Surface Ocean CO_2 Variability and Vulnerabilities Workshop

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Co-sponsored by the International Ocean Carbon Coordination Project (IOCCP)
Surface Ocean Lower Atmosphere Study (SOLAS)
Integrated Marine Biogeochemistry and Ecosystem Research (IMBER) program, and
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1. Introduction to the Workshop

The oceans have taken up approximately 48% of the total fossil-fuel and cement-manufacturing emissions since the beginning of the industrial revolution (*Sabine et al., Science, v.305, 367-371, 2004*). This represents only 1/3rd of the ocean's long-term potential to absorb anthropogenic CO_2, making it a powerful natural sink for anthropogenic CO_2. But how will this sink behave in the future under changed climate and ocean conditions? While we are now close to monitoring oceanic CO_2 uptake on decadal and regional scales, meaningful predictions of its future behaviour are difficult. Climate change impacts ocean biology and physics and could lead to reduced efficiency of the carbon sinks, a process that atmospheric data and ocean models indicate is already occurring in the Southern Ocean. Attempts to set a baseline stabilization target for the atmospheric CO_2 concentration will ultimately depend on our understanding and prediction of oceanic CO_2 sinks. There is a critical and urgent need to better understand the ocean processes regulating CO_2 uptake and to identify research and observational priorities for the future.

On April 11-14, over 100 scientists from 20 countries gathered at the United Nations Educational, Scientific, and Cultural Organization (UNESCO) in Paris to review the current knowledge base and enhance international cooperation to resolve the magnitude, variability and processes governing ocean sources and sinks of carbon, from observations, process-based models and atmospheric and oceanic inversions. This workshop, co-sponsored by the International Ocean Carbon Coordination Project (IOCCP), the Surface Ocean Lower Atmosphere Study (SOLAS), the Integrated Marine Biogeochemistry and Ecosystem Research (IMBER) program, and the Global Carbon Project (GCP), addressed several key questions through plenary talks, a poster session, and working groups, including:

- What are the decadal changes in the air-sea CO_2 flux in the oceans today and how well can we predict their changes in the future?
- What processes have controlled the observed CO_2 flux variability?
- Are present oceanic and atmospheric models simulating the observed changes?
- How do changes in ocean physics (temperature, salinity, and circulation) and atmospheric dynamics impact air-sea CO_2 fluxes today, in the future, and in the far future?
- What is the possible contribution of changes in marine ecosystems on air-sea CO_2 fluxes?
- How can we use evidence from the present and the past to set bounds on the possible response of the carbon cycle to physical and biological changes in the future?
- Can we estimate how CO_2 fluxes have changed in the coastal ocean?
- What observational strategies, instrumentation and model developments are required to deliver better air-sea CO_2 flux estimates into the future

New results were presented for a global air-sea CO_2 flux climatology and detection of decadal variations in oceanic partial pressures of CO_2 (pCO_2). Observations conducted over more than 20 years show the long term pCO_2 increase of surface waters is generally close to the atmospheric CO_2 increase, indicating relatively constant sinks. However, in recent years significant decadal changes in pCO_2 have been observed in some parts of the ocean, e.g. in the North Atlantic and Equatorial Pacific. But while trends can be detected in some areas, for many regions there are still no routine observations. Quantification of the decadal changes of the air-sea CO_2 fluxes has also been improved using atmospheric CO_2 data, especially for the vulnerable Southern Ocean, where oceanic data are sparse. Following invited talks and poster presentations, the workshop participants broke down into three working groups to address issues of vulnerabilities in the ocean carbon – climate system, observation strategies required to address our largest unknowns, and needs for global and regional synthesis activities. The workshop resulted in actions for developing joint synthesis papers, establishing a standard and well documented global surface CO_2 data set, and producing a regular atlas of surface ocean CO_2. Regional synthesis groups were formed to analyze the underlying causes for variability and vulnerability in the system and to develop plans for a sustained observing system.

2. About the Sponsors

IOCCP: The International Ocean Carbon Coordination Project promotes the development of a global network of ocean carbon observations for research by:

- providing an international forum for agreements on standards and best practices,
- assessing whether current observations are sufficient to meet science goals, and
- encouraging international cooperation in observation program implementation and data synthesis.

Understanding surface pCO_2 variability requires large-scale synoptic datasets that can only be developed through international collaborations, and facilitating this process is one of the major goals of the IOCCP for this workshop.

SOLAS/IMBER: IMBER and SOLAS have established a joint carbon implementation group to provide scientific guidance to, and oversee the development, planning and implementation of the oceanic carbon research. A joint implementation plan that sets out research priorities for ocean carbon research to be conducted over the next ten year was developed (http://www.imber.info/C_WG.html). One approach in the SOLAS/IMBER Carbon Research implementation plan was the formation of a sub- working group on Surface-Ocean-System that is led by Nicolas Metzl. The first mission of this group was to develop the scientific basis for VOS Network design and Data Synthesis efforts jointly with IOCCP, which has materialized in the organization of this workshop.

GCP: The Global Carbon Project supports integration and global analyses of the multiple components of the carbon cycle and its interactions with climate and the human perturbation and response. The ocean is a key part of this cycle, and the GCP supports the efforts of this workshop i) to improve the observing strategy for ocean carbon and ii) to understand the vulnerability of key ocean basins and processes to climate change which could result in the reduction or reversal of current carbon sinks.

