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Southern and Indian Ocean Surface Ocean CO_2 Atlas (SOCAT) Workshop

CSIRO Marine Laboratories, Hobart, Tasmania
16-18 June 2010

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1. BACKGROUND

The Southern and Indian Ocean SOCAT workshop was held at the CSIRO Marine laboratories in Hobart, Australia, 16-18 June 2010. The workshop was chaired by Bronte Tilbrook (CSIRO) and Nicolas Metzl (LOCEAN/IPSL) and attended by 17 participants from 8 countries. The first day of the meeting consisted of presentations on the progress of the quality control of the regional SOCAT data and discussion of issues encountered during the quality control process. The second day of the meeting was on synthesis efforts using the SOCAT database, followed by an overview of the Regional Carbon Cycle Assessment Project (RECCAP). The final day was devoted to the future observing system and plans for SOCAT.

The quality control (QC) of SOCAT data was discussed at a June 2009 SOCAT meeting (http://ioc3.unesco.org/ioccp/FinalRpts/WR222_eo.pdf), held at the University of East Anglia, UK. The meeting focussed on the Atlantic and Southern Ocean basins and developed guidelines for QC procedures. The guidelines were written by Are Olsen and Nicolas Metzl: (http://www.socat.info/upload/Images_Header/SOCAT_QC_Cookbook_v2.doc).

The Southern Ocean was defined as the region south of 30°S with sub-regions for the Pacific, Indian and Atlantic sectors. SOCAT panel members were identified to take responsibility for completion of data QC for each sector:

Indian sector (10°E-120°E)	Metzl
Pacific sector (120°E-70°W)	Tilbrook
Atlantic sector (70°W-10°E)	Bakker, Hoppema

A meeting of the Southern and Indian Ocean panels was required to resolve issues related to QC procedures, and to work towards completion of the data QC and the release of these data. The meeting was planned for 16-18 June 2010 in Hobart, Australia with sponsorship from IOCCP, SOLAS/IMBER and CSIRO. Additional participants were funded by their own agencies. The list of participants and the meeting agenda are provided in Section 10.

2. SOCAT MEETING OBJECTIVES

1) Assess and resolve issues related to completion of the QC of the SOCAT database for the Southern (> 30°S) and Indian Oceans.

2) Determine timelines for completing the database QC and public release of the SOCAT data set, version 1.4.

3) Consider plans to use SOCAT to investigate regional and temporal (seasonal to decadal) variability of the air-sea CO_2 fluxes for the region, and initiate discussions on scientific papers and authors for these topics.

4) Discuss involvement of the meeting participants in the Regional Carbon Cycle Assessment Project (http://www.globalcarbonproject.org/activities/RECCAP.htm).

5) Consider plans for future observations in the Southern and Indian Ocean regions.

3. PROGRESS AND DATA QUALITY DISCUSSION (DAY 1)

3.1 Regional SOCAT QC progress

Benjamin Pfeil (Bjerknes Centre) provided a summary of the status of the SOCAT database based on work carried out by himself and colleagues Jeremy Malczyk and Steve Hankin (NOAA-PMEL).

The SOCAT database has been frozen as version 1.3 since May 2009. Many files had obvious problems with parameters like latitude, longitude, or incorrect assignments (e.g. wind speed incorrectly stored as wind direction). The problems in many cases have been rectified, although the updated data files are not yet available in version 1.3. A more streamlined workflow was proposed based on the experiences of all basin panels. From July 2010, version 1.3 of the data will be updated once a month and will include corrections made by PIs to their data sets and metadata files. The database will translate to version 1.4 once the QC procedures are complete and agreed. Prior to the transfer to version 1.4, data can be updated if (1) the PI wants to update their existing data, and (2) the QC procedure indicates problems with the data that can be resolved through discussions with the PI. The cruise flag for all updated cruises will be reset to 'U' (see Section 3.2.6). These cruises will only be included in the public release (SOCAT version 1.4) if they have been fully quality controlled by completion date for SOCAT QC.

For each set of cruise data, a cruise flag is assigned that indicates the overall quality of metadata and individual data files. The cruise flag is internal for SOCAT and will not be included in the public release of the database. It is aimed at helping data PIs and panel members identify where more information may be required. The use of the cruise flags has been not been consistent and a discussion on this topic was planned for later in the day (see section 3.2).

The talk also included examples of very useful data visualisation features available through the LAS Web site that can be used to QC data.

A series of talks followed on the progress on SOCAT data QC for various regions. Some comments were made by several speakers, but will be reported only once.

