. B., Tignor, M., and Miller, H. L. (Eds.): Climate Change 2007: The Physical Science Basis. Contribution of Working Group I to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change, Cambridge University Press, Cambridge, United Kingdom and New York, NY, USA, 2007.

Stroeve, J., Holland, M. M., Meier, W., Scambos, T., and Serreze, M.: Arctic sea ice decline: Faster than forecast, *Geophys. Res. Lett.*, 34, L09501, doi:10.1029/2007GL029703, 2007.

Sweeney, C., Takahashi, T., and Wanninkhof, R.: Spatial and temporal variability of surface water $p\text{CO}_2$ and sampling strategies, report presented at the Advisory Meeting for the Sea-Air CO₂ Flux Program, National Oceanic and Atmospheric Administration, Boulder, Colorado, USA, 2000.

Swift, J.: A guide to submitting CTD/hydrographic/tracer data and associated documentation to the CLIVAR and Carbon Hydrographic Data Office, version of 22 April 2008, Scripps Institution of Oceanography, University of California, San Diego, 37 pp., 2008.

Takahashi, T., Feely, R. A., Weiss, R. F., Wanninkhof, R. H., Chipman, D. W., Sutherland, S. C., and Takahashi, T. T.: Global air-sea flux of CO₂: An estimate based on measurements of sea-air $p\text{CO}_2$ difference, *P. Natl. Acad. Sci. USA*, 94, 8292–8299, 1997.

Takahashi, T., Sutherland, S. C., and Kozyr, A.: Global ocean surface water partial pressure of CO₂ database: Measurements performed during 1957–2012 (Version 2012), ORNL/CDIAC-160, NDP-088(V2012), Carbon Dioxide Information Analysis Center, Oak Ridge National Laboratory, US Department of Energy, Oak Ridge, Tennessee, doi:10.3334/CDIAC/OTG.NDP088(V2012), available at: http://cdiac.ornl.gov/oceans/LDEO_Underway_Database/, last access: 30 May 2013.

An update to the Surface Ocean CO₂ Atlas

D. C. E. Bakker et al.

Title Page

Abstract

Instruments

Data Provenance & Structure

Tables

Figures

◀

▶

◀

▶

Back

Close

Full Screen / Esc

Printer-friendly Version

Interactive Discussion



- Takahashi, T., Sutherland, S. C., Wanninkhof, R., Sweeney, C., Feely, R. A., Chipman, D. W., Hales, B., Friederich, G., Chavez, F., Sabine, C. L., Watson, A. J., Bakker, D. C. E., Schuster, U., Metzl, N., Inoue, H. Y., Ishii, M., Midorikawa, T., Nojiri, Y., Körtzinger, A., Steinhoff, T., Hoppema, J. M. J., Olafsson J., Arnarson, T. S., Tilbrook, B., Johannessen T., Olsen, A., Bellerby, R. G. J., Wong, C. S., Delille B., Bates, N. R., and De Baar, H. J. W.: Climatological mean and decadal change in surface ocean $p\text{CO}_2$, and net sea-air CO_2 flux over the global oceans, *Deep-Sea Res. Pt. II*, 56, 544–577, doi:10.1016/j.dsr2.2008.12.009, 2009.
- 5 Takamura, T. R., Inoue, H. Y., Midorikawa, T., Ishii, M., and Nojiri, Y.: Seasonal and inter-annual variations in $p\text{CO}_2^{\text{sea}}$ and air-sea CO_2 fluxes in mid-latitudes of the western and eastern North Pacific during 1999–2006: Recent results utilizing voluntary observation ships, *J. Meteorol. Soc. Jpn.*, 88, 883–898, doi:10.2151/jmsj.2010-602, 2010.
- 10 Tans, P. and Keeling, R.: Trends in atmospheric carbon dioxide, available at: <http://www.esrl.noaa.gov/gmd/ccgg/trends/#mlo>, last access: 17 June 2013.
- Telszewski, M., Chazottes, A., Schuster, U., Watson, A. J., Moulin, C., Bakker, D. C. E., González-Dávila, M., Johannessen, T., Körtzinger, A., Lüger, H., Olsen, A., Omar, A., Padin, X. A., Ríos, A. F., Steinhoff, T., Santana-Casiano, M., Wallace, D. W. R., and Wanninkhof, R.: Estimating the monthly $p\text{CO}_2$ distribution in the North Atlantic using a self-organizing neural network, *Biogeosciences*, 6, 1405–1421, doi:10.5194/bg-6-1405-2009, 2009.
- 15 Thomas, H., Prowe, A. E. F., van Heuven, S., Bozec, Y., de Baar, H. J. W., Schiettecatte, L. S., Suykens, K., Koné, M., Borges, A. V., Lima, I. D., and Doney, S. C.: Rapid decline of the CO_2 buffering capacity in the North Sea and implications for the North Atlantic Ocean, *Global Biogeochem. Cy.*, 21, GB4001, doi:10.1029/2006GB002825, 2007.
- 20 Thomas, H., Prowe, A. E. F., Lima, I., Doney, S. C., Wanninkhof, R., Greatbatch, R. J., Schuster, U., and Corbière, A.: Changes in the North Atlantic Oscillation influence CO_2 uptake in the North Atlantic over the past 2 decades, *Global Biogeochem. Cy.*, 22, GB4027, doi:10.1029/2007GB003167, 2008.
- 25 Tjiputra, J. F., Olsen, A., Assmann, K., Pfeil, B., and Heinze, C.: A model study of the seasonal and long-term North Atlantic surface $p\text{CO}_2$ variability, *Biogeosciences*, 9, 907–923, doi:10.5194/bg-9-907-2012, 2012.
- 30 Vaughan, D. G., Marshall, G. J., Connolley, W. M., Parkinson, C., Mulvaney, R., Hodgson, D. A., King, J. C., Pudsey, C. J., and Turner, J.: Recent rapid regional climate warming on the Antarctic Peninsula, *Climatic Change*, 60, 243–274, 2003.

