**Intergovernmental Oceanographic Commission**

Workshop Report No. 229

# Surface Ocean $CO_2$ Atlas Project Equatorial Pacific, North Pacific, and Indian Ocean Regional Workshop

Tokyo, Japan
8-11 February 2010

**IOCCP Report Number 18**

**UNESCO 2010**

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Abstract:

The SOCAT Equatorial Pacific, North Pacific, and Indian Ocean Regional Group Workshop was held at the JAMSTEC office in Tokyo, Japan on 8-11 February 2010. The workshop was chaired by Yukihiro Nojiri (NIES) and Shuichi Watanabe (JAMSTEC) and attended by twenty-three participants from eight countries. The first half of the meeting consisted of the presentation and discussion of results of the JAMSTEC $pCO_2$ buoy project and the $pCO_2$ inter-comparison held in Hasaki, Japan in 2009. The final two days were devoted to the SOCAT regional workshop and included updates on the status of the global SOCAT database and quality control, equatorial Pacific and Indian Ocean $pCO_2$ data status, SOCAT data at CDIAC, Live-Access Server (LAS) tools and their application to SOCAT, and neural network analysis of the Atlantic and Pacific $pCO_2$ data sets.

**SOCAT Equatorial Pacific, North Pacific, and Indian Ocean Regional Workshop**

**8-11 February 2010**

**JAMSTEC Headquarters**

**Tokyo, Japan**

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## BACKGROUND

At the "Surface Ocean $CO_2$ Variability and Vulnerability" (SOCOVV) workshop in April 2007, co-sponsored by IOCCP, SOLAS, IMBER, and the Global Carbon Project, participants agreed to establish a global surface $CO_2$ data set that would bring together, in a common format, all publicly available surface $fCO_2$ data for the surface oceans. This activity has been requested by many international groups for many years, and has now become a priority activity for the marine carbon community. This data set will serve as a foundation upon which the community will continue to build in the future, based on agreed data and metadata formats and standard 1st-level quality-control procedures, building on earlier agreements established at the 2004 Tsukuba workshop on "Ocean Surface $pCO_2$ Data Integration and Database Development". This activity also supports the SOLAS and IMBER science plans and joint carbon implementation plan.

This data set is meant to serve a wide range of user communities and it is envisaged that, in the future, 2 distinct SOCAT data products will be made available:

- a 2nd-level quality controlled, global surface ocean $fCO_2$ (fugacity of $CO_2$) data set following agreed procedures and regional review, and
- a gridded SOCAT product of monthly surface water $fCO_2$ means on a 1° x 1° grid with no temporal or spatial interpolation.

An extended 1st-level quality-controlled data set has been developed as part of the EU CARBOOCEAN project, where Benjamin Pfeil and Are Olsen (Bjerknes Centre for Climate Research) have compiled the publicly available surface $CO_2$ data held at CDIAC (Carbon Dioxide Information Analysis Center) and other public data into a common format, 1st level quality-controlled, database based on the IOCCP-recommended formats for metadata and data reporting. The first SOCAT data compilation (version 1.1), available in May 2008 to SOCAT participants, already includes data from over 10 countries, producing an initial database composed of more than 1250 cruises from 1972 to 2007 with measurements of various carbon parameters.

A small technical meeting was held in Bremen, Germany, on 5 December 2007 (associated with the 3rd CARBOOCEAN Annual Meeting) to agree on 1st-level QC for the data set and to decide on a way forward for the 2nd-level QC issues.

The IOCCP, along with CARBOOCEAN and the SOLAS-IMBER Joint Carbon Group, held a 2nd technical workshop (SOCAT-2 meeting) at UNESCO, Paris, on 16-17 June 2008 to develop internationally agreed 2nd-level quality-control procedures and to discuss the coordination of regional scientific groups to conduct the 2nd-level quality control analyses. Refer to the background document SOCAT-II Report for more information http://ioc3.unesco.org/ioccp/Docs/SOCAT2_Final2.pdf

The SOCAT dataset now contains over 2,100 cruises from 1968-2007. Benjamin Pfeil and Steve Hankin have agreed that the best way to access the dataset is to keep each cruise as an individual file and to use the LAS system to serve all the data. The regional groups will use LAS to download data, based on definitions of regional boundaries.

Regional groups were tasked with identifying missing datasets from SOCAT version 1.1. The identified regional groups and chairs are:

- Atlantic and Arctic Ocean – Schuster, Lefèvre
- Indian Ocean – VVSS Sarma
- Pacific Ocean – Feely, Nojiri
- Southern Ocean – Tilbrook, Metzl
- Coastal seas – Borges, Chen.
- Global group – Bakker, Olsen, Sabine, Pfeil, Metzl

SOCAT QC-II Definitions of Regional Boundaries as of June 2009

1. **Tropical Pacific** -- Between 30°S, 30°N, North America and Asia. The boundary between the Indian and the Pacific is Malaysia, Sumatra, Java, and Timor and a line at 130°E to Australia through the Timor Sea.
2. **North Pacific** -- North of 30°N and between North America and Asia, including cruises that go north of Alaska into the Arctic Ocean.
3. **Southern Ocean** -- Everything south of 30°S
4. **Indian Ocean** -- North of 30°S, bounded on the east by the line described above, and on the west by Africa and the Suez Canal.
5. **Atlantic Ocean** -- North of 30°S including the Mediterranean, Black Sea, Barents Sea, and Labrador Sea.
6. **Coastal (a.k.a. "continental margins")** -- All ocean surface within 400 km of land* excluding the Southern Ocean Region.

***** The intent of the various working groups was to exclude the margins around small, isolated islands, so the Distance-To-Land variable is calculated from a 20-minute resolution land mask that was altered (through guidance from Burke Hales) to eliminate such islands. The altered land mask retains New Zealand, Iceland, and Madagascar as 'land' and Caribbean islands that show up at the 20 minute resolution, as well as other islands like Tasmania, Sri Lanka, Japan, etc. The following islands were explicitly masked out: Reunion/Mauritius, New Caledonia, Vanuatu, Solomon Islands, Manus Island (N of New Guinea), Galapagos, Smith Island (Indian Ocean; Bay of Bengal), Hawaii, Azores, South Georgia, Macquarie (south of NZ), French Southern and Antarctic Lands.