Tropical Pacific (30°S to 30°N):

Chris Sabine (NOAA-PMEL) thanked Cathy Cosca (NOAA-PMEL) for her efforts in QC of the tropical Pacific data set. A total of 71 out of 394 files were found to have problems such as duplicate files, missing fCO_2 data, incorrect date fields, no metadata, or links to metadata not working. For an individual cruise file, outliers like incorrect SST and large changes in longitude were obvious. Unrealistic salinity values from the World Ocean Atlas were also at times assigned where underway salinity measurements were not available. A lack of underway salinity data was more common on earlier cruises. The low sensitivity of the fCO_2 calculation to salinity made this a secondary issue. Some cruises also had multiple fCO_2 for the same date/time stamp, with XCO_2 data left out of some of the datasets (e.g. Columbus Waikato cruises). Flags will be assigned once the correct data files are updated on the Live Access Server (LAS). Despite the issues encountered during the QC process, data QC of the tropical Pacific region is expected to be completed by late August 2010.

Indian Ocean (North of 30°S):

VVSS Sarma (NIO) discussed the results from a total of 67 CO_2 cruise data sets in the Indian Ocean. Salinity data are missing in 5 of these cruises, xCO_2 in 40 cruises, and equilibrator pressure in 7 cruises. There are 76 problematic points, which represent 0.02% of the Indian Ocean dataset. The files that don't have reported equilibrator pressure have no assigned cruise flag at present. The Indian Ocean data QC should be complete by the end of August 2010.

Southern Ocean, Indian sector (10°E to 120°E):

Anna Lourantou (LOCEAN/IPSL) carried out the QC processing for the sector. She completed the QC offline and has prepared a report on the process to allow more space for comment than can be inserted in the LAS. Her talk provided a careful consideration of how to assign cruise flags and the need for a consistent application of the flags across all sectors. A number of apparent outliers were usually found close to the coast of Antarctica or Australia. The sector data had 6 cruises having crossover data, which is high compared to the Atlantic and Pacific sectors. The QC process for the Indian sector of the Southern Ocean will be finalised by the late September 2010.

Southern Ocean, Pacific sector (120°E to 70°W):

Bronte Tilbrook (CSIRO) provided a summary of the progress on the Pacific sector QC. Common issues across all sectors are that data is not properly sorted, metadata content is sometimes not accessible or not provided, and there remains uncertainty in how to assign cruise and data quality flags. A number of issues were described that need resolution including how much warming is acceptable, and what flags should be applied to data sets where equilibrator temperatures or seawater temperatures have been estimated assuming constant or empirically-derived warming.

Southern Ocean, Atlantic sector (70°W to 10°E):

Mario Hoppema (AWI) and Dorothee Bakker (UEA) discussed the Atlantic sector data. No crossovers were found in the region. Examples were shown of problems with seawater and equilibrator temperature sensors on several cruises, while Polarstern and other data were found to be incorrectly sorted on the LAS. The Matlab routines available on the SOCAT web site for offline QC of data were found to need updating. Metadata were looked at and comments were added on the LAS, often with considerable difficulty. The difficulty of adding comments about data quality was mentioned a number of times by different speakers and is being fixed. The QC process has progressed well will be completed by the end of September 2010.

3.2 Issues related to QC and release of the SOCAT database:

This section describes issues encountered during the QC process and the recommendations of the meeting participants.

3.2.1 Finalising the SOCAT database

An October 1 deadline was agreed for finalising the Southern and Indian Ocean data QC. It was agreed that a proposition be put to all regional groups that the data QC be completed by 1 October 2010, and that the database be available only to SOCAT members from this date until public release in 2011.

Action: Dorothee Bakker contacted regional panel leaders about the 1 October 2010 deadline to finalise the data. All regional chairs have since responded and agreed to the timeline.

3.2.2 Public release of SOCAT database

The Southern and Indian Ocean regional panels discussed an appropriate date for the public release of the database. The release date should be timed to allow for synthesis of data for inclusion in the IPCC Assessment Report 5. This requires papers to be submitted before July 2012. Nicolas Metzl mentioned that a SOLAS/IMBER meeting on surface and deep ocean carbon is planned for 2011 and may occur as early as April/May 2011. He suggested a public release of SOCAT at the meeting. The panel members agreed that an April/May 2011 release date was possible. If the SOLAS/IMBER meeting is postponed or delayed, the public release could still occur in April/May 2011, with the release date still to be determined by all SOCAT panels.

Action: Dorothee Bakker to contact all regional panel chairs to determine a public release date for the SOCAT database. All chairs responded to this query and agreed to a public release of the SOCAT data base in April/May 2011 was feasible.