An update to the Surface Ocean CO₂ Atlas

D. C. E. Bakker et al.

Title Page

Abstract

Instruments

Data Provenance & Structure

Tables

Figures

◀

▶

◀

▶

Back

Close

Full Screen / Esc

Printer-friendly Version

Interactive Discussion



Wada, A., Midorikawa, T., Ishii, M., and Motoi, T.: Carbon system changes in the East China Sea induced by typhoons Tina and Winnie in 1997, *J. Geophys. Res.*, 116, C07014, doi:10.1029/2010JC006701, 2011.

Wanninkhof, R., Bakker, D. C. E., Bates, N., Olsen, A., Steinhoff, T., and Sutton, A.: Incorporation of alternative sensor into the SOCAT data base and adjustments to dataset quality control flags, consultation document, draft April 2013, available at: http://www.socat.info/upload/Recommendationnewsensors_REVIEW_COPY.pdf, last access: 1 May 2013a.

Wanninkhof, R., Park, G.-H., Takahashi, T., Sweeney, C., Feely, R., Nojiri, Y., Gruber, N., Doney, S. C., McKinley, G. A., Lenton, A., Le Quéré, C., Heinze, C., Schwinger, J., Graven, H., and Khatiwala, S.: Global ocean carbon uptake: magnitude, variability and trends, *Biogeosciences*, 10, 1983–2000, doi:10.5194/bg-10-1983-2013, 2013b.

Watson, A. J., Schuster, U., Bakker, D. C. E., Bates, N. R., Corbière, A., González-Dávila, M., Friedrich, T., Heinze, C., Johannessen, T., Körtzinger, A., Metzl, N., Olafsson, J., Olsen, A., Oschlies, A., Padin, X. A., Pfeil, B., Santana-Casiano, J. M., Steinhoff, T., Telszewski, M., Ríos, A. F., Wallace, D. W. R., and Wanninkhof, R.: A network to accurately estimate the North Atlantic sink for CO₂, *Science*, 326, 1391–1393, 2009.

Table 1. Key differences between SOCAT versions 1 (released as versions 1.4 and 1.5) and 2.

	Version 1	Version 2
Description	Pfeil et al. (2013); Sabine et al. (2013)	This study
Data coverage	1968 to 2007, 6.3 million surface water $f\text{CO}_2$ values, 1853 cruises	1968 to 2011, 10.1 million surface water $f\text{CO}_2$ values, 2660 cruises
Time stamp	The time stamp did not contain seconds. Some multiple entries for the same time stamp were reported in individual cruise files (version 1.4), but were averaged in the synthesis files (version 1.5).	The time stamp includes seconds for all new and updated cruises. Seconds were added artificially to time stamps for most version 1 cruises to avoid multiple entries. Artificial times with tenths and hundreds of a second have been generated for historical data reported at midnight or with insufficient decimals in the time stamp.
Version numbers	Two version numbers, version 1.4 and 1.5, highlighted the different treatment of multiple entries for the same time stamp.	Version 2 only.
Expocode	Expocodes were not used for moored and drifting buoys.	Expocodes have been used for moored and drifting buoys.
Arctic region	Arctic data were included under the North Atlantic, North Pacific and coastal regions.	An Arctic region has been defined as all open ocean and coastal waters north of 70° N for 100° W to 43° E, elsewhere north of 66° N.
WOCE flags	WOCE flags 3 and 4 were reset unintentionally to flag 2. Most $f\text{CO}_2$ values were reported with a flag of 2 (good), including 0.2% of data initially given a flag of 3 (questionable) or 4 (bad).	The $f\text{CO}_2$ values have been assigned WOCE flags of 2 (good), 3 (questionable) and 4 (bad). Flags of 3 and 4 given during version 1 quality control have been reinstated. Individual cruise files contain all $f\text{CO}_2$ values with flags of 2, 3 and 4. Synthesis files only contain $f\text{CO}_2$ values with a flag of 2.
Output format	Atmospheric CO_2 mole fractions were from GLOBALVIEW-CO2 2008.	Atmospheric CO_2 mole fractions are from GLOBALVIEW-CO2 2012. New parameters are the data set quality control flags A to D and distance to a major land mass.

An update to the Surface Ocean CO_2 Atlas

D. C. E. Bakker et al.

Title Page

Abstract

Instruments

Data Provenance & Structure

Tables

Figures

◀

▶

◀

▶

Back

Close

Full Screen / Esc

Printer-friendly Version

Interactive Discussion



An update to the Surface Ocean CO₂ Atlas

D. C. E. Bakker et al.

Title Page

Abstract

Instruments

Data Provenance & Structure

Tables

Figures

◀

▶

◀

▶

Back

Close

Full Screen / Esc

Printer-friendly Version

Interactive Discussion



Table 2. Key characteristics of the three SOCAT data products for surface ocean $f\text{CO}_2$ values in version 2, as described in Sect. 2.4. All data products can be accessed via the SOCAT website (<http://www.socat.info>).

