4.0 OCEAN CARBON AND OTHER ACTIVITIES

4.1 IOC/SCOR International Ocean Carbon Coordination Project (IOCCP)

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International Ocean Carbon Coordination Project
Progress Report for SCOR, August 2012

Ocean carbon research, observations, and modelling are conducted at national, regional, and global levels to quantify the global ocean uptake of atmospheric CO_2 and to understand controls of this process, the variability of uptake and vulnerability of carbon fluxes into the ocean. These science activities require support by a sustained, international effort that provides a central communication forum and coordination services to facilitate the compatibility and comparability of results from individual efforts. Such an activity can also promote the development of the ocean carbon data products that can be integrated with the terrestrial, atmospheric and human dimensions components of the global carbon cycle. The International Ocean Carbon Coordination Project (IOCCP) was created in 2005 by the Intergovernmental Oceanographic Commission (IOC) of UNESCO and the Scientific Committee on Oceanic Research (SCOR), funded by the U.S. National Science Foundation (NSF). IOCCP provides an international, program-independent forum for global coordination of ocean carbon observations and integration with global carbon cycle science programs. This report highlights the main activities of IOCCP between September 2011 and August 2012.

Project Highlights

The Surface Ocean CO_2 Atlas (SOCAT) Project

The Surface Ocean CO_2 Atlas (SOCAT, (http://www.socat.info/) was initiated by IOCCP, SOLAS, and IMBER in April 2007 (IOCCP, 2007). The first public release of SOCAT (version 1.5) took place on 14 September 2011 (Bakker et al., 2012).

SOCAT version 1.5 has 6.3 million surface water CO_2 measurements from 1,851 voyages in the global ocean, including the Arctic Ocean and coastal seas, between 1968 and 2007. The surface

water fCO_2 (fugacity of carbon dioxide) data in SOCAT have been put in a uniform format and recalculated using transparent and fully documented methods (Pfeil et al., 2012). In addition, a mean monthly fCO_2 atlas has been constructed from this data set (Sabine et al., 2012). To make the dataset user-friendly, it is available on the Web through a sophisticated online data visualisation and manipulation tool called the Live Access Server. The LAS provides interactive maps that enable users to interrogate the data. Gridded monthly data are also available via http://www.socat.info/.

The first SOCAT release significantly improves data access for global carbon scientists. Potential applications include carbon budgets; studies of seasonal, inter-annual and decadal variations in oceanic CO_2 uptake at meso-, regional-, and global scales; and of the processes driving these. SOCAT will help inform scientists of the minimum fCO_2 data coverage required for accurate quantification of the oceanic CO_2 sink, its variation and trends. Monthly, basin-wide maps of CO_2 air-sea fluxes can be created with, for example, statistical techniques, neural networks, modeling, and data assimilation for constraining global atmospheric carbon budgets. SOCAT provides initialization and validation fields for ocean carbon cycle models.

The Global Ocean Ship-based Hydrographic Investigations Panel (GO-SHIP)

Ship-based hydrography is still the only method for obtaining high-quality, high spatial and vertical resolution measurements of a suite of physical, chemical, and biological parameters over the full water column on a global scale. Only ship-based hydrography can document ocean changes throughout the water column, including the deep ocean below 2 km (52% of global ocean volume) not sampled by profiling floats.

The sustained ship-based hydrography program has two closely linked scientific objectives: (1) understanding and documenting the large-scale ocean water property distributions, their changes, and drivers of those changes; and (2) addressing questions of how a future ocean will interact with natural ocean variability, as it increases in dissolved inorganic carbon, becomes more acidic and more stratified, and experiences changes in circulation and ventilation processes due to global warming, an altered water cycle, and changing sea-ice distribution.

The GO-SHIP committee (see http://www.go-ship.org/) recognized that it is essential to maintain a sustained hydrography program that is firmly linked to national, regional and global research programs, but that some elements of coordination, including planning and implementation, would benefit highly from a dedicated oversight structure and formal agreements. The committee secured partial funding to engage with IOC-WMO JCOMMOPS regarding opening the Ship Operations position. It is envisaged that this initial and limited GO-SHIP coordination officer (part-time) would lead to the development of the international hydrographic program office as outlined in the GO-SHIP Development Plan 2010-2012. The vision is that, working with an international scientific steering committee, the program office would be responsible for facilitating international agreements on implementation, data release and sharing, and data management; monitoring cruise implementation and data flow; facilitating collaborations to ensure that the full suite of core variables are measured on each cruise; providing technical support for meetings of the scientific steering committee, the data management committee, the

synthesis groups, and the network evaluation group; working with the other observing system components to harmonize and integrate observations and data streams; and serving as a central communications and information forum for the hydrography community.

Workshops and Meetings

The IOCCP Surface Ocean CO_2 Data-to-Flux Workshop, Paris, France, 12-13 Sept. 2011

In 2010, a series of community and plenary white papers (CWP) were published as part of the OceanObs'09 proceedings that set out decadal challenges to the surface ocean CO_2 flux community as well as identifying technical obstacles towards achieving them. Perhaps one of the biggest challenges is the reduction of the global flux uncertainty to a level that is necessary and meaningful to resolve interannual trends. Presently, this is considered to be in the 10–15% range. While this has been achieved on the basis of ship-of-opportunity (SOOP) observations in some regions, such as the North Atlantic Ocean, it is clear that the same approach is not feasible in the Southern Ocean south of 30°S, where seasonal biases are an additional challenge.

The Surface Ocean CO_2 Data-to-Flux Workshop organized and sponsored by IOCCP (held at UNESCO Headquarters in Paris on 12-13 September 2011) used the CWP from the Global Surface Ocean Observation community together with other topic-specific CWPs as a starting point to assemble issues and participants from all the communities (observational, modelling, sensor development, platform development and operations, data management) that have a strong contribution to make in enabling the above-mentioned decadal goals to be achieved in a realistic way. The workshop included experts in observations, modeling, sensor development, platform development, and operations and data management. During plenary sessions and theme-focused discussion groups the workshop participants focused on the following goals and challenges:

- Approaches and requirements to reduce global surface ocean CO_2 flux uncertainties to levels that enable interannual trends in regional and global fluxes to be resolved
- Empirical and model-based approaches to close the regional and seasonal cycle of CO_2 fluxes
- Requirements for ancillary observations to link interannual CO_2 flux trends to underlying changes in the upper ocean physics and biogeochemistry, as well as emerging sensor developments that support the above goals
- Strengthening SOCAT's contribution to the global carbon science and stakeholder communities in converting pCO_2 data to CO_2 flux products of wide regional and global utility
- A re-assessment of the regional- and global-scale spatial and temporal sampling activities (VOS and others) in the light of:
    - Recent ideas that ΔpCO_2 is a small part of the overall error
    - Improved empirical approaches to deriving relationships linking remote sensing variables to pCO_2
    - Potential role for model data assimilation
    - Regionally and globally optimized sampling strategies

- Expansion of methodologies and QC systems to keep sampling error to < 1 μatm
- Data QC, assembly and data–model interfaces (data availability, quality and assimilation)
- Anticipated data and flux products
- Ancillary observations and modelling approaches that can provide a better grasp on sensitivities and drivers of the CO_2 flux trends
- Role of terrestrially derived (rivers) C_{ant} fluxes
- How can surface ocean CO_2 observations tie into efforts to understand ocean acidification?