3.2.3 Matlab QC routines update

The Matlab QC routines available at www.socat.info have a number of bugs. Corrected scripts have recently been tested and will be made available at the SOCAT web site.

Action: Benjamin Pfeil to contact Are Olsen for updated version. This was completed and the updated routines were made available in late June 2010.

3.2.4 Monthly updates of SOCAT database

Monthly updates will start in July 2010 to help speed up the QC process. Data files, flags and metadata files that have been corrected will now be updated regularly. All cruises with an update of the data file will be flagged 'U' (see section 3.2.6). Benjamin Pfeil said he will inform PI's and QC people when updates occur.

3.2.5 Metadata links and updates

Many of the metadata files submitted are incomplete and links to the metadata files do not always work. The links are being fixed. Incomplete metadata files are common for earlier datasets where the PI is no longer available, or the required information (e.g. gas standard concentrations, sensor calibration data and dates, equilibrator temperature or pressure values missing) has been lost. The absence of information in the metadata file will impact the internal cruise flag for the data, but will not necessarily exclude the cruise data from the final database. When cruise flags have been assigned, and prior to the data translating to version 1.4, the PI will be alerted to the flag for their contributed data and have the option of updating the metadata. The person carrying out the QC also has the option of contacting the PI.

Action: Dorothee Bakker, Are Olsen, Chris Sabine, Benjamin Pfeil and Alex Kozyr will prepare an update to the current metadata forms, such that the required metadata information is specifically asked for.

3.2.6 Cruise Flags

The cruise flag (also referred to as the Wanninkhof flag) is internal to SOCAT. This is separate to the WOCE flags used for data in each cruise data set. The cruise flag is used to

assess if there are duplicate files, incorrectly labelled data columns, incomplete metadata, or problems with data needed to reduce measurements of CO_2 mole fraction to fugacity. Benjamin Pfeil mentioned he had been contacted by some PIs who are concerned at the cruise flags assigned to their data. The intention is not to release the SOCAT cruise flag, but the final database will only to include the WOCE quality flags for data in cruises that meet the minimum requirements of flags of A,B,C or D. Once a cruise flag has been assigned, the PI will be alerted by Benjamin Pfeil and can either update the data or leave it. The criteria for assigning the flags are in the SOCAT cookbook
http://www.socat.info/upload/Images_Header/SOCAT_QC_Cookbook_v2.doc,
and are listed below:

Category A: 1) followed approved methods / SoP criteria; 2) metadata documentation complete; 3) 2nd level QC performed and deemed acceptable + comparison with other data performed and deemed acceptable

Category B: 1) followed approved methods / SoP criteria; 2) metadata documentation complete; 3) 2nd level QC performed and deemed acceptable

Category C: 1) did not follow approved methods / SoP criteria; 2) metadata documentation complete; 3) 2nd level QC performed and deemed acceptable (including if possible comparison with other data)

Category D: 1) did or did not follow approved methods/SOP criteria (for sure, or could not be evaluated); 2) metadata documentation incomplete; 3) 2nd level QC performed and deemed acceptable (including if possible comparison with other data)

Category F: (F for “failure”): 1) did or did not follow approved methods / SoP criteria (for sure, or could not be evaluated); 2) metadata documentation complete or incomplete; 3) 2nd level QC revealed non-acceptable data.

Category S: (S for “suspend”): 1) did or did not follow methods / SoP criteria
2) metadata documentation complete or incomplete; 3) 2nd level QC revealed non-acceptable data, but data are being updated (all cruise or part of the cruise).

Category X: (X for ”exclude”): 1) the cruise (all data) are duplicates of another set of data in SOCAT.

Category N: indicates that no flag has been assigned to the cruise and is the starting flag.

In July 2010, and before completion of this report, the U-flag was added to the LAS SOCAT data base:

Category U: (U for ‘’Update’’): 1) Data updated. This flag indicates data have been updated in version 1.3, the flag on the cruise was reset to 'U', and WOCE flags were removed. Previous QC on the file remains logged in the system. The cruise data file will only be included in the next SOCAT version, if an “A” through “D” cruise flag and appropriate WOCE flags are assigned to this cruise before the completion date of SOCAT QC (1 October 2010). Otherwise, this cruise will await QC and inclusion in a future SOCAT release.

3.2.7 WOCE flags for fCO_2 data

Each line of data has a WOCE-style flag for assessing the quality of the CO_2 data. The flag refers to the reported fCO_2 values on a cruise (2= good, 3=questionable, 4=bad). The assignment procedures for the flag are detailed at:

(http://www.socat.info/upload/Images_Header/SOCAT_QC_Cookbook_v2.doc). The interpretation of the WOCE flags was discussed and recommendations were made by the group on standardising the QC procedures.