3. Vulnerabilities in the Ocean Carbon-Climate System

Science Highlights

Co-chair Bronte Tilbrook opened the meeting by reminding the participants of the purpose and goals for the workshop (see Section 1) and Corrine Le Quéré introduced the first session on vulnerabilities in the ocean carbon – climate system. She began by noting that total CO_2 emissions are currently at 9.3 $PgCyr^{-1}$ and increasing rapidly, while the observed uptake of anthropogenic carbon (from indirect observations) suggests that the percentage of the total emissions taken up by the oceans has decreased between 1850-1994 and 1980-2005. This would be consistent with the expected rate at which the oceans can absorb carbon, but the uncertainty in this estimate does not allow firm conclusions. She emphasized that it is vital that we understand how the ocean CO_2 sink has evolved in the recent past, and how it will evolve in the future under a changing climate, particularly in the current context where stabilization of atmospheric CO_2 is becoming a political and economic issue. This is a complex problem, with changes in ocean physics and biology driving both positive and negative feedbacks. Changes in ocean physics have partly been documented. The heat content of the oceans has increased since at least 1955. Over this same time-period, the observed changes in salinity suggest an enhancement of the water cycle, with saline regions becoming saltier and less saline regions becoming fresher. Furthermore, the winds have intensified and moved southward in the Southern Ocean. However, no changes in ocean circulation have been detected by direct observations. Due to the timescales involved, there are still very few observations of statistically significant trends in the oceanic carbon cycle (with the exception of a few time series sites) giving us little constraint for evaluating models that make projections for the future. While the ocean provides a valuable service by reducing atmospheric CO_2, there is also a risk that CO_2-induced acidification of the oceans will have adverse effects on a variety of marine life forms, in particular calcifying organisms.

Nicolas Gruber provided a detailed overview of the major vulnerabilities in the ocean carbon – climate system, suggesting a list of the three most vulnerable processes in the ocean system (in decreasing importance):

1. Circulation feedback: Reduction in ocean circulation, especially in the Southern Ocean, and its negative impact on the oceanic uptake of anthropogenic CO_2
2. Warming feedback: Ocean warming, and its negative impact on the natural carbon cycle (solubility pump)
3. Biological pump feedback: Changes in the biological pump, whose consequences on the net air-sea balance can be either positive (enhanced uptake through a more a efficient biological pump) or negative (enhanced outgassing through a weakening of the efficiency of the biological pump).

Given that almost nothing is known about how the biological pump will react to global climate change and ocean acidification, its future role as a potential feedback cannot be established at this time. Gruber noted that there is some evidence that the Southern Ocean sink has decreased by 0.3 $PgCyr^{-1}$ over the past 50 years, possibly linked to the Southern Annular Mode trending towards more positive values, increasing wind speeds and upwelling around Antarctica. Gruber also noted that the vulnerability criterion needs to be viewed relatively broadly, and not just in the perspective of atmospheric CO_2 change. He listed three regions where ecosystems are most at risk:

1. Coastal regions
2. Arctic and Antarctic oceans
3. Subtropical gyres

He emphasized that there is large uncertainty in these lists, and that monitoring is key to understanding the processes taking place.

Ken Caldeira looked to the geological past to search for analogues of the present and projected future environmental change. He concluded that if current trends continue, the oceans are likely to experience pCO_2 and pH levels that have not been experienced over the past tens of millions of years. Current rates of change in atmospheric CO_2 and surface ocean chemistry exceed those typical of glacial-interglacial cycles by two orders of magnitude. Furthermore, he pointed out that while atmospheric CO_2 has been much higher and pH much lower in the distant past, the degree of saturation with respect to carbonate minerals (e.g., calcite and aragonite) may have been greater than it is today. This situation can arise over time periods greater than 10 kyr because the ocean saturation state adjusts so that the fluxes of $CaCO_3$ to the sediments balances the flux of cations coming in from rivers. In the distant past, high pCO_2 is correlated with high rates of rock weathering, and thus high cation fluxes to the ocean, high alkalinity, high carbonate mineral saturation states and high fluxes of $CaCO_3$ to the sediments. This contrasts with the situation occurring now, in which high pCO_2 is associated with a decrease in carbonate mineral saturation states. Thus, extended time periods with high CO_2 in the distant past are not good analogues for understanding the marine biotic response to increasing CO_2 concentrations over the next decades and centuries

Laurent Bopp presented results from the Coupled Carbon Climate Model Intercomparison Project (C4MIP), using 11 models to investigate the range of sensitivities to feedbacks resulting from coupling the carbon and climate systems. For the period 1860 to 2100, due to positive feedback effects, the models simulated a release of an additional 20 to 200 ppm of CO_2 to the atmosphere. For the ocean carbon cycle, the differences between the models are explained both by their responses to increasing atmospheric CO_2 and climate change. The response to increasing atmospheric CO_2 seems to be closely related to the volume of the surface mixed-layer. The response to climate change is different between the different models and no clear relationship to global physical variables has been established.

Andreas Schmittner presented a modelling study looking 2000 years into the future using the University of Victoria ESCM model. Results from a simulation using the A2 emission scenario (with fossil emissions reaching a maximum of 28 $PgCyr^{-1}$ in 2100 before decaying to zero) showed warming of 6°C in the surface ocean and 2°C in the deeper ocean. Sea ice was reducing by 90%, sea levels rose by 2.5m due to thermal expansion alone and ocean circulation slowed (e.g. Circumpolar Deep Water inflow into the Indian and Pacific oceans decreased from 13 to 2 Sv) before partly recovering. Net Primary Production (NPP) doubled due to the increase in temperature while exports to deeper water decreased due to slowing in the ocean circulation. It was noted that the response in the model was lagged by 200 years from the emissions, indicating that impacts we create now will have an effect for a long time into the future. Changes in the biological pump due to increased calcite production in the model simulation became important after year 2500 further increasing atmospheric CO_2 (although it was noted that the direct effect of acidification on calcite production was not considered and hence this result needs to be taken with caution). Discussions queried the temperature NPP relationship suggesting other factors (light limitation, nutrients) would prevent the NPP from doubling even with the increase in temperature.