	Key characteristics	Available formats
Individual cruise files	The cruise files contain all $f\text{CO}_2$ values with flags of 2, 3 and 4 and the original CO_2 measurements for data sets with flags of A, B, C or D (Table 6).	Text files ¹ .
Global and regional synthesis files	The synthesis files contain $f\text{CO}_2$ values with a flag of 2 (Table 6). The global synthesis file has been created by merging the individual cruise files. Regional files contain data from a specific region.	Zipped text files ² , in Ocean Data View format ³ , and via the Cruise Data Viewer ⁴ .
Gridded files	Gridded means of $f\text{CO}_2$ values on a $1^\circ \times 1^\circ$ grid with minimal interpolation. Means are per year, monthly per year, monthly per decade and per climatological month from 1970 to 2011. A monthly $0.25^\circ \times 0.25^\circ$ data set is available for coastal regions.	NetCDF files ⁵ , in Ocean Data View format ⁶ , and via the Gridded Data Viewer ⁷ .

¹ <http://doi.pangaea.de/10.1594/PANGAEA.811776>

² <http://cdiac.ornl.gov/ftp/oceans/SOCATv2/>

³ http://odv.awi.de/en/data/ocean/socat.fCO2_data

⁴ http://ferret.pmel.noaa.gov/SOCAT2_Cruise_Viewer/

⁵ http://dx.doi.org/10.3334/CDIAC/OTG.SOCAT_V2_GRID,
http://cdiac.ornl.gov/ftp/oceans/SOCATv2/SOCATv2_Gridded_Data/

⁶ http://odv.awi.de/en/data/ocean/socat.fCO2_data

⁷ http://ferret.pmel.noaa.gov/SOCAT_gridded_viewer/

Table 3. Activities and key participants in SOCAT versions 2 and 3. Regional group leads are in Table 4.

Activity	Key Participants
Global group for coordination	Bakker (chair), Hankin, Kozyr, Metzli, Olsen, Pfeil, Pierrot, Telszewski
Data retrieval, data entry, recalculation of $f\text{CO}_2$	Pfeil, Olsen
Quality control	Alin, Bakker, Barbero, Castle, Cosca, Evans, Hales, Harasawa, Hoppema, Huang, Hunt, Huss, Park, Paterson, Pierrot, Schuster, Skjelvan, Steinhoff, Suzuki, Tilbrook, Van Heuven, Vlahos, Wada, Wanninkhof
Live Access Server	Hankin, O'Brien, Smith
Cruise files, synthesis products and gridded products	Pfeil, Smith, Manke, Hankin
Ocean Data View	Schlitzer
Matlab files	Pierrot, Landschützer
SOCAT website	Pfeil
Data archiving and online access	Pfeil, Sieger, Kozyr, Smith, Manke, Hankin
Meetings	Alin, Bakker, Hales, Hankin, Nojiri, Telszewski
Automation (version 3)	Hankin, S. Jones, Kozyr, O'Brien, Pfeil, Smith, Bakker, Olsen, Schweitzer
Alternative sensors (version 3)	Wanninkhof, Steinhoff, Bakker, Bates, Olsen, Sutton

An update to the Surface Ocean CO₂ Atlas

D. C. E. Bakker et al.

Title Page

Abstract

Instruments

Data Provenance & Structure

Tables

Figures

◀

▶

◀

▶

Back

Close

Full Screen / Esc

Printer-friendly Version

Interactive Discussion



An update to the Surface Ocean CO₂ Atlas

D. C. E. Bakker et al.

Title Page

Abstract

Instruments

Data Provenance & Structure

Tables

Figures

◀

▶

◀

▶

Back

Close

Full Screen / Esc

Printer-friendly Version

Interactive Discussion



Table 4. Regions and regional group leads in SOCAT version 2 (Fig. 5).

Region	Definition	Lead(s)
Coastal seas	Less than 400 km from land; between 30° S and 70° N for 100° W to 43° E; between 30° S and 66° N elsewhere	Alin, Cai, Hales
Arctic Ocean	North of 70° N for 100° W to 43° E; north of 66° N elsewhere, incl. coastal waters	Mathis
North Atlantic	30 to 70° N	Schuster
Tropical Atlantic	30° N to 30° S	Lefèvre
North Pacific	30 to 66° N	Nojiri
Tropical Pacific	30° N to 30° S	Cosca
Indian Ocean	North of 30° S	Sarma
Southern Ocean	South of 30° S, incl. coastal waters	Tilbrook, Metzl

An update to the Surface Ocean CO₂ Atlas

D. C. E. Bakker et al.

Title Page

Abstract

Instruments

Data Provenance & Structure

Tables

Figures

◀

▶

◀

▶

Back

Close

Full Screen / Esc

Printer-friendly Version

Interactive Discussion



Table 5. Meetings for SOCAT versions 2 and 3 to date.