Some parameters included in the cruise data do not influence the fCO_2 calculation significantly. Based on the meeting discussions, the following variables should not be used to assign the WOCE flag for the fCO_2 data quality.

- Wind speed
- Ship speed
- Ship direction
- Salinity

Some data files have incorrectly labelled data columns. For example, wind speed is sometimes incorrectly labelled as wind direction. If this becomes apparent in the QC process, Benjamin Pfeil should be alerted.

Ship speed is calculated from the time and position. Incorrect values of ship speed may have been calculated where there are small time intervals between data.

Many early cruises have interpolated salinity values from infrequent spot measurements, or did not report it. When salinity data is not available, it is estimated from the World Ocean Atlas (WOA). Other cruises may have poorly calibrated conductivity sensors. While salinity is a useful water mass tracer, it has only a minor influence on the fCO_2 calculation and should not be used to flag fCO_2 data as bad.

Key parameters that influence the fCO_2 data and should be considered in the assignment of the WOCE flag for fCO_2 are:

- Mole fraction of CO_2
- Temperature of equilibration
- Sea surface temperature
- Atmospheric pressure
- Equilibrator pressure

The amount of warming between the sea surface and the equilibrator is a useful diagnostic for flow or measurement problems. Low sea-surface temperatures in the Southern Ocean can lead to large amounts of warming due to heat gain from the seawater pump and as the water passes through pipework in the ship's warm interior. The Takahashi warming correction is applied to all SOCAT data, and a warming of about 0.3°C results in a correction of about 5 µatm to the fCO_2 values. For the Southern Ocean, warming of 1°C or more is common. This increases the magnitude and the potential uncertainty in the correction of fCO_2 values. Changes in temperature across the many fronts in the region can also lead to noise in the calculated warming if there is a significant travel time between the intake and equilibrator. Anomalous warming also occurs when sea-ice blocks or partially blocks the intake. The panel recommended the following flags be applied based on the warming in cold high-latitude waters:

- Warming greater than 3°C; flag=3
- Warming rate of greater than 1°C/hr indicates bad data unless rapid temperature change in a front is apparent; flag=4
- Warming outliers greater than 0.3°C compared to background data; flag=4

A substantial number of cruises were found to have empirical or interpolated rather than measured values of equilibrator temperature or sea surface temperature. These values were calculated assuming a constant warming between the sea surface and equilibrator. Such approximations were not always described in the metadata. In cases where measured warming values constrain the interpolated value, the recommendation is to accept the estimated temperature as good.

4. SYNTHESIS EFFORT (DAY 2)

4.1 Sokolov (CSIRO) "Southern Ocean Fronts and Chl-a variability"

Sergei Sokolov described work he has been carrying out using sea surface height (SSH) to map the location of Southern Ocean fronts. Comparison of front locations determined using SSH with hydrographic measurements (T and S) show the SSH provides a good proxy for the front locations. The satellite products for SSH allow the variability in the frontal locations to be tracked on a weekly basis. Since 1992, the major fronts in the Southern Ocean have varied from year to year, with an overall tendency to move south by about one half degree of latitude. The association of the fronts with satellite-derived surface chlorophyll (ocean colour) was also described. This analysis showed the fronts were often the boundaries of regions with high surface chlorophyll variability. This is somewhat at odds with the more traditional view that the maximum variability in chlorophyll occurs in the frontal zones.

4.2 Telszewski (NIES): "Sea surface pCO_2 mapping in the North Pacific"

Maciej Telszewski has been modifying a neural network technique (Telszewski et al., 2009) to compute 84 monthly (January 2002 to December 2008) basin-wide pCO_2 maps for the North Pacific. Preliminary estimates of the seasonal cycle, annual amplitude and interannual variability of the North Pacific pCO_2 field suggest that this methodology can effectively distinguish most of the spatial and temporal patterns found *in situ*. Several improvements to the method have occurred in the past year (Telszewski et al., in preparation). In order to obtain higher labelling efficiency, the spatial resolution and temporal frequency were increased to 0.25° and daily, respectively. The coverage of chlorophyll-*a* concentrations was also increased by filling "empty" pixels with 2002-2008 weekly climatological values. Finally, other predictor variables (sea surface salinity and sea surface height anomalies) were added into the SOM algorithm. Further development of this method may provide near real-time estimates of the net air-sea flux of CO_2 at regional and perhaps global scales by assimilating VOS measurements, satellite data and the self-organizing neural network.