Ulf Riebesell reported on CO_2 sensitivities of biologically-driven processes with a potential for feedbacks to the climate system. Most notably, CO_2 induced ocean acidification is likely to cause a slow down in bio-calcification, leading to decreased stability of calcium carbonate shells and skeletons. Aside from its effect on marine ecosystems, reduced calcification provides a small negative feedback to increasing atmospheric CO_2 concentrations. Among the non-calcifying organisms, some groups appear to respond favorably to CO_2 enrichment. Most prominently, photosynthetic carbon fixation of some algal groups is stimulated at elevated CO_2 concentrations. CO_2-enhanced rates are also measured for nitrogen fixation of diazotrophic cyanobacteria. Recent studies also showed changes in the production of climate relevant gases, such as DMS and chloriodomethane, in response to ocean acidification. Little is presently know about synergistic effects from other environmental changes, such as global warming and related changes in surface ocean stratification and nutrient supply. Model simulations indicate that the observed biological responses have the potential to trigger shifts in key biogeochemical processes, with significant feedbacks to the climate system.

Scott Doney and Phil Boyd's presentation discussed the potential impact of climate-induced changes in marine ecosystems on the ocean carbon cycle. The talk focused on both bottom-up (nutrients, temperature, light) and top-down (e.g., fisheries) processes. Of particular note are ecological regime shifts documented in the observational record. Due to computational constraints, the current generation of coupled atmospheric-ocean models use relatively simple ecosystem models with at most phytoplankton functional groups (e.g., diatoms, coccolithophores). There is a critical need for more field data, especially higher trophic levels, and more complete understanding of the complex food web interactions, also at higher trophic levels, to be able to link climate, foodwebs and ocean biogeochemistry.

Alessandro Tagliabue showed that the effects of reduced dust deposition on CO_2 fluxes and marine productivity are quite small, with a reduction in the ocean uptake of just 3%, reducing the cumulative sink by 19 PgC over 240 years. This is because the reduced aeolian iron input results in an excess of macronutrients that then fuel increased ocean uptake in adjacent, non-iron limited waters. This spatial retroaction in primary productivity, and thus ocean uptake, results in a rather small global effect, despite local variability. In addition, a reduction in dust deposition is unlikely to unbalance the ocean dissolved inorganic nitrogen inventory, since lower N_2 fixation rates were found to be counterbalanced by a comparable decline in the rate of denitrification.

Galen McKinley discussed a process based regional model (MITgcm) being used for the North Atlantic. The model has 0.5 degree horizontal resolution and the ecosystem has 2 phytoplankton classes and 1 zooplankton class and is coupled to a carbon and oxygen cycles. Initial analyses include a deconvolution of the CO_2 flux, which shows that in the subpolar gyre, the effect of the bloom and the effect of seasonal winds are out of phase, but that the bloom drawdown dominates the seasonal flux cycle. When integrated over the whole basin the flux variability is small, but regionally the variability can be large. Vertical mixing and the spring bloom are key components of the variability, particularly in the subpolar region.

Liqi Chen discussed the variability of pCO_2 in the Southern and Arctic Oceans. In the Southern Ocean, the distribution of pCO_2 has a large variation between different months and different years. These variations are also present in the western Arctic Ocean. However, major control factors are quite different. In the Southern Ocean, biology and circulation are important factors. For the western Arctic Ocean, a significant contributor to variability is the transition from shelf to deep water and the local advective currents which can have very different properties. He outlined future plans including the installation of an innovative onboard new production measurement using ^{234}Th and a sophisticated NOAA underway system for Arctic and Antarctic cruises.

Working Group Outcomes and Actions

Meeting participants in this working group on vulnerabilities in the ocean carbon-climate system were asked to address several questions: Can we identify from field observations and model outputs the most likely regions of the ocean where the large-scale air-sea CO_2 fluxes have changed in the recent past and are most susceptible to change in the future (i.e. most vulnerable)? Can we identify the underlying processes? Can we assess the content and quality of the models that are used to quantify the observed and projected changes? The group defined vulnerable regions as regions where the air-sea CO_2 fluxes are susceptible to changes large enough to impact the measurable or projected trend in the global oceanic CO_2 sink (a) up to 2030, (b) 2100, and (c) stabilisation CO_2. This includes consideration of the physical, chemical and biological processes which affect the marine carbon cycle.

The discussion in the working group focused on assessment of observed trends in the air-sea difference of pCO_2, and on an assessment of potential future vulnerabilities of the ocean carbon cycle.

Assessment of Observed Trends:

Estimates from the different oceanic regions (also pertaining to different time periods) were collated into a single global map. Substantial differences between the different regions emerged, with a few regions showing negative trends (i.e. oceanic pCO_2 decreasing relative to atmospheric pCO_2), but with the majority of the regions showing either no trend (oceanic pCO_2 in sync with the atmospheric pCO_2) or increasing trend (oceanic pCO_2 increasing faster than that of the atmosphere). Given the fact that under constant climate, the air-sea difference in pCO_2 should have a negative trend (oceanic pCO_2 rising more slowly than the atmosphere), these observations suggest that the ocean carbon sink may already show signs of a decreasing strength.