The various regional groups met to evaluate the initial data quality, learn to use the LAS tools for conducting 2$^{nd}$ level quality control, and performing the 2$^{nd}$ level QC checks. Previous workshops were held by the Coastal Regional Group (Kiel, Germany; January 2009), the Pacific Regional Group (Tsukuba, Japan; March 2009), and the Atlantic, Indian, and Southern Ocean Regional Groups (Norwich, UK; June 2009). Workshop reports are available at http://www.ioccp.org/Workshops.html.

**INTRODUCTION TO THE WORKSHOP**

SOCAT Equatorial Pacific, North Pacific, and Indian Ocean Regional Workshop
8-11 February 2010
JAMSTEC Office
Tokyo, Japan

The SOCAT Equatorial Pacific, North Pacific, and Indian Ocean Regional Workshop was held at the JAMSTEC office in Tokyo, Japan on 8-11 February 2010. The workshop was chaired by Yukihiro Nojiri (NIES) and Shuichi Watanabe (JAMSTEC) and attended by twenty-three participants from eight countries. The first half of the meeting consisted of the presentation and discussion of results of the JAMSTEC $pCO_2$ buoy project and the $pCO_2$ inter-comparison held in Hasaki, Japan in 2009. The final two days were devoted to the SOCAT regional workshop and included updates on the status of the global SOCAT database and quality control, equatorial Pacific and Indian Ocean $pCO_2$ data status, SOCAT data at CDIAC, Live-Access Server (LAS) tools and their application to SOCAT, and neural network analysis of the Atlantic and Pacific $pCO_2$ data sets.

Large sets of oceanic $pCO_2$ data are necessary to improve our understanding of the Earth's climate system. The development of autonomous $pCO_2$ measurement buoys for drifting and mooring use have resulted in expanded spatial and temporal coverage of the data set. At this workshop, the development, results of an inter-comparison experiment, and improvement of an autonomous buoy developed by JAMSTEC, as part of the Japan EOS Promotion Program (JEPP) program, were presented. The $pCO_2$ drifting buoy development program by JAMSTEC also aims buoy operation attached with the TRAITON and TAO array.

Inter-comparison exercises are conducted to assure the analytical accuracy due to the lack of reference materials for $pCO_2$ measurements. The exercises require large water flow for underway systems for ship board use and a large seawater tank for autonomous buoy systems. In 2009, an inter-comparison experiment of $pCO_2$ measurement systems, including autonomous buoys, was conducted in Hasaki, Japan. Results of the Hasaki inter-comparison experiment and the usefulness of autonomous buoy systems in the future were discussed at this workshop.

The second half of the workshop was devoted to the SOCAT Equatorial Pacific, North Pacific, and Indian Ocean Regional Workshop. Updates were provided on the status of the regional and global SOCAT database, quality control, and Live-Access Server (LAS) tools and their application to SOCAT. In this SOCAT regional meeting, quality control and data integration of the existing data set was discussed.

## PRESENTATIONS

### *$pCO_2$ Buoy Symposium*

### Monday 8 February

**a. Shuichi Watanabe,** Japan Agency for Marine-Earth Science and Technology (JAMSTEC)

*"Development of autonomous $pCO_2$ buoy under JEPP"*

A number of researches have been carried out in the world ocean to understand the long-term climate change related with carbon dioxide trend in the atmosphere. However, these are not spatially and temporally sufficient to evaluate the transport of carbon dioxide between atmosphere and sea surface with high precision of 0.1 PgC. JAMSTEC developed a compact and handy autonomous $pCO_2$ measurement floating buoy (diameter 250-340 mm, length 470 mm, weight 15 kg) supported by Japan EOS Promotion Program (JEPP), the Ministry of Education, Culture, Sports, Science and Technology (MEXT). Precision and sensitivity of this system are less than 2 μatm and less than 1 μatm, respectively.

This autonomous $pCO_2$ buoy was tested in the equatorial Pacific, the east Labrador Sea, the eastern Indian sector of the Southern Ocean and others. The obtained values were similar to historical one obtained in the neighboring area. The variability is about 30 μatm. However, the variability would include diurnal and spatial changes.

**b. Yoshiyuki Nakano[1], Tetsuichi Fujiki[2] and Shuichi Watanabe[2]**
[1]Marine Technology Center, Japan Agency for Marine-Earth Science and Technology, 2-15 Natsushima, Yokosuka, 237-0061, Japan. E-mail: ynakano@jamstec.go.jp
[2]Mutsu Institute for Oceanography, Japan Agency for Marine-Earth Science and Technology, 690 Kitasekine, Sekine, Mutsu, 035-0022, Japan.

*"Discussion and follow-up after the Hasaki inter-comparison*
*$pCO_2$ buoy system improved after the Hasaki inter-comparison"*

To monitor the spatial and temporal variations of surface $pCO_2$ in the global ocean, new automated $pCO_2$ sensor which can be used in platform systems such as drifting buoys or moorings is strongly desired. We have been developing the compact drifting buoy system (diameter 250-340 mm, length 470 mm, weight 15 kg) for $pCO_2$ measurement. The measurement principle for the $pCO_2$ sensor is based on spectrophotometry. The $pCO_2$ is calculated from the optical absorbance of the pH indicator solution equilibrated with $CO_2$ in seawater through a gas permeable membrane.

In the Hasaki inter-comparison, the buoy system obtained a precision within 4 μatm and response time 4 hours. The reason for poor results was that our $pCO_2$ buoy had some problems at the Hasaki inter-comparison. Some components of buoy system are improved (pH indicator, pump, valves and light sauce) to increase the precision and accuracy, and to obtain faster response. To confirm the performance of buoy system, we prepared 10t pool and the same as underway system of National Institute for Environmental Studies (NIES) in Mutsu institute for oceanography (JAMSTEC). We can manage $pCO_2$ by hydrochloric acid and sodium hydroxide. In the Mutsu inter-comparison, the buoy system obtained a precision within 3 μatm and response time 3 minutes.