Joint IOCCP/SOLAS/IMBER Carbon Synthesis Meeting, Paris, France, 14-16 Sept. 2011

The ocean carbon cycle is changing at rates whose magnitude and pattern we are only beginning to document, quantify, and understand. The uptake of anthropogenic CO_2 from the atmosphere and climate fluctuations, as well as long-term trends in ocean circulation and biology, have led already to substantial changes in the ocean carbon cycle, with potentially larger changes looming ahead. In the last decade, substantial efforts have been undertaken to measure these changes, and several projects are underway to synthesize them and to put them into the context of climate variability and change. In particular, IOCCP, the SOLAS-IMBER carbon working groups, and other international organizations (e.g., PICES, EU FP7) have initiated and supported several analysis and synthesis activities, such as SOCAT, CARINA and PACIFICA, with the goal to arrive at (i) homogeneous and quality-controlled data sets and (ii) regional-to-global assessments of the changing ocean carbon cycle.

This meeting, organized and co-sponsored by IOCCP, SOLAS, and IMBER on 14-16 September 2011 and held at UNESCO Headquarters in Paris, brought together more than 120 scientists. Some of these scientists work on these particular synthesis projects and others generally are interested in developing an integrated view of how the ocean carbon cycle has changed in recent decades. Of interest were syntheses, analyses, and modeling studies focusing on air-sea CO_2 fluxes, changes in ocean surface and interior carbon properties, and how the changes in these realms are connected to each other.

This meeting aimed at providing critical inputs to the further development of the ocean carbon observing systems, and to the next (5^{th}) assessment report of the Intergovernmental Panel on Climate Change (IPCC).

SOCAT Automation Planning Meeting, Seattle, USA, 10--11 May 2012

Streamlining and automating SOCAT is essential for prompt, regular, future SOCAT releases, for example, every 1 to 2 years after the release of SOCAT version 2. Eleven scientists from the broader SOCAT community were charged to develop procedures, software, and an implementation strategy for SOCAT automation. This workshop allowed them to brainstorm several technical and conceptual aspects and to produce a work plan for the following 6-8 months when most of the automation is supposed to be ready. Three general aspects were considered:

- Automation of metadata submission;
- Automation of data submission; and
- Automation of initial (meta-)data quality control.

Below follows a summary of decisions and recommendations that will eventually form the automated, publicly available SOCAT.

1) SOCAT user interface

SOCAT.info will host a user interface for uploading data and metadata to SOCAT. The user interface will:

- Enable data PIs to upload metadata;
- Enable data PIs to upload data;
- Enable SOCAT to carry out file conformance tests;
- Enable data PIs to carry out initial quality control on these data;
- Enable data PIs to download their 'original' data and metadata for submission elsewhere;
- Enable data PIs to submit their data to SOCAT and:
  a) Make their 'original' data and metadata public via CDIAC upon submission to SOCAT (instantly),
  b) Make their 'original' data and metadata public via CDIAC upon inclusion of these data in a SOCAT release,
  c) Take responsibility of making their 'original' data and metadata public (via a data center(s) of choice).

  (At least 1 of these 3 options has to be selected as part of data submission to SOCAT).

Data submitted to SOCAT will undergo further quality control and will be subject to SOCAT reformatting and recalculation protocols. If the data are deemed of sufficient quality, they will be included and made public in the next suitable SOCAT release. Such data and metadata in SOCAT format will be archived at Pangaea.

12-character cruise Expocodes will link data (at SOCAT.info) with metadata (at CDIAC OME). The first two characters of a 12-character Expocode identify the country code of the vessel (http://www.nodc.noaa.gov/General/NODC-Archive/countrylist.txt) and are followed by the two-character National Oceanographic Data Center (NODC) vessel code (http://www.nodc.noaa.gov/General/NODC-Archive/platformlist.txt). The final 8 characters denote the starting date of the measurements of the cruise (as YYYYMMDD). For instance, 06MT19920510 means that this cruise was conducted on the German (06) research vessel Meteor (MT) and that the first measurement was reported for 10 May 1992. In case of doubt, the CDIAC or SOCAT data managers can be contacted.

2) Metadata creation and management

The SOCAT metadata will be hosted at CDIAC in OME. The OME metadata form will communicate with the SOCAT data via the user interface by small files (MyExpocode.xml) with the Expocode as the unique cruise identifier. Metadata should provide all information required for SOCAT quality control. Metadata forms will be saved and past forms will be available for future use by their creators. As part of the automation, it will be made possible to either complete metadata forms in situ or to import metadata from the headers of data files. A facility for uploading attachments (e.g., project cruise reports, calibration reports) to the metadata forms will be added.

3) Data formats and file conformance tester

The self-documenting data files will have a mandatory header, an optional header, and mandatory column identifiers. The mandatory header will contain information essential for creating the Expocode for the data. The optional header will contain metadata for automatic upload to the OME metadata form. The column identifiers will enable identification of the column contents, as well as units. Ideally, most columns can be identified automatically by standardization of the column identifiers. A user interface will further assist in identifying column contents. Acceptable file formats will be CSV (comma) or tab-separated text.

4) Initial Quality Control by the data PI prior to submission

The user interface will create a series of property-property plots of the data, such that the data PI can carry out initial quality control prior to submission of the data to SOCAT.

5) Submission of data and metadata to SOCAT

Once the data and metadata are complete, the file conformance tests come out satisfactorily, and the data PI has carried out initial quality control of the data, he/she may proceed to submission of the data and metadata. At this stage, the data PI can download their 'original' data and metadata for his/her records and for submission elsewhere.

6) Quality control by SOCAT participants

The SOCAT quality-control interface will be redesigned for version 3.