Assessment of Future Vulnerabilities:

The 2^{nd} part of the discussion focused on the establishment of a first global map of regions and processes that might be particularly vulnerable to future change. The construction of this map was guided by model results, but a quick consensus emerged that presently available models should only be used as indicators, since (i) regional trends are not projected robustly across the few models available, and (ii) current models lack a substantial number of potential feedbacks. Therefore, the approach taken to identify the oceanic vulnerabilities was based on the expert knowledge of the people present.

Following the working group discussions, the group outlined several action items for continued work and development of a synthesis paper, under the leadership of session co-chairs Corinne Le Quéré and Nicolas Gruber :

1. Finish the regional trend map. Check against original published work. Compare with expected trends in a constant climate scenario with the oceanic pCO_2 change driven solely by the increase in atmospheric CO_2.
2. Finish the vulnerability map. Open for discussion.
3. Write synthesis paper on observed trends and potential vulnerabilities of the ocean carbon cycle on the basis of 1 and 2. Le Quéré to take lead, Gruber to assist.

4. Ocean Carbon Sources and Sinks and Strategies for Estimating Air-Sea Fluxes of CO_2

Science Highlights

Global Climatology

Presenting Dr. Taro Takahashi's work, Rik Wanninkhof showed an updated global air-sea CO_2 flux climatology. It is based on a global database of pCO_2 observations assembled by Takahashi, comprised of 2.8 million observations obtained from dozens of researchers around the globe. But despite the 3-fold increase in observations from the '97 climatology, there are still regions that show significant observational gaps. For instance, in the southeast Pacific there are several 4˚ by 5˚ pixels that have no observations at all. The increase in data is mostly in regions with prior observations, thereby improving the monthly flux estimates and providing better resolution for the longer-term trends and seasonal variability. The Southern Ocean coverage has improved, including observations in the marginal ice zone, and this is reflected in the reduction in uncertainty in this region and smaller CO_2 uptake the Southern Ocean compared to the previous climatology.

Globally, the ocean pCO_2 is tracking the atmospheric CO_2 increases fairly closely based on linear interpolations of seasonal detrended data with a notable exception in the South Bering Sea where the pCO_2 appears to have been decreasing over the past three decades. Wanninkhof observed that the North Pacific appears to have more regional variability in the long terms trends than the North Atlantic.

The global annual net air sea CO_2 flux is estimated at -1.2 $PgCyr^{-1}$. This translates into an anthropogenic CO_2 input of 1.6 $PgCyr^{-1}$ when accounting for a net efflux of 0.4 $PgCyr^{-1}$ prior to the anthropocene. Significant uncertainties in the climatology include the choices of gas transfer velocity algorithms and wind speed products. These factors contribute to an uncertainty in the global flux of 25%. A comparison of the sea surface temperatures determined in conjunction with the pCO_2 measurements with independent global SST climatologies suggests a bias of 0.08°C. When this bias is accounted for it could increase the net uptake by 0.3 $PgCyr^{-1}$.

Basin Overviews

Ute Schuster showed that trends of sea surface pCO_2 are different in different biogeochemical regions of the North Atlantic from 1990 to the present. In the tropical regions, sea surface pCO_2 has closely followed the increasing trend in atmospheric pCO_2. Further north, sea surface pCO_2 has increased faster than in the atmosphere as shown at two sites, one in the eastern temperate region and one in the western subpolar region. As well as this decadal variability, interannual variability has occurred in all regions. Several underlying causes led to the observed changes in sea surface pCO_2. Most likely, low-frequency modes, such as the North Atlantic Oscillation and the El-Nino Southern Oscillation, lead to changes in wind speed and/or barometric pressure, in turn leading to changes in sea surface circulation, vertical mixing, in turn leading to changes in sea surface temperate and/or biological activity, all affecting sea surface pCO_2. An estimation of the air-sea flux of CO_2, using both multilinear regression and neural networks, show that the North Atlantic sink in 2005 between 10° and 65° N was between 0.33 to 0.36 $PgCyr^{-1}$,. As a comparison, the recalculated flux (for the same geographical extent) using climatological data, showed a sink of 0.47 $PgCyr^{-1}$ for 1995.

Are Olsen showed a relationship between salinity and the growth rates of surface pCO_2 in the Nordic Seas, with more saline waters showing a faster increase in pCO_2. The pCO_2 growth rate in Atlantic waters exceeds that of the atmosphere, which appears due to advection of anthropogenic CO_2. In the broader Arctic there are very limited data and it is not possible to assess the interannual variability. With decreasing sea ice and changes in aragonite saturation, the Arctic can expect to see significant feedbacks on atmospheric CO_2 and marine ecosystems.

The carbon sources and sinks of the North Pacific were reviewed by Yukihiro Nojiri. The data coverage between Japan and Vancouver and California is very good, with around 160 successful pCO_2 missions over the last 12 years. The tracks vary substantially, giving excellent coverage between

20°N and 55°N. On average, the trends match the atmospheric increase, but spatially the trends in pCO_2 are highly variable, with trends below the atmospheric trend in the region between 150°E-170°W, 40°N, while there are trends greater than the atmosphere in the region around 160-145°W, 40°N. Importantly, the atmospheric observations are made using a separate system, providing very accurate atmospheric measurements and there is a need to get these data into the Global View atmospheric CO_2 data integration.