4.3 Lenton (CSIRO): "Updated trends in oceanic pCO_2 in the Southern Ocean"

Andrew Lenton presented a talk on the evolution of the trends in oceanic pCO_2 over the last two decades for the Southern Ocean. The LDEO 2009 pCO_2 data set was used for the study. Triplets of measured pCO_2, SST, SSS were used to calculate TA with SSS using the Lee et al. relationship and TCO_2 was calculated from pCO_2 and TA values. The results show that trends in the less stratified SO (LSSO) (1996-2009) are consistent with Metzl et al. 2009 results. This implies the LSSO is becoming less of a sink for atmospheric CO_2. No trends were significant in the more stratified SO (MSSO), in the Drake Passage, from 2002 to 2009. The reasons for the different responses in the MSSO and LSSO regions are under investigation.

4.4 Metzl (LOCEAN/IPSL): "Surface CO_2 changes in the Southern Ocean"

Nicolas Metzl presented an overview of the atmospheric and oceanic changes in CO_2 for the Southern Ocean. Air-sea fluxes of CO_2 can be estimated using observations, models and inversion methods. From observations, the high latitude Southern Ocean acts as a source of

CO_2 in winter but a sink in summer. This seasonality is captured in several inversion models. The understanding of the decadal scale changes in the surface ocean CO_2 is less clear. Metzl pointed out that Southern Ocean data between the years 2001 and 2003 is sparse in the current version (1.3) of the SOCAT database and that he hopes this will be corrected in the next SOCAT release. He found that the Southern Ocean waters (>45°S) were increasing at or above the atmospheric CO_2 rate of increase, based on winter data collected between May and October since about 1990. However, regional differences in the oceanic increase were apparent. Weddell Sea data available since about 2000 closely tracked the atmospheric increase (1.8 µatm/yr), while the circumpolar waters outside the Weddell Sea showed a much greater rate of increase (about 3.3 µatm/yr). There was also some evidence suggesting the rate of increase in the circumpolar waters (excluding Weddell Sea) may have increased since about 2000.

4.5 Lourantou (LOCEAN/IPSL): “Islands of the subantarctic region”

Anna Lourantou described a preliminary assessment of surface fCO_2 variability around the Kerguelen and Crozet Islands in the subantarctic region using SOCAT data. The monthly air-sea fCO_2 gradient and the net sea-to-air fluxes of CO_2 were calculated on monthly to inter-annual scales. Summer cruises (Dec-Jan-Feb) were examined in more detail, due to higher sampling resolution. For both island regions, an increasing tendency for a CO_2 sink over time was determined. Oceanic fCO_2 seems to have been driven by biological processes for Kerguelen Island. Physical processes seem to be more important near the Crozet Islands. For both island regions, the SSS increased about 0.01 per year. The net CO_2 fluxes into the ocean were about three times greater in the Kerguelen Island region than near the Crozet Islands. The Northeast Kerguelen region, where extensive phytoplankton blooms occur each summer, are now being studied in more detail. This research is being extended to other subantarctic islands and will include assessments of the influence of bathymetry, Fe fertilization (from below and/or above), and frontal position changes on the surface CO_2 variability.

4.6 Sabine (NOAA/PMEL): “RECCAP-Southern and Indian Oceans Sectors”

Chris Sabine discussed the Regional Carbon Cycle Assessment Project (RECCAP: www.globalcarbonproject.org/reccap/syntheses.htm), which is coordinated through the Global Carbon Project. RECCAP goals are:

1. Establish the mean carbon balance of large regions of the globe at the scale of continents and large ocean basins, including their component fluxes, using a combination of regional bottom-up estimates based on data and models and global analyses.

2. Compare these bottom-up estimates with the results of regional top-down atmospheric inversions, and thereby test the compatibility of regional bottom-up estimates with global atmospheric constraints.

3. Evaluate the regional ‘hot-spots’ of interannual variability and possibly the trends and underlying processes over the past decades by combining available long-term observations and model results.

Two of the ocean regions are the Southern Ocean (>44°S) and the Indian Ocean, north of 44°S. The Southern Ocean boundary at 44°S was considered a reasonable approximation to the northern edge of the Subantarctic Zone. Recommendations for a change in sub-regions of the Indian Ocean will be made by the lead authors for this region (N. Metzl and VVSS Sarma).

Many of the SOCAT workshop participants are involved in RECCAP. The timelines for RECCAP are short with a lead authors meeting planned for October 2010 and the regional chapter drafts submitted by June 2011. The SOCAT database will not be available in time to use in RECCAP and the surface CO_2 data from the LDEO 2009 database will be used. A number of questions were discussed on how error estimates for regional flux measurements might be incorporated in the assessment and how to reconcile the flux estimates from inversions and ocean observations.