7) Versioning of SOCAT data output files and DOI numbers

All SOCAT output files are and will be stored at Pangaea. Each SOCAT release will be given a DOI number and a version number (e.g., version 1.5). New output files and revised output files will be given a DOI number, as they are released as part of a specific SOCAT version. The Pangaea entry to each SOCAT data output file will have a link (a 'key') to all the SOCAT versions that this file is part of.

An International Workshop to Develop an Ocean Acidification Observing Network of Ship Surveys, Moorings, Floats and Gliders, Seattle, USA, 26-28 June 2012

In order to coordinate international efforts to document the status and progress of ocean acidification in open-ocean and coastal environments, and to understand its drivers and impacts on marine ecosystems, it is necessary to develop a coordinated multidisciplinary multinational approach for observations and modeling that will be fundamental to establishing a successful research strategy for ocean acidification. This will facilitate the development of our capability to predict present-day and future responses of marine biota, ecosystem processes, biogeochemistry, and climate change feedbacks.

Required research elements include regional and global networks of observations collected in concert with process studies, manipulative experiments, field studies, and modeling. Global and regional observation networks will provide the necessary data required to firmly establish impacts attributable to ocean acidification.

IOCCP, together with the NOAA Ocean Acidification Program, the Global Ocean Observing System, the Integrated Ocean Observing System, and the University of Washington, supported this international workshop, which proposed an integrated global observing network for both carbon and ocean acidification that addresses the requirements of nations affected by this emerging environmental problem in response to societal needs. The 3-day workshop was held at the University of Washington on June 26-28, 2012 for a group of 64 international scientists and program managers from 21 countries. The workshop report will provide the strategy for the observing system for review and vetting and hopeful support by the member countries. See http://www.pmel.noaa.gov/co2/OA2012Workshop/WorkshopHome.html.

The principal goals of this international workshop were to (1) design the components and locations of an international carbon ocean acidification observing network that includes repeat hydrographic surveys, underway measurements on volunteer observing ships, moorings, floats, and gliders taking into account existing networks and programs wherever possible; (2) identify a minimum suite of measurement parameters and performance metrics for each major component of the observing system; (3) develop a strategy for data quality assurance and data distribution; and (4) discuss requirements for program integration at the international level.

The focus of this workshop was to design a global ocean acidification observing network that will delineate the physical-chemical processes controlling the acidification of the ocean and its large-scale biological impacts (changes in productivity, nutrient distributions, etc.). IOCCP coordinates the existing global oceanic carbon observatory network of repeat hydrographic surveys, time-series stations, floats and glider observations, and volunteer observing ships in the Atlantic, Pacific and Indian oceans. This network can provide a strong foundation of observations of the carbonate chemistry needed to understand ocean acidification. Enhancing these activities and expanding the global time-series network with new carbon and pH sensors on floats and gliders will provide additional important information on the changing conditions in both open-ocean and coastal environments that are presently under-sampled.

Ideally, this network would also have the capability to measure $CaCO_3$ saturation states, biological production rates, and species functional group changes. Additional sensors for dissolved inorganic carbon and total alkalinity would also be beneficial for detecting changes in the marine inorganic carbon system, including inputs of other non-CO_2 sources of acidification. Measurements of net primary production, either directly or from nutrient or oxygen inventories, along with an understanding of water movements in coastal zones, are also important to identify biological adaptations to ocean acidification. These additional measurements are needed to predict ecosystem responses to ocean acidification.

These activities will require a coordinated and interdisciplinary research effort that is closely linked with the majority of international carbon research programs. Leveraging existing infrastructure and carbon monitoring programs will enable research to be conducted efficiently and quickly. Identification of new time-series stations, repeat surveys, and underway measurements are also urgently needed in under-sampled open-ocean and coastal regions. Moored buoys equipped with carbon system sensors and ancillary technologies for ocean acidification should be added to the present carbon network as well as adding new sensors to the existing network. The global ocean acidification observing network must be developed in a collaborative international context in order to guide international coordination and infrastructure development.

SOCAT Annual Meeting, Tsukuba, Japan, 2-4 July 2012

The SOCAT annual meeting aims mainly at consolidating various aspects of SOCAT that are worked on continuously by various subgroups. The attendance of SOCAT management members gives an opportunity to focus, for 2-3 days every year, solely on future SOCAT directions with regard to the needs of marine biogeochemists worldwide. This year, the Japanese National Institute for Environmental Studies (NIES) and IOCCP organized the annual SOCAT meeting in Tsukuba, Japan. The meeting report has not been finalized yet, but the main aspects discussed included:

- Feedback on the Web site, including statistics and end-user opinions
- The current status of and workload left for the SOCAT 2 release, as well as for automation of procedures to be ready for SOCAT 3
- Update on personnel needs.
- Adding additional parameters (nutrients, DIC, TA, O_2, atm CO_2): scientific and technical needs and challenges. Decision needs to be taken for SOCAT 3.
- Involving the new coastal leaders in data quality decisions and overall SOCAT decisions.
- Practical Salinity Unit versus Practical Salinity Scale
- Addition of the fCO_2 measurements by cavity ringdown spectrometers (CRDS) with daily calibration to the SOCAT database
- Addition of the fCO_2 measurements by moorings, gliders, and drifters to the SOCAT database

Project Office

New IOCCP Project Office

The U.S. National Science Foundation (NSF) has provided staff salary support for IOCCP since the formation of the Project in 2005. Due to the vote of the UNESCO General Conference in October 2011 to admit Palestine as a Member State of UNESCO, the United States was required by federal law to withdraw all direct and voluntary contributions to UNESCO. As a result, NSF funding for IOCCP staff support through IOC was cut off on 2 November 2011.

IOC was able to identify emergency funding from the Global Ocean Observing System to continue the staff positions through 31 March 2012. Following multilateral negotiations, the Project office headquarters was relocated to the Institute of Oceanology of Polish Academy of Sciences (IO PAS) in Sopot, Poland beginning 1 April 2012. Since then SCOR has provided the IOCCP staff salary support through a grant from NSF. Starting 1 October 2012, the IOCCP staff will be reduced to one person until further financial support will be secured. IOC and SCOR continue to co-sponsor the IOCCP by providing financial support for critical activities.