Timing	Meeting description	Location	Reference
09/2011	Public release of version 1. Session on future SOCAT.	UNESCO, Paris, France	SOCAT (2011)
05/2012	Automation planning meeting	NOAA-PMEL, Seattle, USA	SOCAT (2012a)
07/2012	SOCAT progress meeting	Epochal Centre, Tsukuba, Japan	SOCAT (2012b)
10/2012	Coastal and Arctic SOCAT quality control workshop	NOAA-PMEL, Seattle, USA	IOCCP (2012)
06/2013	SOCAT side event at the 9th International Carbon Dioxide Conference. Public release of version 2.	Beijing International Convention Center, Beijing, China	SOCAT (2013b)

Table 6. Content of the individual cruise files and the synthesis files in SOCAT version 2.

Individual	Synthesis	Unit	Description
–	Expocode	–	12-character expocode
–	SOCAT.DOI	–	Digital object identifier for the individual cruise and metadata
–	QC.ID	–	Data set quality control flag with 11 for A, 12 for B, 13 for C and 14 for D
Date/Time	–	–	yyyy-mm-dd/hh:mm:ss (ISO8859)
–	yr	Year	Year (UTC)*
–	mon	Month	Month (UTC)*
–	day	Day	Day (UTC)*
–	hh	Hour	Hour (UTC)*
–	mm	Minute	Minute (UTC)*
–	ss	Seconds	Seconds (may include decimals)*
Longitude	longitude	° E	Longitude (0 to 360)*
Latitude	latitude	° N, ° S	Latitude (–90 to 90)*
Depth water	sample_depth	m	Water sampling depth ¹
Sal	sal	–	Salinity on Practical Salinity Scale*
Temp	SST	°C	Sea surface temperature*
Tequ	Tequ	°C	Equilibrator chamber temperature*
PPPP	PPPP	hPa	Atmospheric pressure*
Pequ	Pequ	hPa	Equilibrator chamber pressure*
Sal interp	WOA-SSS	–	Salinity from WOA (2005) ²
PPPP interp	NCEP_SLP	hPa	NCEP Atmospheric pressure ³
Bathy depth interp	ETOPO2_depth	m	ETOPO2 Bathymetry ⁴
Distance	d2l	km	Distance to major land mass
xCO2air_interp	GVC02	μmol mol ⁻¹	Atmospheric xCO ₂ from GLOBALVIEW-CO2 (2012)
xCO2water_equ_dry	–	μmol/mol	xCO ₂ (water) at equilibrator temperature (dry air)*
fCO2water_SST_wet	–	μatm	fCO ₂ (water) at sea surface temperature (wet air)*
pCO2water_SST_wet	–	μatm	pCO ₂ (water) at sea surface temperature (wet air)*
xCO2water_SST_dry	–	μmol mol ⁻¹	xCO ₂ (water) at sea surface temperature (dry air)*
fCO2water_equ_wet	–	μatm	fCO ₂ (water) at equilibrator temperature (wet air)*
pCO2water_equ_wet	–	μatm	pCO ₂ (water) at equilibrator temperature (wet air)*
fCO2water_SST_wet	fCO2rec	μatm	Recommended fCO ₂ calculated following the SOCAT protocol
Algorithm	fCO2rec_src	–	Algorithm for calculating fCO ₂ .rec (0: not generated; index 1–14 in Table 3 in Pfeil et al., 2013)
Flag	fCO2rec_flag	–	WOCE flag for fCO ₂ .rec (2: good, 3: questionable, 4: bad) ⁵

* Refers to data reported by the data originator; ¹ If the intake depth has not been reported by the data originator, an intake depth of 5 m has been assumed; ² Sea surface salinity on the Practical Salinity Scale interpolated from the World Ocean Atlas (WOA) 2005 (Antonov et al., 2006), available at: http://www.nodc.noaa.gov/OC5/WOA05/pr_woa05.html (last access: 1 May 2013); ³ Atmospheric pressure interpolated from the NCEP/NCAR (National Centers for Environmental Prediction/ National Center for Atmospheric Research) 40 yr Reanalysis Project on a 6-hourly, global, 2.5° latitude by 2.5° longitude grid (Kalnay et al., 1996), available at: <http://www.esrl.noaa.gov/psd/data/gridded/data.ncep.reanalysis.surface.html> (last access: 1 May 2013); ⁴ Bathymetry interpolated from ETOPO2 (2006) 2 min Gridded Global Relief Data, available at: <http://www.ngdc.noaa.gov/mgg/global/etopo2.html> (last access: 1 May 2013); ⁵ Individual cruise files contain all fCO₂.rec data. Synthesis files only contain fCO₂.rec data with a WOCE flag 2.