**c. Iwao Ueki,** Research Institute for Global Change, Japan Agency for Marine-Earth Science and Technology (JAMSTEC)

*"Introduction of TRITON mooring"*

As a part of the Tropical Atmosphere and Ocean (TAO) / Triangle Trans-Ocean Buoy Network (TRITON) array in the tropical Pacific and the Research Moored Array for African-Asian-Australian Monsoon Analysis and Prediction (RAMA), we are conducting two types of mooring named TRITON and m-TRITON buoy systems. The TRITON buoy system is a kind of taut-line mooring and has a relatively large surface buoy. On the other hand, the m-TRITON buoy system is adopted slack-line mooring method for the purpose of easy maintenance by smaller vessels, and has a relatively small surface buoy. Both buoy systems basically observe temperature and salinity at 12 levels in the upper ocean, ocean current at 10 m depth, and 6 meteorological variables near the ocean surface. The observed data are transmitted to laboratory on land via Argos satellite system within a day. In addition to basic valuables described above, both buoy systems allow us to install additional other sensors. Actually, the small floating buoy system for $pCO_2$ measurement, developed by JAMSTEC, has been installed on a TRITON buoy system moored at 2˚N 156˚E from July 2007. The TRITON buoy system has a potential to install additional other sensors, including chemical and biological sensor. For the real time data transmitting, our system can contribute after some arrangement. We are ready to discuss for using our buoy system as a kind of platform for installing the new sensors.

**d. Muhammad Ilyas[1], Agus Setiawan[2], Iwan E. Setiawan[1], Adi S. Riyadi[1], Mutiara R. Putri[3], Fitri Sucianti[3] and Agus Sudaryanto[1]**

[1]Technology Center for Marine Survey, Agency for the Assessment and Application of Technology (BPPT), Jakarta, Indonesia.
[2]Center for Environmental Technology, Agency for the Assessment and Application of Technology (BPPT), Jakarta, Indonesia.
[3] Program Study of Oceanography, Faculty of Earth Science and Technology, Bandung Institute of Technology, Indonesia.

*"Present Status for $pCO_2$ Measurement in Indonesia and Expectation to Autonomous Buoy"*

Indonesia is an archipelago state where positioned between two oceans, two continents and distributed along equator. About 70% of total area is covered by ocean, and as consequences interaction between ocean ecosystems and human activities are very intense. Pollution and global warming effects are part of national issue in marine sector where the government has paid attention. Currently, study of carbon budget in the ocean has been a matter of growing concern by Indonesian Government, including estimation of ocean $pCO_2$ using empirical approach, analysis of dissolved inorganic carbon (DIC) in laboratory as well as direct measurement with underway $pCO_2$ equipment. In the fiscal years of 2008 – 2012, Agency for the Assessment and Application of Technology have conducting study of ocean carbon with scope of research activities including water sampling for DIC analysis (2009-2012), estimating $pCO_2$ from SST & Chl-a data (2009), estimating ocean carbon biomass using Carbon-based Productivity Model (CbPM), developing marine biogeochemical model for Indonesia waters (2008-2012), direct measurement with underway $pCO_2$ equipment (2010-2012) and possible application of autonomous $pCO_2$ buoy by utilized Indonesian Tsunami Buoys.

As preliminary results, the calculation of net flux of $CO_2$ in the Indonesian waters has been conducted based on the algorithm of Zhu et al. (2009). Through this approach, the estimated net flux of $CO_2$ in Indonesian waters was around -0.3 Pg C/yr, which was comparable to those of subtropical Atlantic Ocean that serve as $CO_2$ sink area. However, this model still needs further improvement by collecting more $pCO_2$ data and developing algorithm that suitable for Indonesian waters. Furthermore, improvement should also be done since our results in ocean $pCO_2$ through analysis of DIC and alkalinity from collected water samples are still far from the accurate values. Based on the estimation of Net Primary Production (NPP) in the Indonesian waters, we found that the average value of NPP is about 600 mgC/$m^2$/day with the exchange of Carbon through biological pumping 1,27 Pg C/year. This result explained that high primary productivity in Indonesian waters may capable to highly absorb the $CO_2$ from atmosphere.

From this result it can be concluded that continues observation of ocean carbon in the Indonesia waters, including the advantage of autonomous $pCO_2$ buoy, is needed to obtain comprehensive data to improve the estimation of carbon budget in the whole Indonesian waters. However, since there is still large gap of data, information, knowledge, technology etc, an international cooperation is needed.

## *Inter-Comparison Discussion*

**Tuesday 9 February**

**a. Yukihiro Nojiri,** National Institute for Environmental Studies (NIES)

*"International ocean $pCO_2$ instrument inter-comparison using indoor seawater pool"*

Results of an international ocean $pCO_2$ instrument inter-comparison, including underway and autonomous buoy systems was held at National Research Institute of Fishery Engineering in Hasaki, Kamisu City, Ibaraki, Japan using the indoor seawater pool. The campaign was supported by $pCO_2$ buoy project by JAMSTEC/MEXT and $pCO_2$ data analysis project by NIES/MOE. Seven underway systems and seven buoy systems were gathered for the campaign.

List of underway systems

- NIES Tandem equ. + LICOR 7000 (A1 and A2) by Kimoto Electric Co.
- Down sized Tandem equ. + LICOR6262 (B) by Kimoto Electric Co.
- NOAA Serial shower equ. + LICOR 7000 (C1) by General Oceanic Co.
- NIO Serial shower equ. + LICOR 7000 (C2) by General Oceanic Co.
- NIWA Shower equ. + LICOR 6251 (D), laboratory made
- PML Beads equ. + LICOR 840 (E) by Dartcom Co.

List of buoy systems

- NIES Gore-Tex tube equ. + LICOR 840 (W1 and W2) by Kimoto Electric Co.
- NOAA Bubbling equ. + LICOR 820, NOAA/PMEL MAPCO₂ System
- Montana Univ. SAMI colorimetry with tube equ. (Z1 and Z2) by Sunburst Sensors Co.
- JAMSTEC Colorimetric detection with tube equ. (Y1 and Y2), laboratory made (equ.=equilibrator)

The pool has a nominal volume of 170 $m^3$ and is enable to be kept at a stable $pCO_2$ over night because of the small temperature change. The pool water was well circulated by submergible pumps. Main water line of 300 L/min flow rate was installed at the pool side and water is supplied for underway systems. Because the line water temperature was warmed by heat from the water line pump, underway $pCO_2$ result was critically corrected by the measured difference of line and pool waters. It was in between 0.04 to 0.06 degree C during the inter-comparison period.