Dick Feely presented an overview of the Equatorial and South Pacific regions. He showed that the pCO_2 trend is positive at around 1.8 ppmv yr^{-1} in the equatorial Pacific and that the trend has significantly increased after 1990, which is consistent with an increase in overturning circulation. There is a strong temperature-pCO_2 relationship in the Equatorial Pacific although it can differ between normal and El Nino conditions. There is a strong seasonal cycle in the ΔpCO_2 in the band 14°N-50°N, which is out of phase with the seasonal cycle for 14°S-50°S. Satellite-derived maps of pCO_2 distributions and fluxes show good agreement with the Takahashi climatology.

For the Indian and Southern Oceans, Nicolas Metzl first described observed pCO_2 and air-sea CO_2 fluxes seasonal cycles. Because of recent observations made during austral winter, the seasonality is now much better described in high latitudes (south of the Polar Front). Metzl noted that the new Takahashi climatology shows a smaller Southern Ocean sink than previous climatologies mainly due to the availability of more winter measurements when the ocean acts as a source to the atmosphere. The Southern Ocean as a whole is a small sink of approximately 0.05 $PgCyr^{-1}$. New models do considerably better at simulating the seasonal pCO_2 cycle (previous models had the cycle out of phase) and these models also estimate a small carbon sink in the southern ocean (< 0.1 $PgCyr^{-1}$, see also presentation by S. Mikaloff-Fletcher). In high latitudes, the interannual variability (observed during austral summer only) is high and it is somehow difficult to detect long-term trends from these data. However, three recent independent studies based on observations do suggest that over the last 40 years ocean pCO_2 increased at a rate close to the atmospheric increase. This is important for understanding air-sea CO_2 flux variations in the recent past and present, and for future scenarios. Several analyses have recently related the decadal variability of the carbon sink in the Southern Ocean to large-scale climate forcing (e.g. Southern Annual Mode, see C. Rödenbeck presentation). In the Southern Ocean, where observations are still sparse, the pCO_2 data synthesis will be extremely important to investigate processes (e.g. changes of Net Primary Production, dust, water mass formation, etc) linked to both variability and vulnerability in a region where climate change could impact significantly on stratification, circulation, chemistry (e.g. acidification) and biological activity.

Arthur Chen presented an overview on the role of the coastal ocean in the ocean carbon cycle. Based on current research to date, it is not yet clear if the coastal zones are carbon sources or sinks to the atmosphere. In fact, the first LOICZ report (Kempe, 1995) concluded that coastal seas could be net sinks or sources of CO_2 for the atmosphere, with slim prospects for a quick resolution. LOICZ did not seem to provide a clear answer after the completion of the first phase. Arthur Chen said that many people have assumed the coastal areas to be sources, releasing the riverine carbon near the coast. However, mass balance calculations, as well as direct pCO_2 measurements, indicate a consistent pattern. Chen estimates that although the estuaries and coastal waters are generally sources of carbon, the much larger continental shelves are sinks due to upwelling of nutrient-rich subsurface waters from offshore. As a result, he estimates that the continental shelves are a sink for carbon of 0.3-0.4 $PgCyr^{-1}$.

Carbon Sources and Sinks

The variations of ocean surface pCO_2 are closely linked to biological activity. On the decadal scale, observed trends of pCO_2 are likely related to warming and circulation but long-term changes of primary production or changes in ecosystems have to be taken into account and their effect on the ocean carbon cycle to be quantified. The following two presentations were aimed at describing the current knowledge of the long-term variations of ecosystems and species and sea surface chlorophyll and primary production.

Gregory Beaugrand presented observations from the Continuous Plankton Recorder (CPR) which has been used since 1931 in the North Atlantic Ocean. Changes in the distribution, diversity, dominance and phenology of species are clearly linked to climate variability. Beaugrand identified a cool period of 1964-1981 and warm period in 1987-onwards in the North Sea with a shift to decreased export in the warm period. Many biological changes are in agreement with predicted changes, and show strong sensitivity to temperature. Based on both satellite chlorophyll data and CPR observations, a critical thermal boundary has been identified (window around 9-10°C), where the northward progression of this boundary is associated with abrupt ecosystem shifts and pronounced reduction of cod stocks. These changes may have strong consequences for commercial fisheries resources in the North Sea and possibly some biogeochemical cycles.

David Antoine noted that future changes in the biological pump due to warming, changes in stratification, and nutrient availability are believed to be different in high and low latitudes. However, the detection of these processes is not simple and cannot be inferred from chlorophyll observations alone. Field data for chlorophyll are very limited on a global scale, while satellite observations are just beginning, and issues still exist regarding merging data from different sensors. Field data from a transect in the Southern Indian Ocean south of Australia show an increase in chlorophyll over the period 1965 to the present. In the high latitudes of the North Atlantic in-situ observations (CPR colour index) calibrated with satellite data also show an increase of sea surface chlorophyll concentrations over the last 50 years. Interannual changes of chlorophyll and net primary production in the tropics have been also correlated with large-scale climate indices (e.g., multivariate ENSO index). At the global scale, a previous analysis of CZCS (Coastal Zone Color Scanner) vs SeaWIFS (Sea-viewing Wide Field-of-view Sensor) data suggested a global decrease in chlorophyll (~6%) over the past 20 years, but a new study based on the same data shows an increase of about 20%. These differences must be explained. These global products help to validate current ocean simulations; models seem to capture the increase in chlorophyll in high latitude and a decrease in low latitudes, but disagree with observations in some regions (i.e. Indian Ocean, Southern Ocean). Overall, chlorophyll shows the potential to be a good indicator of net primary production changes, but longer time series of good quality remote sensing data calibrated by *in situ* sensors are required (the so-called "climate quality data records"). They should include chlorophyll and any other product that may help in the understanding of long-term changes (e.g., phytoplankton functional types, coloured dissolved organic matter).