An update to the Surface Ocean CO₂ Atlas

D. C. E. Bakker et al.

Title Page

Abstract

Instruments

Data Provenance & Structure

Tables

Figures

◀

▶

◀

▶

Back

Close

Full Screen / Esc

Printer-friendly Version

Interactive Discussion



An update to the Surface Ocean CO₂ Atlas

D. C. E. Bakker et al.

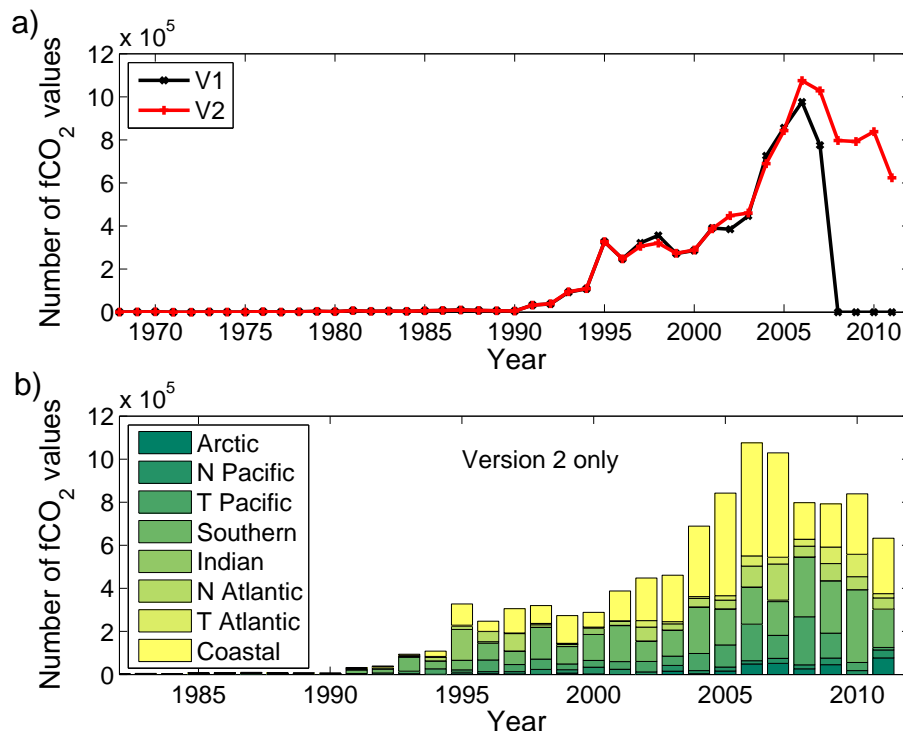


Fig. 1. (a) The number of surface water $f\text{CO}_2$ values per year in SOCAT versions 1 and 2 and (b) per region per year in version 2. The SOCAT regions are the Arctic Ocean, the North Pacific Ocean, the Tropical Pacific Ocean, the Southern Ocean, the Indian Ocean, the North Atlantic Ocean, the Tropical Atlantic Ocean and the Coastal seas (Fig. 5, Table 4). These data points originate from data sets with flags of A, B, C or D and have a WOCE flag of 2. The subsequent figures only show $f\text{CO}_2$ values with these characteristics.

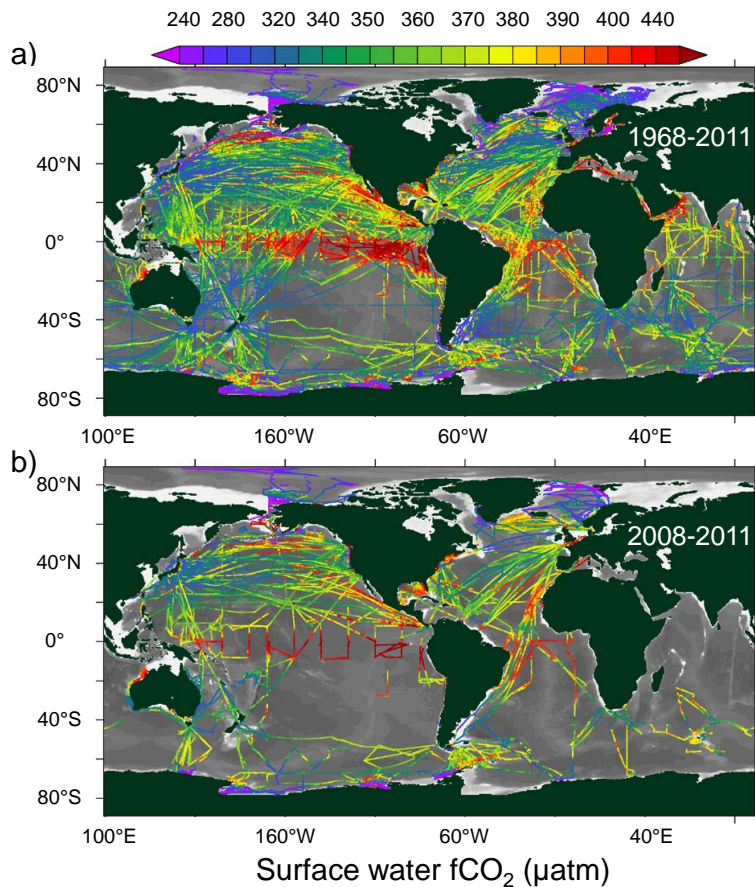


Fig. 2. The global distribution of surface water $f\text{CO}_2$ values in SOCAT version 2: **(a)** for 1968 to 2011 and **(b)** for 2008 to 2011.