Five overnight comparisons were run on Feb. 27, 28, Mar. 1, 2 and 3. First, second and third night runs were fixed $pCO_2$ comparison at 281, 437, and 357 ppm, respectively. In the fourth and fifth night runs, $pCO_2$ was abruptly changed at mid night by HCl or NaOH.

The result of inter-comparison was very successful and we confirmed well-designed NDIR $pCO_2$ systems would give very tight agreement for wide $pCO_2$ range even for underway and buoy application. Underway system agreement of three NIES, two NOAA/NIO and NIWA systems can be stated the range is generally within plus minus 0.5ppm in $xCO_2$ scale, and NIES and NOAA/MBARI buoys are generally within plus minus 1ppm compared with standard underway value. Colorimetric buoy has been improved and very stable operation for the whole comparison period was achieved for SAMI, however, situation of buoy $pCO_2$ system may be similar to the first international inter-comparison of $pCO_2$ system organized at Scripps Institute for Oceanography by in 1994, when some system worked stable but some not.

**b. Chris Sabine**, Pacific Marine Environmental Laboratory, National Oceanic and Atmospheric Administration (PMEL/NOAA)

*"MAPCO$_2$ system"*

The MAPCO$_2$ system used for this study was built at PMEL but was identical to systems now being built by Battelle that are commercially available to the community. The system was set up the first day and attached to the high $CO_2$ standard gas the way it is normally used in the field. Results from the first three days of the inter-comparison indicated that measurements were generally within 1 ppm of the underway systems. On the fourth day the system was switched to run on the low $CO_2$ standard gas. The measurements were close when the pool $CO_2$ was low, but when the pool water $CO_2$ was significantly higher than the calibration gas the $MAPCO_2$ readings were as much as 3 ppm low. This is not the recommended configuration for the $MAPCO_2$ system, but illustrated the problems with extrapolating measurements beyond the high standard calibration gas.

**c. Chris Sabine,** Pacific Marine Environmental Laboratory, National Oceanic and Atmospheric Administration (PMEL/NOAA)**; Craig Neill,** Commonwealth Scientific and Research Organization (CSIRO)**; VVVS Sarma,** National Institute of Oceanography (NIO)

*"General Oceanics (GO) Underway Systems"*

The two General Oceanics (GO) underway systems gave values that were very consistent with the NIES underway systems. One observation with these systems is that the LiCor-7000 NDIR systems do not correct for dilution by water vapour in their readouts. Even though these systems mostly dry the air before measurement, a small water vapour correction is needed to get the correct values.

List of underway systems

- NIES Tandem equ. + LICOR 7000 (A1 and A2) by Kimoto Electric Co.
  Down sized Tandem equ. + LICOR6262 (B) by Kimoto Electric Co.
- NOAA Serial shower equ. + LICOR 7000 (C1) by General Oceanic Co.
- NIO Serial shower equ. + LICOR 7000 (C2) by General Oceanic Co.
- NIWA Shower equ. + LICOR 6251 (D), laboratory made
- PML Beads equ. + LICOR 840 (E) by Dartcom Co.

**d. Kim Currie,** National Institute of Water and Atmospheric Research (NIWA)

*"$pCO_2$ Intercomparison, Japan, February – March 2009"*

The NIWA $pCO_2$ system is a shower head / bubble type equilibrator, with infra-red measurement of the equilibrated gas phase by a LiCor 6251 gas analyser. A LabView programme is used for data logging, control of the calibration and other measurement parameters is manual.

The system was designed and built at NIWA, for use on a small boat on voyages typically less than 12 hours duration. The system can be set up and dismantled very quickly, and the user can choose calibration timing based on the particular needs of the voyage. The system has also successfully been used on longer open-ocean type cruises. Other requirements were that it be constructed and maintained by non-skilled personnel, and on a limited budget.

The system has participated in other intercomparison experiments, and various improvements have been implemented. The most recent modification is automation of the calibration procedure.

The system is primarily used for a time series project. The Munida time series is a surface transect in the south-west Pacific Ocean, extending from the New Zealand coast to subantarctic surface waters. $pCO_2$, and other supporting parameters have been measured along the transect every 2 months since 1998, allowing seasonal, interannual, and long-term variations to be determined (Currie, K.I., Reid, M.R., Hunter, K.A., 2009. Interannual variability of carbon dioxide drawdown by subantarctic surface water near New Zealand. Biogeochemistry doi:10.1007/s10533-009-9355-3.).

**e. Chihiro Miyazaki, Shin-ichiro Nakaoka, and Yukihiro Nojiri,** National Institute for Environmental Studies (NIES)

*"Underway $pCO_2$ measurement of NIES: the composition, QA/QC and recent findings"*

NIES Ocean $pCO_2$ measurement of VOS has been performed by the three VOS (Skaugran, Alligator Hope and now Pyxis) over the Northern Pacific since March 1995 and by another ship (Trans Future 5) over the Western Pacific since June 2006. The sequence of NIES oceanic $pCO_2$ observation system is followed as below; 1) SST measurement using two Pt-100 thermometers is performed at the fore-location of the water pump to avoid heating. 2) Salinity is measured using 2 thermosalinographs made by Seabird Electronics (SBE). 3) The $pCO_2$ mole fraction of sea water equilibrated air is measured every 10-second by a Tandem-type gas-liquid equilibrator, with the calibration using 5 standard gases (0ppm, 260ppm, 330ppm, 390ppm and 450ppm) twice a day. 4) The water temperature in the equilibrator (EqT) is also observed by a Pt-100 sensor. 5) To check the performance of NDIR measurement quickly, pH sensor and Chlorophyll fluorescence sensor are installed. 6) Atmospheric $pCO_2$ is also observed by an independent $pCO_2$ system installed in the atmospheric observation room. Hence we can calculate delta $pCO_2$.

For the accuracy of water temperature measurement, the SBE thermometers in our system are calibrated by the manufacturer once per a couple of years. Their departures from the manufacturer standard temperature are generally within 0.002 degree C. Using these fairly accurate SBE thermometers, we check and calibrate Pt-100 thermometers for SST and EqT once per 6 months and result in the uncertainty generally within 0.02 degree C.

For the accuracy of $pCO_2$ system, Murphy et al. (2001) showed that Tandem-type Equilibrator was faster response and more stable compared with Shower-type Equilibrator. During Alligator Hope era, we installed double $pCO_2$ systems on board and get averaged difference of the two systems generally less than 1 ppm. The present logging interval of the $pCO_2$ system with tandem-type equilibrator is 10-second.