Scott Doney discussed the patterns and underlying mechanisms of interannual variability in air-sea CO_2 flux using numerical simulations with the (Coupled Community Climate System Model) model. Variability maxima occur in the Equatorial Pacific, Southern Ocean, and temperate to subpolar regions of the northern hemisphere ocean. Most of the interannual variability in these regions is driven by variation in the lateral and vertical advection of dissolved inorganic carbon and thus pCO_2. In the subtropics, the dominant source of variability is thermal variations in surface pCO_2.

Sara Mikaloff-Fletcher described an inverse method used to estimate separate natural and anthropogenic air-sea fluxes of CO_2 based on GLODAP observations of dissolved inorganic carbon and other tracer concentrations in the interior ocean and Ocean General Circulation Models (OGCMs). They found a substantial natural outgassing in the Southern Ocean, which is cancelled by vigorous uptake of anthropogenic carbon, to yield a small net sink. These results contradict results from the OCMIP-2 (Ocean Carbon Model Intercomparison Project) simulations, but agree with the most recent Takahashi flux estimates based on pCO_2 data and recent model simulations from the CCSM model. The flux estimates from the ocean inversion imply relatively small cross-equatorial transport of natural carbon, which suggests that the northern hemisphere carbon sink is primarily due to terrestrial uptake rather than the preindustrial carbon transport loop proposed by Keeling et al. [1989]. Mikaloff-Fletcher went on to detail the limitations of inversions in general, including model errors, data scarcity, and potential errors associated with the inverse method. The flux estimates were robust across a suite of 10 different OGCMs and several scenarios used to assess biases in the tracers used to constrain the inversion. Nevertheless, the inversion could be sensitive to biases common to all of the OGCM's and biases in the inverse methodology, such as the assumptions about temporal variability.

The greatest limitation of the ocean inversion is that it cannot be used to estimate temporal variability using the data and models currently available.

Mark Battle presented Atmospheric Potential Oxygen (APO), a proxy atmospheric tracer which is modified by ocean carbon fluxes, ocean oxygen fluxes, only slightly by fossil emissions and not at all by land biota fluxes. APO observations from Japanese stations suggest a global ocean carbon sink of roughly 1.8 $PgCyr^{-1}$ for the 6-year period beginning in mid-1999. Other recent observations confirm that the APO values are highest in the tropics, and lowest at the northern high latitudes, and that the interhemispheric gradient varies considerably over time. Forward models are now able to capture the seasonal cycle well, although uncertainties in atmospheric tracer transport are significant compared to the measured spatial gradients. There is also some indication that interannual variability in APO reflects primarily ocean ventilation.

Christian Rödenbeck showed the set up and results from an atmospheric CO_2 inversion. The relatively small variability in the oceans compared to the land makes it difficult to infer ocean processes in most ocean regions. Focusing on the Southern Ocean Rödenbeck showed that the inversions infer a decrease in the Southern Ocean sink of 0.031 $PgCyr^{-1}$ per decade, whereas given the increase in atmospheric CO_2 the sink would have expected to have increased by 0.051 $PgCyr^{-1}$ - a statistically significant difference of almost 0.1$PgCyr^{-1}$ per decade, attributable to changes in wind-driven upwelling of carbon-rich deep water. A similar inversion was shown for Atmospheric Potential Oxygen. Results indicate a statistically significant correlation of tropical oceanic oxygen fluxes with ENSO, consistent with reduced upwelling of the oxygen minimum.

Strategies to Estimate Air-Sea Fluxes of CO_2

Chris Sabine reported that, despite the significant improvement in the pCO_2 observing network, we are still struggling to produce annual global flux maps. The CO_2 fluxes exhibit significant variability in time, meaning *in situ* autonomous instruments can greatly help reduce uncertainty in the fluxes and he discussed the use of moorings to improve the temporal observations and enhance the spatial information obtained from the VOS network. He outlined the colorimetric-based pCO_2 drifter and moored systems (e.g. CARIOCA, $SAMICO_2$). He also discussed the NDIR systems such as those used in the MBARI and NOAA/PMEL $MAPCO_2$ systems. Sabine noted that two carbon parameters must be measured to constrain the ocean CO_2 system and discussed some of the current efforts to develop a second carbon parameter that can be measured on moorings. He showed work to develop autonomous pH and alkalinity sensors from DeGrandpre, Byrne, Kimoto and Sayles. Sabine highlighted the variability that the moorings can capture that infrequent ship visits to a station do not capture and how the higher frequency data can help the interpretation of ship board time series. He showed examples from the Equatorial Pacific, the Hawaii Ocean Time-series station, the Bermuda Atlantic Time-Series station and DYFAMED each with different sources of high frequency variability that was not captured by the ships.

But even with all the carbon and carbon related observations combined, it is not possible to measure the air-sea carbon fluxes everywhere – clearly some proxy techniques need to be utilized. Sabine discussed several approaches, including SST and ocean colour relationships including Multiple Linear Regression approaches (see presentation by U. Schuster), neural networks (see presentation by C. Moulin), atmospheric inversions (see Mikaloff-Fletcher and Rödenbeck) and process-based models (see C. Lequéré, G. McKinley and S. Doney). He showed that the different approaches gave different results, and promoted the idea of a comparison exercise to evaluate the strengths and weaknesses of the different approaches and encourage improved collaboration in the development of improved flux maps in the future.