IOCCP Scientific Steering Group Meetings

The **Sixth** IOCCP Scientific Steering Group meeting was held on 17-18 September 2011 at UNESCO Headquarters in Paris, France. Chris Sabine (Chair-NOAA/PMEL, USA) was joined by members Alex Kozyr (CDIAC, USA), Masao Ishii (JMA-MRI, Japan), Pedro Monteiro (CSIR, South Africa), Yukihiro Nojiri (NIES, Japan), Ute Schuster (UEA, UK), Bernadette Sloyan (CSIRO, Australia), and Toste Tanhua (IfM-Geomar, Germany). Dorothee Bakker (UEA, UK) and Nicolas Gruber (ETH, Switzerland) attended as representatives of the SOLAS-IMBER Carbon Working Groups. In addition, Albert Fischer (IOC/UNESCO) and David Hydes (NOCS, UK) were invited to present updates on "A Framework for Ocean Observing" and Integrated Carbon Observing System (ICOS), respectively. Ed Urban (SCOR), Melchor Gonzalez (U Las Palmas, Spain), Are Olsen (IMR, Norway) and Jean-Pierre Gattuso (CNRS-UPMC, France) were unable to attend. The meeting report is available at http://www.ioccp.org/Events.html.

The **Seventh** IOCCP Scientific Steering Group meeting was held on 12-13 June 2012 in the Institute of Oceanology of Polish Academy of Sciences (IO PAS) in Sopot, Poland. Toste Tanhua (Chair-GEOMAR, Germany) was joined by members Alex Kozyr (CDIAC, USA), Masao Ishii (JMA-MRI, Japan), Laura Lorenzoni (USF, US), Yukihiro Nojiri (NIES, Japan), Ute Schuster (UEA, UK), Benjamin Pfeil (UiB, Norway) and Are Olsen (IMR, Norway). In addition, Ed Urban (SCOR) was invited to provide input on new IOCCP strategies and directions and Albert Fischer (IOC/UNESCO) was invited to present an update on "A Framework for Ocean Observing". Pedro Monteiro (CSIR, South Africa), Todd Martz (U Las Palmas, US), Chris Sabine (NOAA-PMEL, US), Bernadette Sloyan (CSIRO, Australia) and Jean-Pierre Gattuso (CNRS-UPMC, France) were unable to attend. Representatives of the SOLAS-IMBER Carbon Working Groups: Andrew Lenton (CSIRO, Australia) and Nicolas Gruber (ETH, Switzerland) attended virtually via GoToMeeting Web conferencing tool provided by SCOR.

IOCCP FUTURE DIRECTIONS

IOCCP will execute specific actions developed during the Seventh Scientific Steering Group meeting (12-13 June 2012). In addition, more general actions will be taken to meet new challenges dictated by changing needs of marine biogeochemistry community. During the course of the next year IOCCP priorities will include the following:

A Framework for Ocean Observing

A task team of limited duration was formed at the OceanObs'09 conference to develop recommendations on a Framework for Ocean Observing (FOO). Specifically, the task team was asked to develop a framework for an enhanced global sustained ocean observing system over the next decade, integrating new physical, biogeochemical, and biological observations while sustaining present observations, and taking best advantage of existing structures. The Framework envisioned a biochemical observing panel based on the IOCCP. The IOCCP feels this effort should involve other programs and plans to investigate how best to contribute to the FOO activity through dialogue between the IOCCP, GOOS, IGBP, SCOR, SOLAS, and IMBER. To this end, the IOCCP is now seeking to take on some coordination tasks for a wider range of biogeochemical parameters, in particular oxygen and nutrients. The IOCCP is well placed to incorporate coordination of nutrients and oxygen observations into its mission for at least two following reasons:

1. There is a tight relation between the carbon cycle and biogeochemistry in the ocean, so that a well-coordinated observational network for oxygen (hopefully leading to better data quality, availability, and coverage) is beneficial also for the ocean carbon science.
2. There is currently no sustained body/organization for coordination of observations of oxygen and nutrients in the ocean explicitly (although we recognize that several groups have made significant progress over the years), and we believe that the observational network of biogeochemical variables would benefit from an experienced coordination body.

As a step in this process, the IOCCP has decided to add two members to its Scientific Steering Group (SSG), one with expertise in nutrients and one in oxygen observations. The new SSG members will start their duty on the panel at the beginning of 2013.

Improved coordination of surface carbon observations

A more efficient and better coordinated network of surface ocean carbon observation platforms, including voluntary observing ships and research ships, remains one of the key objectives for IOCCP. To achieve a sustained, scientifically robust and cost-efficient ocean carbon observing system, stronger implementation ties with other global observation programs, such as GOOS, GCOS, DBCP and Argo, will be developed. In addition, the IOCCP will continue collaboration with the World Ocean Council, a high-profile advocacy group aiming at improving ocean understanding through the involvement of ocean user industries (e.g., shipping, oil and gas, fisheries, tourism) in ocean observations. The IOCCP will take an active role in designing the Industry-Global Ocean Observing and Data System (I-GOODS). This system, based on

experience of IOCCP and other global ocean observing networks, would be designed to incorporate opportunities from various industries into scientific efforts and would allow synergies between ocean users' industries, technology industry and key national, regional and global ocean observing coordinators.

Sensors and Instruments

IOCCP maintains a comprehensive directory of commercially available ocean inorganic carbon measurement technologies, which could be broadly categorized as benchtop/underway instruments and autonomous sensors. Calibration, standardization and Quality Control of measurements made on the benchtop/underway systems are relatively mature and traceable to standard gases or CRMs. A multitude of intercomparison experiments, fostered by UNESCO, IOCCP, and other coordinating organizations, have been carried out for these instruments over the past several decades in order to bracket measurement errors for data reporting.

In contrast, none of the autonomous sensors listed on the IOCCP website would meet the quality management requirements set for the benchtop/underway systems or other environmental fields of study involved in generating "climate quality" data. The remote location of autonomous sensor deployments makes this undertaking one of the great challenges in modern oceanography. Consequently, data generated by in situ sensors are uploaded into databases with insufficient validation. As autonomous carbon sensors mature, the need for frequent and systematic in situ intercomparison experiments will sharply increase. Verification-Validation criteria need to be explicitly defined and associated with the various data quality levels defined in the metadata. The community needs are voiced with ever-increasing frequency and strength. The IOCCP decided (during its Seventh SSG meeting) to add a Sensors and Instruments panel member in order to strengthen its potential for coordination if this important aspect of marine carbon observations. The most urgent needs that IOCCP will try to answer to are listed below:

- Controlled laboratory test tanks should be supported by and coordinated as (internationally) shared facilities by IOCCP and other international organizations/agencies
- Field-based intercomparisons present a significant challenge and should be carefully planned with regularity and expert oversight for both coastal and open ocean locations.
- Laboratory and field testing should be coordinated to complement each other, with a clear statement of the tradeoffs and limitations of each. For example, lab testing is ideal for verification of sensor dynamic range and establishing calibration protocols, while field testing is necessary to reveal true performance under real environmental stresses that cannot be simulated in the laboratory. As demonstrated by some of the previous attempts at sensor intercomparison, attempting to carry out dynamic range or accuracy assessments in the field (in the presence of biofouling and intense spatiotemporal gradients) is often insurmountable. In these tests, the sensor errors of interest were largely dwarfed by bottle sampling errors, likely due to the choice to carry out the tests in highly dynamic coastal settings with large spatiotemporal gradients, yielding results of limited value.