Our QA/QC process of VOS measurement data are summarized briefly as below; 1) 3 automatically sampled parameters are calibrated using the manually sampled data; Ambient pressure are calibrated based on the reading value from meteorological agency calibrated barometer by the seaman. On salinity, the data of SBE are calibrated against daily sampled bottle salinity. Calibration of Pt-100 thermometers for SST and EqT as above mentioned. 2) The every 10-second values of $xCO_2$, $pCO_2$

and $fCO_2$ are calculated with the warming correction of Weiss et al. (1982). 3) Finally, average and standard deviation of 60 data within 10 minutes are calculated. 4) On salinity, air bubble contamination occurred in the case of bad weather is flagged.

Our frequent observation over the North Pacific has clarified its intimate seasonal variation of $\Delta pCO_2$; the winter source and summer sink over its northwestern part, whereas the winter sink and summer source over the central and eastern part. Furthermore, its observation for more than 15 years has suggested long-term trend of oceanic $pCO_2$. It should be especially noted that lower value of the oceanic $pCO_2$ trend than 1.0 μatm/yr was seen in the part of western Pacific over the mid-latitude (40˚-45˚N). This result indicates the amount of oceanic $CO_2$ uptake in this area was expected to increase from year to year.

$CO_2$ observation data over the western Pacific for more than 3 years also showed some interesting results. Two climatological distributions are prominent; the summer source and other seasons' sink over the Kuroshio region, and the all-year strong sink over Tasman Sea. Over the western equatorial Pacific, the variation of ocean $pCO_2$ is strongly influenced by ENSO; the very large $\Delta pCO_2$ (>40μatm) in the spring of 2008 was caused by cold and saline water transported from the eastern equatorial Pacific at the end of La Nina.

## *SOCAT Equatorial Pacific Regional Workshop*

**Wednesday 10 February 2010**

a. **Benjamin Pfeil,** University of Bergen, Norway

*"Present status of SOCAT"*

SOCAT is based on a surface $fCO_2$ database developed at the Bjerknes Centre for Climate Research (Bergen, Norway). The historical development of SOCAT, including goals and the outcome of previous SOCAT related meetings, was presented. The current database holds data from data centers (CDIAC, WDC-MARE), project and institute webpages. SOCAT version 1.3 holds data between the years 1968-2007 with approx. 7 million surface $CO_2$ measurements divided over 2150 cruises. All input data has been re-calculated to the same standards, metadata was standardized and essential missing variables were added from global data collections (WOA 2005, NCEP-NCAR). In late 2009 the SOCAT cookbook was released- it gives involved scientists a guideline on how to quality control and flag data. In late 2009 a dedicated SOCAT was established which gives access to all scripts used for recalculations, the SOCAT cookbook and reports. The homepage can be accessed under http://www.socat.info.

**b. Jeremy Malczyk,** Pacific Marine Environmental Laboratory, National Oceanic and Atmospheric Administration (NOAA/PMEL)

*“Overview of LAS”*

A short tutorial was given on how to use the SOCAT Live Access Server tools for quality control on the SOCAT web site. The purpose of the SOCAT site is to provide a centralized repository for SOCAT data files, visualization / analysis tools for the scientists involved, and a logging system to collaboratively quality control the data. Access to the SOCAT site is currently restricted to contributing members, with the goal of fully open access when 2$^{nd}$ order quality control is completed and the complete dataset is published. The site consists of three main parts:

1. A version control that stores the data files, metadata files, and auxiliary QC documents.
2. A mySQL database that allows dynamic queries to be made of the dataset.
3. A Live Access Server with a user interface customized for SOCAT
   Key features of this server are:
   - Interactive maps of all parameters in the dataset
   - Tools to constrain the data by latitude, longitude, time, region, quality control flag, cruise ID, ship, season, and parameter value ranges.
   - Interactive property / property plots with cruise ID symbols to help identify outliers.
   - Property / property “filmstrips” that divide a property/property plot into year, month, or seasonal subset plots.
   - A sort-able table of cruise metadata
   - A metadata editing interface
   - A table of quality control entries (flags and comments)
   - An audit tracking table to view all past QC entered on a cruise or group of cruises.

**c. Chris Sabine,** Pacific Marine Environmental Laboratory, National Oceanic and Atmospheric Administration (PMEL/NOAA)

*“Equatorial Pacific Synthesis”*

The scientific lead for the evaluation of the Equatorial Pacific SOCAT data is Dick Feely and the actual evaluations were performed by Cathy Cosca (NOAA/PMEL), but since neither could attend the workshop, Chris Sabine presented their work.

Sabine reminded the group that the data base was frozen at version 1.3 last year so that the QC groups do not have a moving target for their analyses. While Benjamin has done an amazing job of cleaning up the data in this version, it was apparent in the Pacific data that there are still some first order quality problems with the data. We found that these fliers and problems were easily identified with a series of property-property plots. Jeremy has now implemented a procedure in LAS to make these standard plots. For example, in the Equatorial Pacific there were 71 out of 394 cruises that had some noted problems. A few of these were serious problems like duplicate files, very noisy data, or problems with time or location. By far most of the files noted to have just a few random fliers.

After reviewing the problems with the Equatorial Pacific data set, there was a group discussion on how the SOCAT groups should proceed from here. The participants of the meeting agreed:

1) All groups should go through each cruise file in their region to check for fliers or unusual results as soon as possible. You can either use the LAS tools to do this or download the zip files and make the plots on your own. Inform Benjamin with the details of any problems as soon as possible.

2) Files with 10 fliers or less should have the individual records flagged as bad before proceeding with the 2nd order QC.

3) Files with more than 10 fliers or other significant problems will be marked as suspended (be sure Benjamin knows which files you are suspending and why).

4) Proceed with 2nd level QC of non-suspended files following the QC cookbook.

5) Benjamin will examine all of the files noted to have problems from step (1) and determine if he is able to fix the problems. If he cannot fix the problems he will contact the PI for that cruise to see if they are willing to provide a cleaned up file.

6) Benjamin will fix problem files in his database (not SOCAT v1.3 on LAS), but will not add any additional cruises compared to version 1.3. This will be done in parallel with the QC efforts of the regional groups.