An important source of uncertainty in CO_2 flux estimates from observations is the gas transfer velocity. David Ho discussed the range of parameterizations that have been used, and why previous tracer-based methods using ^{14}C and ^{222}Rn are not able to constrain these parameterizations. He then showed that $^{3}He/SF_6$-based measurements of gas transfer velocities from the open ocean, including at high wind speeds (> 15 m/s), are most consistent with the Wanninkhof (1992), Nightingale et al. (2000), and Ho et al. (2006) parameterizations. Furthermore, global CO_2 uptake calculated using these parameterizations give very good agreement with other data- and model-based estimates (1.2 to 1.6 $PgCyr^{-1}$). Ho outlined the upcoming Southern Ocean Gas Exchange Experiment (GasEx III) to be conducted in an area of high wind speed and large waves. He talked about the goals of the experiment, showed the justification for choosing a location in the Western Atlantic sector of the Southern Ocean, and mentioned some of the planned measurements.

Reiner Schlitzer gave a presentation on the current state of the art of data assimilation as applied to ocean carbon. He described a global coupled physical/biogeochemical model in which ocean circulation, biological productivity and air-sea CO_2 fluxes are systematically varied (by means of the adjoint method) until model simulations for a large suite of ocean tracers, including carbon, agree best with water column data. The tracers used in the model are complementary in the sense that some provide constraints on physical processes only (CFCs, natural radiocarbon) while others also include information on biological production and CO_2 air-sea gas exchange (nutrients, oxygen, carbon). Schlitzer presented results of a steady-state model run yielding annual-average pre-industrial CO_2 air-sea fluxes and their geographical patterns. The meridional contrast between outgasing in equatorial regions and ingassing in mid and high latitudes appears to be more pronounced as compared to results of other studies; however, basin-wide integrated fluxes are found to be of similar magnitude. He also reported on efforts now underway to utilize the temporal variability in the observed nutrient and carbon data to infer monthly variations in CO_2 air-sea gas fluxes. In addition to water column data, this study will make use of the large and growing set of oceanic surface pCO_2 measurements that will become available in the near future.

Cyril Moulin described how neural networks (NN) are powerful tools to define non-linear relationships that allow estimates of the pCO_2 concentration from SST (from NCEP reanalysis), Chlorophyll (from both MODIS and SeaWIFS) and mixed layer depth (MLD) from the FOAM model. NN are “trained” by binning *in situ* VOS pCO_2 observations acquired within the CarboOcean IP in 2005 and 2006. Two types of NN were tested and the self organizing map (SOM) turned out to be superior to the more classical multi-layer perceptrons to parameterize pCO_2 as a function of SST, chlorophyll and MLD. Both NN methods lead to much better results than a simple multi-linear regression. These techniques were applied to the whole North Atlantic and results showed strong improvements in terms of monthly maps when compared to Takahashi’s climatology.

Nick Hardman-Mountford gave an overview of the UK effort within CASIX (Centre for observation of Air-Sea Interactions and fluXes) to reduce uncertainties associated with global air-sea CO_2 flux estimates using an integrated approach combining satellite data with 3-D coupled physical-ecosystem ocean models and *in situ* measurements. Earth observation satellites target the air-sea interface in all areas of the global ocean, so are well suited to flux studies at both global and regional scales. Models are needed to overcome the spatio-temporal mismatch between near-instantaneous uptake rates and re-equilibration with the atmosphere over several weeks-months and displaced hundreds of kilometres from the sink due to ocean circulation. Some recent examples of CASIX research were presented, including: 1) gas transfer coefficient hybrid models that take account of sea-state measured from altimeters; 2) assimilation of satellite-derived chlorophyll data into 3D coupled physical-ecosystem ocean models; 3) new algorithms to estimate phytoplankton functional types (functional units of ecosystem models) in the ocean using satellite data; 4) estimates of CO_2 fluxes using *in situ* data from near-autonomous underway pCO_2 measurement systems and *in situ*-satellite data interpolation techniques (incl. neural networks); and 5) direct satellite measures of full atmospheric column CO_2. The combined application of these methods will be used to reduce uncertainties in CO_2 flux hindcasts and forecasts, better constraining the global carbon budget.

Using world-wide publicly available pCO_2 data, Joellen Russell et al. have repeated Sweeney and Takahashi's original analysis of pCO_2 variability: quantifying the variability in surface pCO_2 and estimating annual fluxes to establish where surface pCO_2 and associated air-sea fluxes are most variable and therefore need more sampling. She also calculated a version of "decorrelation" length scales for cruises in the global database. These length scales are the distances between regularly-spaced measurements necessary to estimate the true fluxes within 5% of fine-scaled data.

Andrew Lenton presented a sampling strategy to capture large-scale integrated CO_2 fluxes in the North Pacific, North Atlantic and Southern Ocean. Air-sea CO_2 fluxes from the IPSL coupled model were sub-sampled in both space and time to determine what sampling strategy is necessary to reconstruct air-sea CO_2 fluxes in the model. It was shown that regular sampling of four times per year, every 10° in longitude and 5° in latitude for the North Pacific, 10° in longitude and 5° in latitude for the North Atlantic, and 30° in longitude and 3° in latitude for the Southern Ocean, can capture the large-scale CO_2 integrated fluxes and spatial patterns of pCO_2 and DIC as predicted by the model now (1990-1999) and the future (2090-2099; SRES A2).