5. SURFACE CO_2 MEASUREMENT SYSTEMS (DAY 3)

The third day of the workshop started with an overview the NIES-JAMSTEC sponsored pCO_2 intercomparison experiment. The experiment was run between 27 February and 4 March 2009 at the National Research Institute for Fisheries Engineering near Tokyo. A large seawater pool was used to manipulate the pCO_2 of seawater and supply underway and moored systems. Experiments were run over a range of pCO_2 values often encountered in the open ocean (about 280, 360 and 440 µatm). A range of experiments were used to assess the accuracy, drift, and response times of the various systems, relative to an NIES system.

5.1 Nakaoka (NIES) "pCO_2 intercomparison results"

Shinichiro Nakaoka described the major outcomes of the NIES/JAMSTEC sponsored experiment to examine the accuracy and precision of commercially available and research-based underway pCO_2 and moored systems. These included NDIR based underway systems from NIES, General Oceanics (GO; one system each provided by NOAA and the National Institute of Oceanography, India), NIWA (New Zealand), and PML (UK). Moored or drifting systems with spectrophotometric detection from JAMSTEC, and the University of Montana, and systems with NDIR detection from NIES and NOAA/MBARI were also tested. A similar intercomparison was carried out by NIES in 2003. The 2009 experiment provided a way to assess how surface pCO_2 systems have improved over the six year period and to evaluate new systems. For example, a key result from the 2003 inter-comparison was that most shower equilibrator systems suffered some degree of contamination by ambient air through a vent, which led to the addition of a "vent equilibrator" to pre-equilibrate the vent air.

The results for the underway systems were encouraging with the NIES, NIWA and GO underway systems agreeing to within about ± 0.3 µatm for most of the experiment. An issue with pressure measurement in the PML system was identified and work is in progress to correct this. The moored systems showed more variable responses. All of the moored systems showed good agreement at times, although the NDIR based versions appeared more reliable and were also generally within ± 1 µatm of the underway systems. The spectrophotometric based detection systems were most subject to drift or offsets and further improvement in these systems is recommended. A detailed inter-comparison report is in preparation.

5.2 Neill (CSIRO) "Underway pCO_2 system developments"

Craig Neill described the development of the Neill/GO underway pCO_2 systems, including results from the inter-comparison exercise in Japan. These systems were designed based on input from the user community and have proven very robust and compatible with the needs of many research groups. The GO systems are now one of the most commonly used systems on ships of opportunity. The two GO systems used in the intercomparison were in excellent agreement with the NIES systems (better than ± 0.3 µatm). Since the intercomparison, the equilibrator design has been altered to include a water jacket, which is now being trialled. This will be particularly useful in Southern Ocean waters where there are often large temperature gradients between the inside of the equilibrator and the surrounding air. LICOR have also replaced the LI6262 NDIR analysers recently with LI7000 models and many labs

are now using the newer NDIR. In early 2010, it was discovered that the LI7000 (and LI840) do not report mole fraction of XCO_2 corrected for H_2O dilution as the earlier LI6262 analysers did. This will need to be corrected in the post processing of the data.

6. SYNTHESIS EFFORT USING THE SOCAT DATABASE

A number of participants expressed interest in global and Southern/Indian Ocean synthesis efforts using the SOCAT database. Benjamin Pfeil and Are Olsen indicated that a technical paper would be written on the development of the database. Others expressed interest in using the database to reassess the variability and net air-sea flux for all basins as a follow paper to Takahashi et al., (2009). Ideas for a number of papers focussed on the regional and temporal variability in surface CO_2 for the Southern and Indian Ocean regions were also discussed. The participants will be working to further develop the synthesis plans.

7. SOCAT FUTURE

Regular updates of the SOCAT products are envisaged, as new high quality carbon data are submitted to the Carbon Dioxide Information Analysis Center (CDIAC). The data compilation is an ongoing process, so data can be submitted at any time for inclusion in the next version of SOCAT.

At present funding for future upgrades of the SOCAT database is limited. The current level of support in the EU for a continuation of SOCAT is unlikely to be sufficient. Some SOCAT work has been incorporated into the 4-year European Carbochange project, currently being negotiated. Benjamin Pfeil and Dorothee Bakker have three and two months of funding, respectively, to work on SOCAT updates in this project. The funding situation for other SOCAT participants is uncertain.

Any new data should be sent to CDIAC and Benjamin Pfeil at the Bjerknes Centre for Climate Research, Norway. The data contributors should submit metadata and quality controlled data, ideally following the SOCAT recommendations in the cookbook. Nicolas Metzl pointed out that there is a gap in data between 2001 and 2003 and that new submissions would hopefully contain some data in this period.