- Un-validated in-situ data are not necessarily low quality and should not be labeled at the same data quality level as data that are ostensibly bad. Yet, un-validated data must be identified as such in any database. Metadata defining a validation level in addition to a quality level may be of some utility.
- The results of routine intercomparison experiments will inform the IOCCP recommendations for verification/validation. For example, if bottle samples cannot be satisfactorily spatiotemporally aligned with sensors, IOCCP may recommend that only in-situ sensors with automated in situ validation systems would meet the highest validation quality level.
- Due to the wide price range of in situ systems, IOCCP could perform a needed service by posting recent price quotations of each sensor listed in the online directory. Furthermore, the directory could be modified into a formal database listing many other features such as deployment duration, size, weight, and manufacturer specifications for accuracy, precision, response time, drift, etc.

SOCAT 2

An ambitious timetable for SOCAT version 2 has been set, with data submission until 31 December 2011, SOCAT quality control by the regional groups from August to October 2012, and a tentative date for the public release in early 2013. Regular (every 1-2 years), future updates to SOCAT are envisaged. Automation of data submission and quality control in SOCAT are essential for enabling future, prompt SOCAT releases. Several technical and practical aspects of the second release such as streamlining data submission procedures to incorporate agreed formats and automation of data quality control procedures will be coordinated over the next 12 months. Another improvement to SOCAT may be the inclusion of additional carbon parameters relevant for ocean acidification research. The IOCCP is responsible for drafting the SOCAT Implementation Strategy to ensure a stable project development in the short to mid-term (3 to 5 years). Possibilities to fund a technical position focused on SOCAT issues will be investigated and will become an integral part of the SOCAT Implementation Strategy.

Repeat Hydrography

The IOCCP will continue to serve as a resource for the ocean carbon hydrography through collaboration with CDIAC, CCHDO, and GO-SHIP. Resources provided will include information on cruise plans, continuously updated cruise maps and reference section tables including measurement being made at each location.

Ocean Time Series

Planning is currently underway for an international time-series workshop focused on time-series methodologies, co-sponsored by IOCCP and OCB. The 2.5-day workshop will be held at BIOS in Bermuda on 28-30 November 2012 and will include thirty scientists from time-series stations in all ocean basins. The organizing committee (Heather Benway - OCB, Kathy Tedesco, Maciej Telszewski and Laura Lorenzoni - IOCCP) has selected a Scientific Advisory Committee made up of researchers from Argentina, Australia, Bermuda, Germany, and the United States.

Workshop Rationale

A more thorough understanding of natural cycles and human-driven changes in the global ocean depends on data from time-series sites around the world. To ensure accurate and meaningful data intercomparison, it is important to exercise transparency in time-series methodologies and implement universal sampling and analytical protocols when possible. This workshop will provide an opportunity to convene technical staff from global biogeochemical time-series sites to review current methodologies being used at the sites, with the aim of standardizing sampling and analytical protocols for key biogeochemical parameters being measured across sites. The workshop will generate a publication describing the protocols used and how they compare to each other. In addition, the workshop will address ways to maintain continuity and analytical integrity, which is especially critical for time-series programs that experience frequent personnel turnover. The effort will contribute to a more effective international research infrastructure focused on understanding the link between regional and global oceanographic processes. The IOCCP and OCB programs provide the optimal combination of expertise in marine biogeochemistry and ocean observing systems to hold such an international dialogue.

Workshop Goals

- Review current oceanographic time-series core sampling and analytical methodologies and rationale behind protocol differences
- To the extent possible, attempt to define standardized methods applicable across time-series
- Attempt to reconcile differences in variable nomenclature
- Examine new techniques available for more accurate and simplified measurements
- Generate a list of suggestions on how automated sensors may improve the type and accuracy of core measurements taken at time-series sites
- Coordinate a publication on sampling and measurement protocols to facilitate data inter-comparison across time-series sites

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4.2 Third Symposium on The Ocean in a High-CO_2 World (SCOR/IOC/IGBP) ***Volkman***

Since last year's SCOR meeting, the plans for the Third Symposium on The Ocean in a High-CO_2 World have been implemented. The activities and status follow:

1. All the plenary speakers were selected and plenary sessions developed for 2 hours each of the first three mornings of the symposium.
2. The symposium Web site was developed (http://www.highco2-iii.org/main.cfm?cid=2259&nid=14514) and a separate Web site was developed to list information from the early-career scientists who would like to be assigned a mentor.
3. Abstracts for oral and poster presentations were solicited and reviewed by the international planning committee. 421 abstracts were received, of which 135 were selected for oral presentations. The oral presentations are divided among 10 different topics in three concurrent parallel sessions (see https://www.confmanager.com/communities/c2259/files/hidden/Detailed_Program_Aug22.pdf).
4. Final arrangements have been made for the plenary hall, break-out rooms, and poster space, as well as audiovisual services.
5. Arrangements for staffing from local volunteers have been made.
6. 120 applications for support were received from early-career scientists and were reviewed. About 60 early-career scientists will receive full or partial support, thanks to support from the U.S. National Science Foundation, the Gordon and Betty Moore Foundation, the UK Ocean Acidification program, IOC, and some commercial sponsors. Mentors have been identified and the matching process is nearly completed. Activities are being developed for the early-career scientists. So far, these include an ice-breaker barbecue before the start of the symposium and a whale-watching cruise after the symposium.
7. As of 20 August, 530 individuals have registered for the symposium.
8. The journal *Biogeosciences* has agreed to host a special issue from the symposium. 52 individuals have indicated an interest in publishing a paper in the special issue. Guest editors are being identified.
9. The meeting expenses are still within budget and we expect them to remain so, although some unexpected costs have resulted from the unexpectedly large number of participants.

4.3 Other Activities

4.3.1 Data Publication Activity *Costello*

What was to become the SCOR/IODE initiative on data publication started in December 2006 at the Second SCOR Summit of International Marine Research Projects (see http://www.scor-int.org/Project_Summit_2/ProjCoord2.htm). The meeting brought together representatives of most large-scale international ocean research projects (e.g. SOLAS, GEOTRACES, IMBER, GLOBEC, etc.). The meeting considered what constituted the major barriers to data sharing and greater data submission to national and global databases and identified a need to create a formal process to ensure that scientists get credit for releasing their data and for every time the data are used by others. To this aim, the meeting recommended that SCOR form a Panel on Ocean Data Publication and Incentives. SCOR and the International Oceanographic Data and Information Exchange (IODE) of the Intergovernmental Oceanographic Commission (IOC) formed an informal group to address this topic.