7) Since we expect the problem files that Benjamin can fix will only be a handful for each region, Benjamin will communicate with those regional groups about QCing the fixed files by hand.

8) Once the QC process is completed, Benjamin will take the flags determined from SOCAT v1.3 and add them to his database with all of the fixed cruise files. This new flagged database will then be posted as SOCAT version 1.4. The files that were suspended and Benjamin could not fix them will not be included in this SOCAT version but if they are fixed later could be included in later SOCAT versions. All of the included cruises should be properly flagged at this point, but the regional groups will have an opportunity to quickly check and confirm the flags before public release.

The Pacific and Indian Ocean groups at the meeting agreed to this procedure and committed to completing their 2nd level QC in time for the Hobart SOCAT meeting in June. Hopefully the Southern Ocean and Atlantic groups will also agree to have their QC work done in time for the Hobart meeting.

**d. Kim Currie,** National Institute of Water and Atmospheric Research (NIWA)

The NIWA data falls in the Southern Ocean Region. The data will not be included in the current version of SOCAT, but will be incorporated into the next revision.

**e. Yoshiyuki Nakano and Akihiko Murata**, Japan Agency for Marine-Earth Science and Technology (JAMSTEC)

*"Atmospheric and surface seawater $pCO_2$ measurements by the R/V Mirai and the data site in JAMSTEC"*

Continuous measurements of atmospheric and surface seawater $pCO_2$ conducted by the R/V *Mirai* of JAMSTEC were introduced. In addition, the data site of JAMSTEC (http://www.jamstec.go.jp/e/index.html), where data obtained by ships belonging to JAMSTEC are collected and opened to public, was introduced. Participants of the workshop tried to use the data search system in the data site.

**f. Masao Ishii,** Geochemical Research Department, Meteorological Research Institute, Japan Meteorological Agency (MRI)

*"Measurements of $pCO_2$ in the western equatorial Pacific by MRI and JMA"*

Geochemical Research Department of MRI has made underway measurements of $pCO_2$ during 55 cruises since 1968 mainly in the North Pacific and in the equatorial Pacific, and in several cruises in the South Pacific and in the Australian sector of the Southern Ocean. Global Environment and Marine Department of JMA has also started $pCO_2$ measurements in 1989 and collected data from 128 cruises until April 2008 mainly in the western North Pacific including those on the repeat lines along 137ºE and 165ºE.

Underway measurements of $pCO_2sw$ in near-surface water has been made using shipboard pumping systems that continuously pumped seawater from the ship's sea chest and gas equilibration methods with shower-head type equilibrators equipped with a non-dispersive infrared gas analyzer (Inoue, 2000). The system uses four $CO_2$-in-air reference gases that have undergone pre- and post-cruise calibration against standards traceable to the primary standards of the World Meteorological Organization. Comparability of data obtained by this system with those obtained by other systems has been examined during an intercomparison exercise made in the North Atlantic on board the RV Meteor (Köertzinger et al., 1999).

For the narrow equatorial band (5ºS- 5ºN), we have provided $pCO_2$ data from 117 cruises including those of JMA's R/V Ryofu Maru and R/V Keifu Maru, the University of Tokyo's R/V Hakuho Maru, JAMSTEC's R/V Natsushima, R/V Kaiyo and R/V Mirai and so on after the year 1968 (mostly after 1983) and have been contributing to understand its decadal as well as interannual variability mainly to the west of 160ºW (e.g., Ishii et al., 2009).

All data of $xCO_2$ in dry, $pCO_2$ in wet at SST and ancillary data are available from WDCGG (http://gaw.kishou.go.jp/cgi-bin/wdcgg/catalogue.cgi).

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Ishii, M., Inoue, H.Y., Midorikawa, T., Saito, S., Tokieda, T., Sasano, D., Nakadate, A., Nemoto, K., Metzl, N., Wong, C. S., Feely, R. A., 2009. Spatial variability and decadal trend of the oceanic $CO_2$ in the western equatorial Pacific warm/fresh water. Deep-Sea Res. II, 56, 591-606.

Körtzinger, A., Mintrop, L., Duinker, J. C., 1999. The international intercomparison exercise of underway $fCO_2$ systems during the R/V *Meteor* cruise 36/1 in the North Atlantic Ocean. Environmental Science Division Publication No.4844, NDP-067, Carbon Dioxide Information Analysis Center, Oak Ridge National Laboratory, U.S. Department of Energy, Oak Ridge, Tenn.

**g. Toru Suzuki,** Marine Information Research Center (MIRC), **Nobuo Tsurushima** National Institute Advanced Industrial Science and Technology (AIST)

*"Surface Ocean $pCO_2$ Data and Statistics in the Pacific Ocean"*

Surface ocean and atmospheric $pCO_2$ data in the Pacific ocean from volunteer observing ship (VOS) program were collected in order to verify a measurement of new autonomous $pCO_2$ buoy developed by Japan Agency for Marine-Earth Science and Technology (JAMSTEC) under Japan EOS Promotion Plan (JEPP). Over 1.4 million data from National Institute for Environmental Studies (NIES), JAMSTEC, World Data Center for Greenhouse Gases (WDCGG) and Carbon Dioxide Information Analysis Center (CDIAC) were merged to Ocean Data View (ODV) collection file. In addition, Northwest Pacific Carbon Cycle Study (NOPACCS), Western Pacific Environmental Assessment Study on $CO_2$ Ocean Sequestration for Mitigation of Climate Change (WEST-COSMIC) and Kyodo Northwestern Pacific Ocean Time Series (KNOT) projects which are not opened in previous were also included. Annual, monthly and seasonal statistics were calculated in 1 and 5 degree square for $pCO_2$ of sea water and atmosphere, mean sea surface temperature normalized $pCO_2$ of sea water and $\Delta pCO_2$. Linear regression is also calculated as a function of year, sea surface temperature and salinity, latitude and longitude. All statistics and the related figures in each square are referred using the Web browser.