8. PLANS FOR SURFACE CO_2 OBSERVATIONS

The UNFCCC has recognised surface CO_2 as one of the essential climate variables for the oceans (GCOS, 2004). The significance of these observations was described in a white paper delivered at the Ocean Obs'09 conference (Monteiro et al., 2010) and the conference statement highlighted the need for a sustained ocean carbon observing system (http://www.oceanobs09.net/statement/).

The existing surface ocean CO_2 observing system now has sparse coverage and relies on individual scientists to fund the measurement programs. The only approach in the short term appears to be for individual researchers to secure national funding to continue observations. This may result in important components of the already sparse observing system not being supported. An international strategy is needed to map out and facilitate the development of a sustained surface ocean carbon observing network (of which SOCAT should be a part) that can eventually become operational. The Joint WMO-IOC Technical Commission for Oceanography and Marine Meteorology (JCOMM) has an interest in working with the surface CO_2 observing network. However, JCOMM is an operational based group, and the current surface CO_2 observation network does not appear to be ready to transition to an operational system.

Tables 1 and 2 are known plans for observations of surface CO_2 in the Southern and Indian Oceans.

GCOS (2004): *Implementation Plan for the Global Observing System for Climate in Support of the UNFCCC*, GCOS-92, October 2004, (http://www.wmo.int/pages/prog/gcos/Publications/gcos-92_GIP.pdf)

Monteiro P. & Co-Authors (2010). "A global sea surface carbon observing system: assessment of changing sea surface CO_2 and air-sea CO_2 fluxes" *OceanObs'09: Sustained Ocean Observations and Information for Society*, Venice, Italy, 21-25 September 2009, Hall, J., Harrison D.E. & Stammer, D., Eds.

Table 1 Surface CO_2 observations planned 2010 -

Country	***PI***	***Vessels***	***Dates***	***Study***	***Study Area***
Australia	Tilbrook (CSIRO)	*Astrolabe* *Aurora Australis* *Southern Surveyor*	until mid 2013	Sustained observations and process studies	Australian sector of the Southern Ocean
China	Liqi Chen (CAA)	*Xue Long*	Nov-Mar 2010 -		Prydz Bay and Indian sector tracks between Zhonghan Station (East Antarctica and Changcheng Station (Antarctic Peninsular)
France	Metzl (LOCEAN) Metzl(LOCEAN) & Goyet (U. Perpignan)	*Marion DuFresne* *Astrolabe*	OISO funded for the next 5 years, every year	OISO KEOPS II (Fe fertilization) Sustained observations	Kerguelen Is. region South of Australia (see Australian plans)
Germany	Hoppema (AWI)	*Polarstern*	Nov 2010 – Feb 2011 Jan - March 2012	ANT XXVII/2 Eddy pump	Weddell Sea and crossings of the Antarctic Circumpolar Current
India	Sarma (NIO)	Various using 4 ocean going and 6 coastal ships	2011-	CSIR-Network project	Open ocean and coastal. Various tracks in the Indian Ocean
Japan	Hashida (NIPR), Inoue (Hokkaido U.) & Ishii (MRI) Murata (JAMSTEC)	*Shirase* *Umitaka Maru* *Hakuko Maru* *Mirai*	Dec, Feb/Mar each year Dec 2010 – Jan 2011 Dec 2011 – Jan 2012 Dec 2010 - Jan 2011 Nov 2012 - Mar 2013	CLIVAR and underway measurements	Indian and Pacific sectors Mirai to reoccupy WOCE S4P line

Korea	Tae Siek Rhee (KOPRI)	*Araon*	2010 -	One per year	Christchurch(NZ) - Antarctic Peninsula- Ross Sea - NZ
Sweden	Chierici & Fransson (U. Gothenburg)	*IB Oden*	Dec 2010 – Jan 2011		Amundsen Sea and Ross Sea
South Africa	Monteiro (CSIR)	*Agulhas*	ongoing	Sustained observations and process studies	Gough Is. South Georgia Is. Marion Is.
The Netherlands	De Baar (NIOZ)	*Polarstern*	2010	GEOTRACES	Western South Atlantic
UK	Hardman-Mountford (PML)	*RRS James Clark Ross*	until May 2013	CASIX	Falkland Is. - Antarctic Peninsula - South Georgia - Falklands (Scotia Sea)
USA	Takahashi (LDEO)	*Palmer and Gould*	Until 2013	CLIVAR adding atmospheric oxygen measurements to understand heat/biological fluxes in the Southern Ocean and how our regional measurements compare	Line S4P on Palmer (Feb/Apr 2011) \ P14-P19 Antarctic sections. P06 and I05 just completed on Melville. A10 on Brown (2011).