Since this time, the MBLWHOI Library joined the project and the group of partners meets annually. Two pilot projects have been developed:

1. Creating data publications from existing and future holdings at national data centers.
2. Providing the "digital backbone" for traditional journal publications.

The group continues to present updates of its work to meetings of oceanographers, data centers, and library specialists. An update article is being drafted for *EOS*, led by Ed Urban. The group will meet in Woods Hole, Massachusetts, USA in mid-October to discuss the progress of the pilot projects, as well as to discuss a "cookbook" that presents information about how the approaches used by the pilot projects could be implemented more broadly by other institutions.

A series of workshop reports have been produced from the annual meetings:

- IOC Workshop Report No. 207: http://www.iode.org/wr207
- IOC Workshop Report No. 230: http://www.scor-int.org/Publications/wr230.pdf.
- IOC Workshop Report No. 244: http://www.scor-int.org/Publications/wr244.pdf.

4.3.2 International Quiet Ocean Experiment *Feeley*

The International Quiet Ocean Experiment (IQOE) workshop in October 2010 concluded that there was sufficient interest in this topic to hold an open science meeting (OSM) to gauge community interest. The OSM was held in late August/early September 2011 (see http://www.iqoe-2011.org/) and a related Web site has been developed as a portal to literature and other information about sound in the ocean (see http://aquaticacousticarchive.com/). A draft science plan has been developed and should be in review by the time of the SCOR annual meeting. Scientists in several countries are developing activities to implement the science recommended in the IQOE Science Plan.

4.4.3 IAPWS/SCOR/IAPSO Joint Committee on Seawater *Urban*

SCOR agreed to form a Joint Subcommittee on Seawater with IAPSO and the International Association for the Properties of Water and Steam (IAPWS). This group is a spin-off of SCOR/IAPSO Working Group 127 on the Thermodynamic Properties of Seawater. The Joint Subcommittee is a subgroup of the IAPWS Working Group Thermophysical Properties of Water and Steam. It will be launched at the IAPWS annual meeting at the end of September and should be able to report to SCOR by the time of the annual meeting.

Proposal for a "Joint SCOR/IAPSO/IAPWS Committee on the Properties of Seawater"

Aug 28, 2012

Background

During the 1960s and 1970s, a great deal of fundamental research was carried out on the bulk properties and major constituents of seawater. At the same time, there was a shift away from Chlorinity titration to the use of electrical conductivity as a primary measurement tool for oceanic salinity. A long-standing group, JPOTS (the UNESCO/SCOR/ICES/IAPSO Joint Panel on Oceanographic Tables and Standards), which was constituted from 1964 through to 1990, monitored the state of progress in this area and standardized procedures with the development of a number of standards, culminating in the Practical Salinity Scale 1978 (PSS-78; UNESCO, 1981a), the International Equation of State 1980 (EOS-80; UNESCO, 1981b), and a standard set of software for computing properties of seawater (Fofonoff and Millard, 1983). The relation between oceanographic measurements and the International System of Units, or SI, was described by the IAPSO Working Group on Symbols, Units and Nomenclature in Physical Oceanography (SUN, 1985).

However, these standards were then basically unexamined in any formal way for the next 25 years. In addition, there was little coordination between oceanographers and the metrological community. 'Salinity' (or more accurately 'Practical Salinity') remains a unit-less oddity in the scientific world.

In contrast, instrumentation technology and operational procedures, developed by large-scale projects such as WOCE, rapidly advanced to allow the calculation of internationally intercomparable in-situ measurements of conductivity to a precision about 5 times greater than had been envisaged by JPOTS. The accuracy of estimates of seawater properties were limited by the theoretical basis of the standards, and not by measurement procedures!

Recently, SCOR/IAPSO Working Group 127 on the Thermodynamics and Equation of State of Seawater (2005-2011) synthesized a great deal of existing research, and added to it to create a new standard for the thermodynamic properties of seawater, the Thermodynamic Equation of Seawater-2010 (TEOS-10; IOC et al., 2010). The new standard provides significant improvements over PSS-78/EOS-80.

However, many fundamental issues regarding the properties of seawater and the way in which we estimate them remain to be addressed. Improving our knowledge of these issues and developing improvements in standard practices will have applications to virtually every oceanographic research project, with outreach to marine technology, industry and climatology. These issues include traceability of calibration procedures to the SI (necessary for long-term climate comparisons, and to maintain compatibility with the rest of the scientific world); development of new algorithms for high and low salinities as well as for high temperatures and pressures (required in sea-ice and industrial applications such as desalination); better characterization of electrical conductivity and other properties such as pH, gas solubility, and refractive index; better understanding of the sources and magnitudes of chemical composition variability in the ocean (which will affect our algorithms); and development of measurement technology for density and other properties. Another indispensable ongoing task is the maintenance of the TEOS-10 standard and its software libraries, and guiding the community in its use.

Although short-term Working Groups are a useful way in which groups of researchers can come together to solve the kinds of specific problems mentioned above, this process is very much "bottom-up" and the coverage of important issues can be uneven. In addition, such WGs are an appropriate way of summarizing, synthesizing, and combining available research, but will not monitor or encourage longer-term projects, nor will it be able to maintain links or liaisons to other standards organizations. However, these kinds of tasks are essential to the health of ocean science.

Proposal: a Joint Committee on the Properties of Seawater

We propose a "permanent" joint committee of SCOR, IAPSO, and IAPWS to act as a point of contact for seawater questions (to be called JCS, Joint Committee of SCOR, IAPSO, and IAPWS on Seawater). It will be jointly sponsored by organizations directly concerned with the properties of seawater, and will act as a permanent source of expertise to the parent organizations, and a conduit for communications to other international organizations like the BIPM and the WMO, or IUPAC. It can summarize present progress to the community at large and suggest areas where gaps exist in the available knowledge. It will maintain a repository of knowledge (e.g., via a web-site).

The committee would consist of a chair and several vice-chairs who would coordinate the work and report to the parent organizations as required. Members would be nominated to the committee based on their participation in relevant Working Groups or operational/research/industrial relevance.

The committee would publish reports from time to time, summarizing and/or endorsing products of the working groups. In addition, it would assist the working groups in coming up with products useful for the wider scientific and technical community, by facilitating the development of standards.