**h. Chihiro Miyazaki, Shin-ichiro Nakaoka, and Yukihiro Nojiri,** National Institute for Environmental Studies (NIES)

*"Oceanic $CO_2$ data over the Equatorial Pacific observed by NIES"*

NIES has observed the oceanic $CO_2$ by some VOS ships over the Equatorial Pacific (from 30N to 30S). Among the northern Pacific-transect cruises, some data of two ships are available; 3 cruises of M/S Skaugran (SK) in 1998, and 55 cruises of M/S Pyxis (PX) that have the shipping route between Japan and east coast of the US via

Panama Canal from 2002 to 2008. Over the western Pacific from Japan to Oceania, we can offer the data by other two ships; 12 cruises of M/S Golden Wattle (GW) from 2001 to 2002, and 28 cruises of M/S Trans Future 5 (TF5) from 2006 to 2008. On the ongoing ships, we can obtain oceanic $CO_2$ data in 10-14 cruises of PX and 16 cruises of TF5, respectively per year.

The data of these 4 ships have been provided from VOS data site of CDIAC. The details of observation on each ship (except for TF5; available since Apr 2010) have been released at NIES Ship of Opportunity site (http://soop.jp).

i. **Maciej Telszewski,** National Institute for Environmental Studies (NIES)

*"Air-sea $CO_2$ flux in the North Atlantic and the North Pacific estimated by neural network"*

Accurate estimates of the air-sea exchange of $CO_2$ are necessary in order to constrain the partitioning of $CO_2$ emitted by human activities between the atmosphere, land and the oceans. Here we present basin scale neural network estimates of seasonal and interannual variability of the sea surface $pCO_2$ distribution, and calculated air-sea flux in the North Atlantic for 2004 to 2006.

Underway measurements of the $pCO_2$ in surface water were collected throughout the North Atlantic as part of an observational network run by the EU-funded and US-funded projects. These measurements offer a coverage which allows for the regional analyses of the highly variable spatial and temporal distribution of $pCO_2$. Most authors suggest that the strength of the North Atlantic sink has decreased over the last decade, with the decline especially significant (up to 50%) in the northern part of the basin. This change indicates that an increasing fraction of the anthropogenic emissions remains in the atmosphere, which is consistent with recent modeling results.

Between June 2004 and October 2006, 137 000 data points were collected through this effort, and used in this study. To produce basin-wide and year-round maps, these data are used to label the outcome of the Self Organizing Map neural network (SOM), trained with commonly used hydrographic and ancillary parameters. The overall root mean-squared error of the data fit equals 9.8 µatm. The mean annual cycle of surface ocean $pCO_2$ estimated by the neural network in main biogeochemical provinces of the North Atlantic agrees well with in-situ measurements and climatology (Telszewski et al., 2009).

A suite of environmental variables is used in conjunction with the $pCO_2$ maps to calculate the air-sea flux. Atmospheric mixing ratios of $CO_2$ were taken from monthly mean values for latitudinal bands for 2004 to 2006 (Globalview-$CO_2$, 2009), monthly mean values of sea surface temperature, atmospheric pressure at sea level and wind speed for 2004 to 2006 were taken from the NCEP/NCAR reanalysis, wind speed was calculated from the NCEP-NCAR reanalysis u-wind and v-wind at 10 m height and the wind speed dependence of the gas transfer velocity by Nightingale et al. (2000) was used.

Finally, 36 monthly basin-wide flux maps were computed and are used to estimate the seasonal cycle, annual amplitude and interannual variability of the North Atlantic Ocean as a net sink for atmospheric $CO_2$.

Development of this method should allow future near-real time monitoring of the sea to air flux of $CO_2$ at the global scale by assimilating VOS measurements, satellite data and the self-organizing neural network.

**Thursday 11 February**

**j. Alex Kozyr,** Carbon Dioxide Information Analysis Center (CDIAC)

*"Update on CDIAC Ocean Data"*

In 2009, CDIAC implemented the new Mercury metadata system to standardize and inventory CDIAC's ocean data holdings. The Mercury has completely new interface, more dynamic and more easy to use system. The Mercury metadata system was developed by staff in ORNL's Computational Physics and Engineering Division. This catalog of CDIAC ocean holdings may be queried at http://mercury.ornl.gov/ocean/.

In 2009, CDIAC updated the Web-Accessible Visualization and Extraction System (WAVES). This data interface permits users to search CDIAC GLODAP and CARINA discrete data and LDEO Database underway data and couples all standardized metadata from the Mercury system to each individual data set. The interface is available at http://cdiac3.ornl.gov/waves/discrete/ for discrete data search and at http://cdiac3.ornl.gov/waves/underway/ for underway data search.

**k. V.V.V.S. Sarma,** National Institute of Oceanography (NIO)

*"Summary of the SOCAT Indian Ocean quality control"*

We have downloaded the entire Indian Ocean $pCO_2$ data from SOCAT website and checked for quality control for individual files. In the Indian Ocean, there is only seasonal data available and it is quite sparse with reference to space. Most of the data were collected after 1990s and mostly it is of high quality and followed SOP. There are 72 cruises took place in the Indian Ocean in which $pCO_2$ data were collected in 67 cruises and 407,592 data pointed were available. Out of 67 cruises, 15 cruises took place in 1995 and 11 in 1999 whereas 6-7 cruises in 1991-1993. During other years, mostly once or twice in a year data were collected. In total 67 cruises, no salinity data available 5 cruises, no equilibrator pressure data available in 7 cruises. It was observed that several files contained bad data points such as very high spikes. We have also observed that what kind of data in each file available and missing parameters. Such data were observed not only in the older data but also WOCE data as well. All these fliers were identified and excel sheet of these details are being made.

## SUMMARY AND RECOMMENDATIONS

Following the presentations, the participants worked on practical exercises with cruise data and 2nd level quality control, including downloading the data files, provisional flagging, and identification of possible crossovers. They were presented with the flagging techniques finalized at the Norwich, UK meeting (see http://www.socat.info/front_content.php?idcat=492 and http://www.ioccp.org/Workshops.html for details)

Good progress has been made on the QC analyses, but more work is needed in order to meet the goal of completing the QC and releasing the first SOCAT product by the summer for inclusion in the IPCC AR5. For example, there are still some first order quality problems with the data. The participants found that these fliers and problems were easily identified with a series of property-property plots. Malczyk has now implemented a procedure in LAS to make these standard plots. For example, in the Equatorial Pacific there were 71 out of 394 cruises that had some noted problems. A few of these were serious problems like duplicate files, very noisy data, or problems with time or location. By far most of the files noted to have just a few random fliers.