An update to the Surface Ocean CO₂ Atlas

D. C. E. Bakker et al.

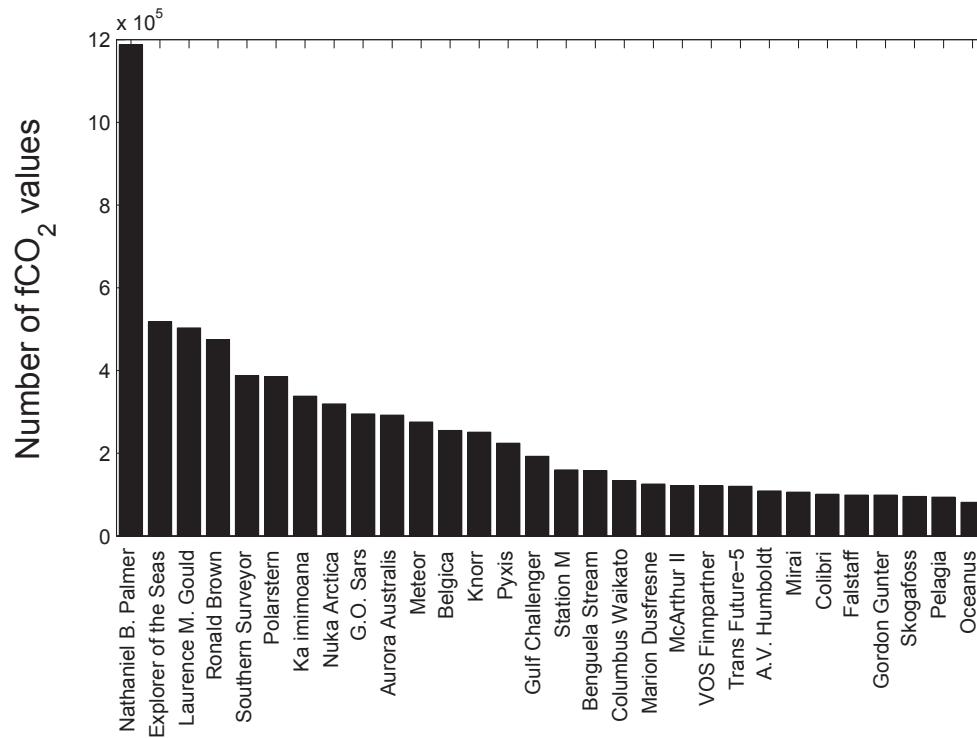


Fig. 3. The number of surface water $f\text{CO}_2$ values obtained on the 30 ships and time series hosting the most intense data collection effort in SOCAT version 2.

Title Page

Abstract

Instruments

Data Provenance & Structure

Tables

Figures

◀

▶

◀

▶

Back

Close

Full Screen / Esc

Printer-friendly Version

Interactive Discussion



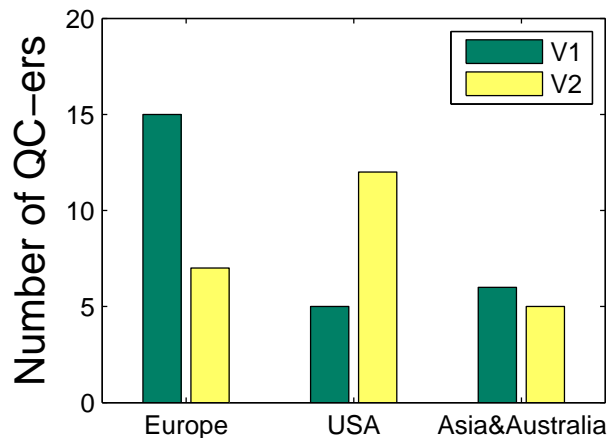


Fig. 4. The number of quality controllers in SOCAT versions 1 and 2 based in Europe, the US, Asia and Austria, respectively. The figure demonstrates the international character of the quality control effort in SOCAT.

An update to the Surface Ocean CO₂ Atlas

D. C. E. Bakker et al.

Title Page

Abstract

Instruments

Data Provenance & Structure

Tables

Figures

⏪

⏩

◀

▶

Back

Close

Full Screen / Esc

Printer-friendly Version

Interactive Discussion



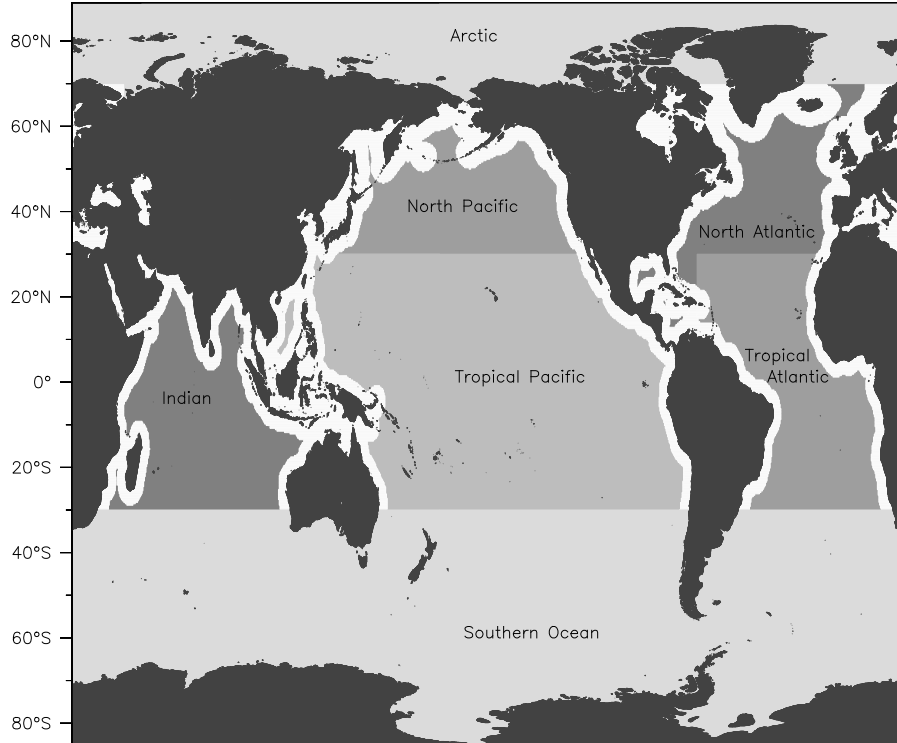


Fig. 5. Quality control regions for SOCAT version 2 (Table 4). White shading corresponds to the coastal region. All regions have been defined for operational reasons and do not necessarily reflect common oceanographic definitions.