Every 6 years (i.e. two terms of the executive) the parent organizations should re-approve the terms of reference.

In detail:

Terms of Reference

1. To act as a 'point of contact' for issues related to the bulk properties of seawater.
2. To maintain and update documents, websites and software of TEOS-10 and other standards.
3. To encourage the uptake of TEOS-10 and other standards by the oceanographic community by acting as a source of advice.
4. To globally coordinate research and the development of standards related to properties of seawater across different scientific communities.
5. To identify developing needs for standards and encourage research in those areas, through small collaborations, more formal Working Groups, conference sessions, or other avenues.
6. To issue reports or other documents from time to time on issues relating to the bulk properties of seawater.
7. To work toward international and interdisciplinary uniformity and consistency of the standards and measurement procedures used in oceanography

Membership

An executive consisting of a chairman and 2 or 3 vice chairs, appointed by the parent organizations for renewable 3-year terms. Members will be appointed by the parent organizations on the advice of the executive, again for renewable 3-year terms.

Proposed Executive:

Rich Pawlowicz (Canada) (proposed chair, member of now-defunct WG-127)

Trevor McDougall (Australia) (proposed vice-chair, chair of now-defunct WG 127, dissemination of TEOS-10 into oceanographic practise)

Rainer Feistel (Germany) (proposed vice-chair, member of WG-127, current chair of IAPWS Seawater Subcommittee, to 2013 only, European coordination)

Members (example):

Members will be proposed by the executive once the committee is approved. Possible members (who have not yet been contacted) include:

Petra Spitzer (Germany) (SI Traceability, other members of EUROMET ocean metrology project)

Allan Harvey (USA) (IAPWS, professional formulation of standards)

Paul Barker (Australia), Jan Reissmann (Germany) (software)

Steffen Seitz, Henning Wolf, Stefan Weinreben (Germany) (conductivity, density measurements, metrology)

Sheldon Bacon (UK), Hiroshi Uchida (Japan) (SSW stability, new density measurements)

Damien Malarde (France) (Refractive Index sensor)

Peter Brewer, Frank Millero, Andrew Dickson (all USA) Chemistry expertise

Ray Weiss (USA) (gas solubilities)

Giles Marion (USA) (thermodynamic numerical chemistry modelling)

Andre Anderko (USA) (transport numerical chemistry modelling)

Jim Swift (USA) (Hydrographer, manager of CCHDO)

Bryan Lawrence (UK) (CF-metadata Standard Names committee, archiving)

Hajo Eicken (USA) Sea-ice and polar science specialist

Jeremy Lovell-Smith (NZ), Olaf Hellmuth (Germany) Ocean-atmosphere, meteorology and humidity specialists, Peter Dexter (Co-President of WMO-JCOMM, Australia) for WMO cooperation and further Maria Filomena Camoes (IUPAC, Portugal), for seawater pH

Thierry Delcroix (France) Specialist for remote sensing of salinity

Industry representatives (Seabird: Norge Larson (USA), Anton Paar: Barbara Laky (Austria), OSIL: Nigel Higgs (UK))

TBD (China) (National Center for Ocean Standards and Metrology, Tianjin, makers of Chinese SSW)

Budget requirements

Regular, if infrequent, face-to-face meetings of the core participants will be needed when substantive issues need to be decided upon. The annual IAPWS meetings presently provide an appropriate venue for such discussions, although other occasions may also arise. No budget pre-commitments to hold JCS meetings are sought at this stage. Rather, a request for funding of a meeting would arise if and when there becomes a clear need to finalize a discussion that has not progressed to completion over email. Working Groups will be handled by parent organizations in the usual way.

A small amount of financial assistance (max $10,000/year) may be requested from SCOR to facilitate the attendance of JCS executive members at important meetings (e.g., those involving the development of formal collaborations between different scientific organizations)

Administrative assistance by one of the parent organizations in maintaining a web presence would be useful to guarantee continuity beyond membership lifetimes. This presence would include a description of the Committee and its members, a permanent email and address, and informational material related to TEOS-10 and other standards directly relevant to ocean science.

Details of Proposed Committee Tasks

The tasks of the committee can be divided into two sets. First, the Level 1 tasks are broad in nature and consist of either ongoing tasks, or important goals which will take a number of years and a broad range of expertise to solve. In contrast, the Level 2 tasks are more immediate short-term research issues, which have been identified as important but can be resolved on a 1-2 year time scale. As these are solved, it is expected that other tasks will follow.

Level 1 Tasks

1. Develop 'SI traceable' metrological standards and procedures for salinity measurements of Standard Seawater
2. Develop a conductivity/salinity relationship to cover the entire range of salinities for which TEOS-10 is valid (from 0 g/kg to the point at which calcium carbonate precipitates) (i.e., extend/update PSS-78). From advanced measurements, estimate the potential drift of SSW conductivity relative to PSS-78 over the past decades.
3. Encourage precision laboratory measurements and experiments with artificial seawater to improve and extend the empirical knowledge on thermophysical properties of seawater, including its chemical composition
4. Develop extensions or updates of TEOS-10 as soon as sufficient quantities of accurate new experimental data become available.
5. Develop additional standard formulations for seawater properties such as conductivity, viscosity, pH, refractive index, surface tension, evaporation and freezing rates, nucleation rates, optical transparency or sound speed attenuation, consistent with TEOS-10.
6. Support studies on less common properties of seawater such as supercooled water at the Antarctic shelf or critical water at hydrothermal vents.
7. Develop a plan to maintain and extend the TEOS-10 code base and encourage its wide use by being incorporated into commercial and research products also beyond oceanography.
8. Assist in the adoption of TEOS-10 and other standards, as they are developed, by the oceanographic community.
9. Encourage and support the use of TEOS-10 and related standards in meteorology, polar sciences and climatology.
10. Recommend, on an occasional but continuing basis, to IAPSO that they continue to approve IAPSO standard seawater, requiring periodically reviewed preparation methods and the support of new methods of traceability to the SI.
11. Develop a better understanding of the composition variations in the ocean (e.g., Ca++ and SO4--, and the marine carbon and silicate systems).
12. Support the development of stable and reproducible standards for marine pH measurement.
13. Accompany and support the development of new CTD sensors such as for density, refractive index or pH, for example by the issue of Certified Research and Development Needs.
14. Develop a metrological practice for systematic and regular estimates of uncertainties for oceanographic observations, archived data and numerical models, consistent with

SI requirements.