The following recommendations were proposed by the participants:

1) All groups should go through each cruise file in their region to check for fliers or unusual results as soon as possible using LAS tools or downloading the zip files and to create the plots and inform Pfeil with the details of any problems as soon as possible.

2) Files with 10 fliers or less should have the individual records flagged as bad before proceeding with the 2nd order QC.

3) Files with more than 10 fliers or other significant problems should be marked as suspended (be sure Pfeil knows which files are being suspended and the reason).

4) Proceed with 2nd level QC of non-suspended files following the QC cookbook (http://www.socat.info/front_content.php?idcat=492).

5) Pfeil will examine all of the files noted to have problems from step (1) and determine if he is able to fix the problems. If he cannot fix the problems, he will contact the responsible PI to see if they are willing to provide a cleaned up file.

6) Pfeil will fix problem files in his database (not SOCAT v1.3 on LAS), but will not add any additional cruises compared to version 1.3. This will be done in parallel with the QC efforts of the regional groups.

7) Since there will likely be only a limited number of problem files for each region that Pfeil can fix, he will communicate with those regional groups about QCing the fixed files by hand.

8) Once the QC process is completed, Pfeil will take the flags determined from SOCAT v1.3 and add them to his database with all of the fixed cruise files. This new flagged database will then be posted as SOCAT version 1.4. The files that were suspended and Pfeil could not fix will not be included in this SOCAT version but could be included in later SOCAT versions. All of the included cruises should be properly flagged at this point, but the regional groups will have an opportunity to quickly check and confirm the flags before public release.

The Pacific and Indian Ocean groups have agreed to this procedure and have committed to completing their 2nd level QC in time for the Hobart SOCAT meeting in June. Hopefully, the Southern Ocean and Atlantic groups will also agree to have their QC work done in time for the Hobart meeting.

# ANNEXES

## ANNEX 1

## PARTICIPANTS

Kim Currie (NIWA, New Zealand)
Makio Honda (JAMSTEC, Japan)
Muhammad Ilyas (BPPT, Indonesia)
Masao Ishii (MRI, Japan)
Alexander Kozyr (CDIAC, USA)
Jeremy Malczyk (NOAA/PMEL, USA)
Chihiro Miyazaki (NIES, Japan)
Yoshiyuki Nakano (JAMSTEC, Japan)
Shin-ichiro Nakaoka (NIES, Japan)
Craig Neill (CSIRO, Australia)
Yukihiro Nojiri (NIES, Japan)
Benjamin Pfeil (Univ.Bergen, Norway)
Chris Sabine (NOAA/PMEL, USA)
VVSS Sarma (NIO, India)
Yoshikazu Sasai (JAMSTEC, Japan)
Agus Sudaryanto (BPPT, Indonesia)
Hiroyuki Sugimoto (JMA, Japan)
Toru Suzuki (MIRC, Japan)
Kathy Tedesco (IOCCP, France)
Maciej Telszewski (NIES, Japan)
Iwao Ueki (JAMSTEC, Japan)
Shuichi Watanabe (JAMSTEC, Japan)
Yasushi Yoshikawa (JAMSTEC, Japan)

## ANNEX II

## AGENDA

| **DAY 1** | **Monday 8 February** |
|---|---|
| Morning | **9:45-10:00**<br>Opening of $PCO_2$ Buoy Symposium – Nojiri (NIES)<br><br>Self introduction of the participants<br><br>**10:00-12:30**<br>S. Watanabe (JAMSTEC) - Development of autonomous $pCO_2$ buoy under JEPP |
| Afternoon | **14:00-16:00**<br>Discussion and follow-up after the Hasaki inter-comparison<br><br>Y. Nakano, Fujiki, Watanabe (JAMSTEC) – $pCO_2$ buoy system improvements following the Hasaki inter-comparison<br><br>I. Ueki (JAMSTEC) - Introduction of TRITON mooring<br><br>**16:00-16:30**<br>M. Ilyas (BPPT ) – Status of $pCO_2$ measurements in Indonesia and update on autonomous buoy<br><br>**16:30- 17:00**<br>Wrap-up of $pCO_2$ Buoy Symposium |
| **DAY 2** | **Tuesday 9 February** |
| Morning | Intercomparison Discussion<br><br>**9:30-10:30**<br>Y. Nojiri (NIES)- Detail for the Hasaki inter-comparison experiment, 2003 and 2009<br><br>**10:30-12:30**<br>C. Sabine (NOAA) – NOAA buoy system<br>C. Sabine (NOAA), C. Neil (CSIRO) and VVVS Sarma (NIO) – NOAA/NIO underway system<br>K. Curry (NIWA) – NIWA underway system<br><br>Discussion |

| | |
|---|---|
| Afternoon | **14:00-16:00**<br>Continuation of inter-comparison discussion and wrap-up including publication of results<br><br>**16:00-16:30**<br>C. Miyazaki (NIES) – Data Management of NIES $pCO_2$ observation by VOS |
| **DAY 3** | **Wednesday 10 February 2010** |
| Morning | SOCAT WORKSHOP<br><br>**9:30-10:30**<br>B. Pfeil (U. Bergen) – Present status of SOCAT database<br><br>**10:30-11:00**<br>J. Malczyk (NOAA) – LAS server and its SOCAT application<br><br>**11:00-12:30**<br>Hands on training |
| Afternoon | EQUATORIAL DATA IN SOCAT<br><br>**14:00-16:30**<br>C. Sabine (NOAA)<br>K. Curry (NIWA)<br>Y. Nakano (JAMSTEC)<br>M. Ishii (MRI/JMA)<br>T. Suzuki (MIRC), N. Tsurushima (AIST)<br>C. Miyazaki (NIES)<br><br>**16:30-17:00**<br>M. Telszewski (NIES) – Neural network analysis of Atlantic and Pacific $pCO_2$ data sets |
| **DAY 4** | **Thursday 11 February 2010** |
| Morning | **9:30-12:30**<br>A. Koxyr (CDIAC) – Present status of SOCAT in CDIAC<br>VVVS Sarma (NIO) – Plan for SOCAT in the Indian Ocean |
| Afternoon | **14:00-16:30**<br>Discussion – Improvement of Equatorial Pacific SOCAT database and contribution to global SOCAT<br><br>Wrap up |
| **DAY 5** | **Friday 12 February** |
| | Committee meeting (Japanese members for JAMSTEC Buoy Project) |