**An update to the
Surface Ocean CO₂
Atlas**

D. C. E. Bakker et al.

Title Page

Abstract

Instruments

Data Provenance & Structure

Tables

Figures

◀

▶

◀

▶

Back

Close

Full Screen / Esc

Printer-friendly Version

Interactive Discussion



An update to the Surface Ocean CO₂ Atlas

D. C. E. Bakker et al.

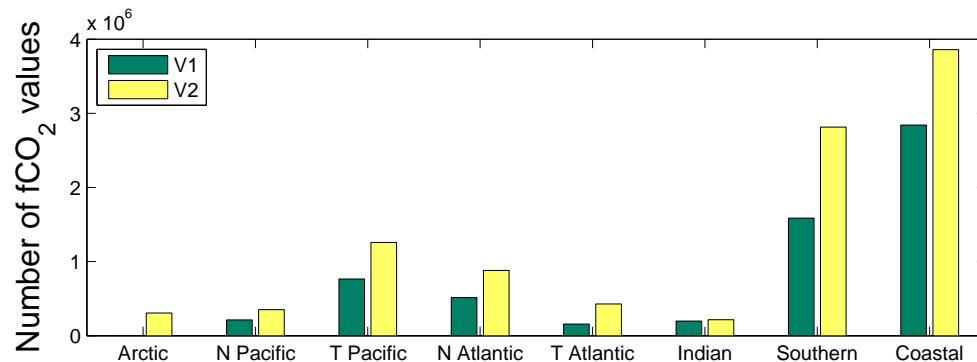


Fig. 6. The number of surface water $f\text{CO}_2$ values for each region in SOCAT versions 1 and 2. The regions are the Arctic Ocean, the North Pacific Ocean, the Tropical Pacific Ocean, the North Atlantic Ocean, the Tropical Atlantic Ocean, the Indian Ocean, the Southern Ocean and the coastal seas (Fig. 5, Table 4). In version 1, Arctic data were included in the North Pacific, North Atlantic and coastal regions.

Title Page

Abstract Instruments

Data Provenance & Structure

Tables Figures

◀ ▶

◀ ▶

Back Close

Full Screen / Esc

Printer-friendly Version

Interactive Discussion



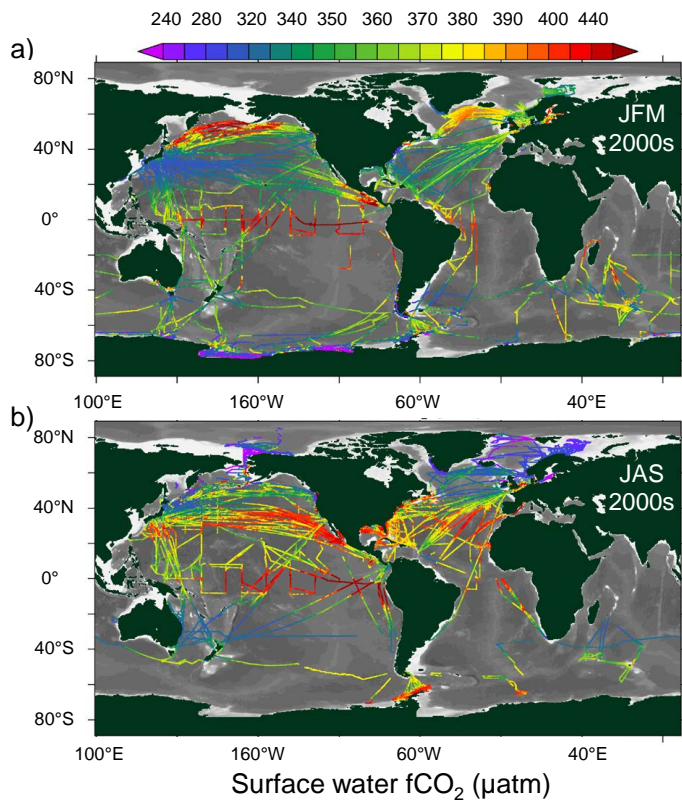


Fig. 7. Seasonal distribution of surface water $f\text{CO}_2$ for 2000 to 2009 in SOCAT version 2 for **(a)** January to March and **(b)** July to September.