Level 2 tasks

1. Characterize the effects of dissolved organic matter (DOM) on density.
2. Resolve outstanding issues on ageing and batch-to-batch variability in conductivity and density of Standard Seawater.
3. Encourage direct measurements of density anomalies in different oceans and adjacent seas and run intercalibration exercises.
4. Re-evaluate the algorithm for Salinity Anomalies after 5 years.
5. Write a 'best practices' document on density measurement.
6. Describe the uncertainty of properties computed from TEOS-10.
7. Support the development of industrial formulations based on TEOS-10 (usually, simplified correlations with reduced accuracy or range of applicability).
8. Review solubility of gases in seawater, and their effects on density and other properties.
9. Characterize the effects of using TEOS-10 (and in particular salinity anomalies) relative to EOS80.
10. Encourage measurements at high salinities and temperatures, and at high pressures.
11. Develop better numerical models for density, electrical conductivity, and other properties of natural waters.
12. Quantify effects of composition variations on the overturning circulation.
13. In intended cooperation with BIPM, prepare an updated document “The International System of Units (SI) in Oceanography”, replacing the obsolete IAPSO/SUN document of 1985.
14. Develop links with Chinese oceanographers and their own primary calibration standard, Chinese SSW

References

- Fofonoff and Millard, 1983: Algorithms for computation of fundamental properties of seawater, UNESCO Technical Papers in Marine Science **44**, 53pp.)
- IOC, SCOR, and IAPSO, 2010: The international thermodynamic equation of seawater – 2010: Calculations and use of thermodynamic properties, IOC, Manuals and Guides No **56**, Unesco, 196pp.
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- UNESCO, 1981a: Background papers and supporting data on the Practical Salinity Scale 1978, UNESCO Technical Papers in Marine Science, **37**, 144pp.
- UNESCO, 1981b: Background papers and supporting data in the International Equation of State of Seawater 1980, UNESCO Technical Papers in Marine Science, **38**, 192pp.

Informal Interim Report on Seawater Activities

Aug. 28, 2012

R. Pawlowicz

Although SCOR/IAPSO WG 127 formally ended last year, activity has continued in 2012 in a number of areas. I have summarized the 'highest profile' achievements here to give you a flavour for the work that the Joint Committee of Seawater will help to coordinate.

Continuing progress on seawater in 2012:

1. R. Feistel (as chair of IAPWS SCSW) attended annual meetings of BIPM-CCQM and BIPM-CCT at Paris-Sevres and gave talks on the future tasks of JCS (BIPM maintains the International System of Units or SI). Cooperation has begun on SI-based definitions of seawater salinity, pH, and atmospheric humidity; first stage is a joint paper to be appear in *Metrologia*, which has gone through several drafts in the last 9 months (see below).
2. European Metrology Research Program (EMRP) Project ENV05 "Metrology for ocean salinity and acidity" held a workshop in Jan 2012 (Biarritz) and will hold another 24 Sept. 2012 (Berlin). This project (6 PIs) targets technical aspects of SI traceability, as well as new measurements of sound speed and dissolved oxygen.
3. New measurements and model calculations for properties at high salinities, extensions of TEOS-10 for lake studies (various workers, see papers below)
4. Dissemination of TEOS-10: The TEOS-10 web site has had ~12,000 unique visits and ~1600 unique downloads of the TEOS-10 computer software since October 2010. Several overviews have been written (see Book Chapters and Other below). *Ocean Science* Special Issue on Thermodynamics of Seawater completed with a historical introductory paper (see below).
5. Many of the PIs involved in 1-4 will meet at the IAPWS annual meeting (Boulder, CO) Oct. 1-5, where in addition JCS will be formally proposed.

Papers in Preparation:

1. Metrological challenges for measurements of key climatological observables: Oceanic salinity and pH, and atmospheric humidity, R Feistel, R Wielgosz, S A Bell, M F Camoes, J R Cooper, P Dexter, P Fisicaro, D P Gatley, A H Harvey, M Heinonen, O Hellmuth, N Higgs, H-J Kretzschmar, J W Lovell-Smith, T J McDougall, R Pawlowicz, S Seitz, P Spitzer, D Stoica and H Wolf. (Position paper on future cooperation activities between BIPM and IAPWS, to be published in *Metrologia*)

Papers Submitted:

1. Olaf Hellmuth, Vitaly I. Khvorostyanov, Judith A. Curry, Alexander K. Shchekin, Jürn W. P. Schmelzer, Rainer Feistel, Yuri S. Djikaev, Vladimir G. Baidakov (2012): Selected Aspects of the Theoretical Description of Ice and Salt Crystallisation in Aqueous Electrolyte and Polymeric Solutions. Submitted for publication in "Nucleation Theory and Applications", edited by Jürn W. P. Schmelzer, Gerd Röpke, and Vyatcheslav B. Priezzhev, Joint Institute for Nuclear Research, Bogoliubov Laboratory of Theoretical Physics, Dubna, Russia.
2. O. Hellmuth, R. Feistel, and A. K. Shchekin (2012): A conceptual contact angle model for atmospheric freezing catalysis. In preparation for Atmos. Chem. Phys. (Discuss.)

Papers published and in press:

1. Millero, Ward, Lo Surdo, Huang, Effect of pressure on the dissociation constant of boric acid in water and seawater, Geochim Cosmochim Acta, 76, 83--92, (2012)
2. Pawlowicz, McDougall, Feistel, and Tailleux, An historical perspective on the development of the Thermodynamic Equation of Seawater - 2010, Ocean Sci., 8, 161-174, (2012)
3. Safarov, Berndt, Millero, Feistel, Heintz, and Hassel, (p,r,T) properties of seawater: extensions to high salinities, Deep Sea Res., I, 65, pg 146--156, (2012)
4. Pawlowicz, The electrical conductivity of seawater at high temperatures and salinities, Desalination 300, 32-39 (2012)
5. Pawlowicz and Feistel, Limnological applications of the Thermodynamic Equation of Seawater 2010 (TEOS-10), Limnology and Oceanography:Methods, in press (accepted June 2012)
6. Graham, F. S. and T. J. McDougall, 2012: "Quantifying the non-conservative production of Conservative Temperature, potential temperature and entropy". Journal of Physical Oceanography, provisionally accepted by the journal.

Book Chapters and other:

1. Pawlowicz, "Key Variables: Temperature, Salinity and Density", online in Physical Oceanography Topic Room, Nature Education Knowledge Project (reviewed, accepted Aug 2012)
2. McDougall, Feistel and Pawlowicz, "Thermodynamics of Seawater". In "Ocean Circulation and Climate 2nd edition", G. Siedler, J. A. Church, J. Gould and S. M. Griffies, eds., Academic Press, awaiting return to the editor. (2013)