Table 2 CO_2 time series sites in Southern Ocean (>30°S)

Country	***PI***	***Stations***	***Dates***
Australia	Tilbrook (CSIRO)	Kangaroo Island Maria Island	March 2011- March 2011-
New Zealand	Currie (NIWA)	Munida time series, east coast of NZ to offshore	Bi-monthly since 1998
UK	Meredith (BAS), Bakker (UEA) & Watson (UEA)	Rothera Oceanographic and Biological Time Series (RATS). Sampling for TCO_2 & TA.	4 depths (two weekly) late 2010-2013
USA	Sabine (NOAA-PMEL)	Ocean Observatories Initiative moorings: SE Pacific Argentine basin Mooring in the Agulhas return current Southern Ocean Flux Station (47°S 142°E)	2011- Sept 2010 -

9. ACKNOWLEDGEMENTS

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ANNEX I

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Southern and Indian Ocean SOCAT Workshop
16-18 June 2010
Hobart, Tasmania

Back row (left to right): M. Ishii, B. Pfeil, VVSS. Sarma, A. Lenton, M. Kuchinke, C. Sabine, M. Hoppema, N. Metzl, B. Tilbrook, G. Hashida.
Front row (left to right): C. Neill, M. Telszewski, D. Bakker, A. Lourantou, K. Paterson, S. Nakaoka.

ANNEX II

Workshop Agenda

Day 1: SOCAT progress and data quality discussion
0900 - 0930: welcome and aims of meeting
0930 - 1030: SOCAT progress 0930 - 1000: Pfeil, progress on finalising database and time lines for data release 1000 - 1030: Sabine: Pacific Ocean SOCAT update
1030 - 1100: Morning tea
1100 - 1230: Summary of SOCAT progress 1100 - 1130: Sarma, Indian Ocean SOCAT update 1130 - 1200: Lourantou, Indian sector of Sth Ocean 1200 - 1230: Tilbrook, Pacific sector of Sth Ocean
1300 - 1400: Lunch
1400 - 1530: Summary of SOCAT progress 1400 - 1430: Hoppema and Bakker, Atlantic sector of Sth Ocean 1430 - 1600: Entire Sth Ocean data quality –Flags for dual cruises and flagging decisions
1600 - 1700: Welcome function at CMAR labs

Day 2: SOCAT progress and synthesis
0900 - 1030: Summary of SOCAT progress continued
0900 - 1030: Session to resolve outstanding issues with data for SOCAT release
1030 - 1100: Morning tea
1100 - 1230: Synthesis effort, what are the issues (SAM, regional variability, decadal change, and who will do it) 1100 - 1130, Sokolov, CSIRO: Southern Ocean frontal positions and chlorophyll variability 1130 - 1200, Telszewski, NIES, Sea surface pCO_2 mapping in the North Pacific - update on recent results 1200 - 1230, Lenton, CSIRO: Controls on surface CO_2 variability: Synthesis from LDEO data
1230 - 1330: Lunch
1330 - 1530: Synthesis effort, what are the issues (SAM, regional variability, decadal change, and who will do it) continued 1330 - 1400, Metzl, LOCEAN/IPSL: SOCAT versus LDEO. Our ocean views of atmospheric inversions 1400 - 1430, Lourantou, LOCEAN/IPSL: Islands effects 1430 - 1530, open discussion
1530 - 1600: Afternoon Tea
1600 - 1700: RECCAP for the Southern and Indian Ocean 1600 - 1615, Sabine, Overview and progress to date 1615 - 1700, Southern and Indian Ocean RECCAP general discussion

Day 3: The future observing system and SOCAT II
0900 - 0930: pCO_2 intercomparison results and timelines 0900 – 0920, Nakaoka, NIES: Summary of intercomparison results 0920 – 0930, Neill, CSIRO: GO system results
0930 - 1030: Future plans: Southern and Indian Ocean observations (10-15 min): Australia: Tilbrook, CSIRO South Africa: Monteiro, CSIR – slides sent France: Metzl, LOCEAN/IPSL Germany, Hoppema, AWI
1030 - 1100: Morning tea
1100 - 1230: Future plans: Southern and Indian Ocean continued (10-15 min): India: Sarma, NIO Japan: Hashida, NIPR UK: Bakker, UEA USA: Sabine, NOAA-PMEL Discussion future SOCAT
1230 - 1330: Lunch
1330 - 1530: The future Southern Ocean and Indian Observing system.
1530 - 1600: Afternoon Tea
1600 - 1700: Summary of meeting and plans for synthesis
1900 - Dinner