An update to the
Surface Ocean CO_2
Atlas

D. C. E. Bakker et al.

Title Page

Abstract

Instruments

Data Provenance & Structure

Tables

Figures

◀

▶

◀

▶

Back

Close

Full Screen / Esc

Printer-friendly Version

Interactive Discussion



An update to the Surface Ocean CO₂ Atlas

D. C. E. Bakker et al.

Title Page

Abstract

Instruments

Data Provenance & Structure

Tables

Figures

◀

▶

◀

▶

Back

Close

Full Screen / Esc

Printer-friendly Version

Interactive Discussion

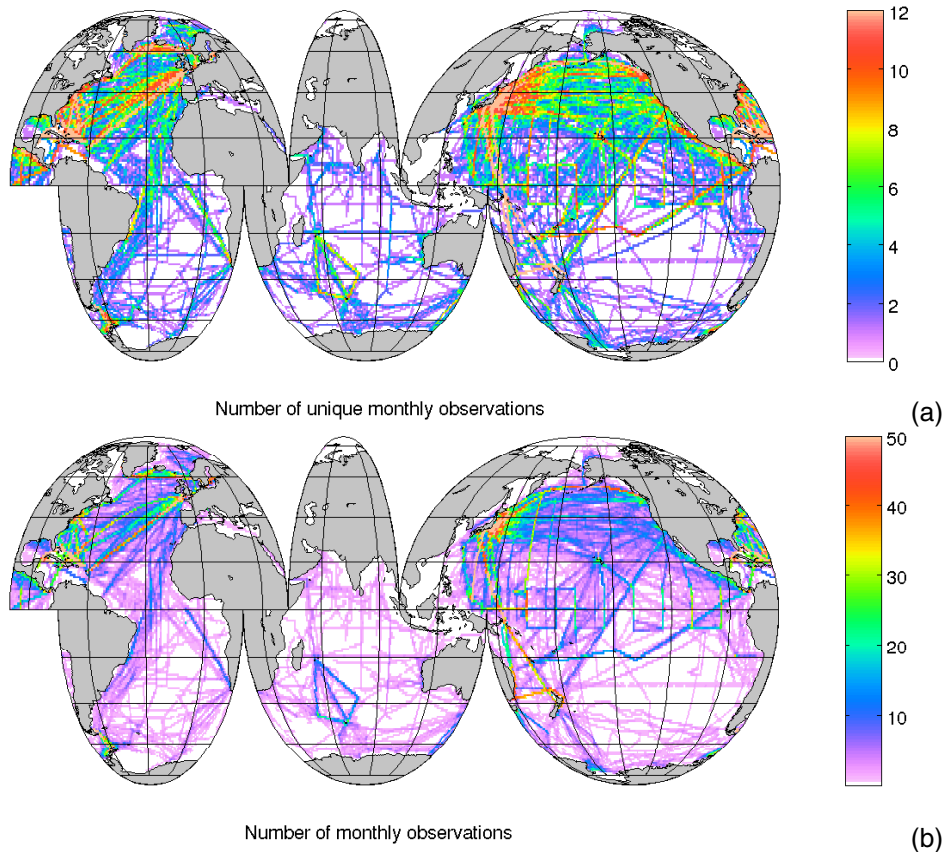


Fig. 8. The number of **(a)** months of the year and **(b)** total months with surface water $f\text{CO}_2$ values in each 1° latitude by 1° longitude grid cell from 1970 to 2011 in SOCAT version 2. **(a)** updates the figure for version 1 in Sabine et al. (2013, Figure 5).

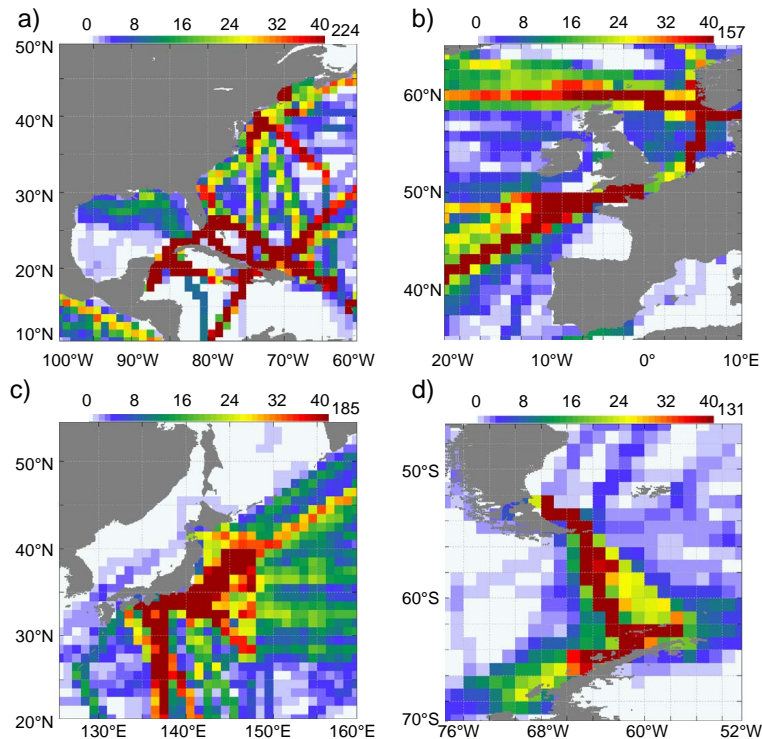


Fig. 9. Number of cruises (see colour bar on top of subplots) with surface water $f\text{CO}_2$ measurements per 1° latitude by 1° longitude grid cell for 2000 to 2009 for **(a)** the Northwest Atlantic Ocean and the Caribbean Sea, **(b)** the Northeast Atlantic Ocean and European shelf seas, **(c)** the Northwest Pacific Ocean and **(d)** Drake Passage in the Southern Ocean. Repeat observations made on voluntary observing ships and research supply ships are clearly visible, both for coastal seas and the open ocean.

**An update to the
Surface Ocean CO_2
Atlas**

D. C. E. Bakker et al.

Title Page

Abstract Instruments

Data Provenance & Structure

Tables Figures

◀ ▶

◀ ▶

Back Close

Full Screen / Esc

Printer-friendly Version

Interactive Discussion