Global Ocean Carbon Data Sets and Synthesis Efforts

Alex Kozyr (Carbon Dioxide Information Analysis Center (CDAIC) / Ocean CO_2 Program) provided an overview of current ocean surface pCO_2 observations, new data releases, and data center / data flow issues. He began by highlighting several of the metadata search techniques and live-access server products that have been developed over the last few years at CDIAC to search and sub-select the surface pCO_2 data holdings. The Web-Accessible Visualization and Extraction System (WAVES) allows users to search the database using visual mapping tools to select regions and variables of interest, to make property plots from selected data or visualize table information on-line, and to obtain a full metadata report (including citation information) for all the data sets available in the selected region. He also provided a brief overview of the full database collected from 1968 – 2006 that is being used by Taro Takahashi (LDEO, USA) to develop the new 2007 climatology. This database at CDIAC includes over 3 million data points and will be available to database contributors in May 2007 via CDIAC using the WAVES, Live-Access Server, or FTP system. This database will be made publicly available after the Takahashi et al. 2007 Climatology paper is published (~ 3rd quarter 2007). This database will be updated every year with new public underway data.

Benjamin Pfeil (Bjerknes Centre for Climate Research, UiB, Norway) presented the latest information about the pCO_2 database and synthesis efforts being developed from public underway CO_2 data from CDIAC and the Carbon in the Atlantic (CARINA) program as well as not-yet publicly available data form the CARBOOCEAN database. Compilation of these historical data into a common format database was complicated by many factors, including different file formats, inconsistent metadata, different naming for parameters and for missing values, different parameters reported, derived parameters using different calculations, and missing parameters. Pfeil briefly reviewed what corrections were made to the data to deal with some of these issues. He noted that these methods are transparent and fully documented with original data files, detailed metadata documentation, and Matlab scripts available on-line (soon available at CDIAC). The result is a common format database that has all data in the same output format, all the metadata in the same format, all derived parameters following the recommended practices agreed at the IOCCP Tsukuba 2004 workshop, and the data are now easily comparable. The publicly-available database is composed of approximately 300 cruises from 1973 – 2005, with approximately 1.3 million samples with various reported carbon parameters. When this database will be combined with the data to be released by the CARBOOCEAN program, we will have a common format database of approximately 3 million measurements (1.6 million in the Atlantic alone) from 1972 – 2007 from more than 550 cruises. Pfeil noted that there are still some issues to be addressed: introducing a systematic naming for all historical cruises; re-calculating atmospheric CO_2 parameters; including non-European VOS line data into the database; and further quality controlling of the data. He encouraged the community to support this effort by sending publicly available data to CDIAC or to CARBOOCEAN.

Working Group Outcomes and Action Items

Overall Goals

It was agreed early in the plenary discussions of the meetings to combine Working Groups II and III, which had highly interdependent goals:

- Working Group II: To develop observing strategies to address our largest unknowns, data and gas exchange uncertainties, and taking into account new techniques, measurement technology, and observing system experiments; and
- Working Group III: To identify opportunities and needs for coordinated data synthesis activities based on existing projects, new results, and recent data releases.

These issues are combined through justifications for a sustained observing system; namely, that a sustained observing system is critical for constraining global and terrestrial carbon budgets and establishing the long-term causes of changes in the airborne fraction of CO_2, and that sustained observations are needed to understand variability and changes in the ocean processes that drive sources and sinks. These goals require both sustained observations and coordinated data synthesis activities to be implemented as part of the same system.

The group agreed that the overall goal for internationally coordinated research and observations, as expressed by the SOLAS-IMBER Joint Carbon Implementation Plan, was to support the establishment of surface ocean and atmosphere carbon observing systems (including associated data streams) suited to constraining net annual ocean-atmosphere CO_2 flux at the sale of an ocean basin to < 0.2PgC yr^{-1}.

Status of Observing Networks and Dataset Development

In 2004, the IOCCP worked with the Global Climate Observing System (GCOS) and other partners to prepare an implementation plan that addresses the requirements identified in the Second Report on the Adequacy of Global Observing Systems for Climate in Support of the United Nations Framework Convention on Climate Change (UNFCCC). The Second Adequacy Report established a list of the Essential Climate Variables (ECVs) that are both currently feasible for global implementation and have a high impact on the requirements of the UNFCCC. For the ocean, the following variables were identified as essential to meeting the goals of the UNFCCC:

- Surface: Sea-surface temperature, Sea-surface salinity, Sea level, Sea state, Sea ice, Current, Ocean colour (for biological activity), Carbon dioxide partial pressure.
- Sub-surface: Temperature, Salinity, Current, Nutrients, Carbon, Ocean tracers, Phytoplankton.

The Second Adequacy Report and the Implementation Plan both stress that, "Without urgent action and clear commitment of additional resources by the Parties, the UNFCCC and intergovernmental and international agencies, the Parties will lack the information necessary to effectively plan for and manage their response to climate change".

Observations - There is currently no agreed strategy for a coordinated surface observation network, and the community has largely been arguing to maintain existing operations and expand onto new ships/lines where possible. In the last several years, we have seen an increase of approximately 60% in the number of CO_2 systems on ships, and we are beginning to reach a situation where we have sufficient data in some regions to do meaningful seasonal flux maps. Millions of new data points are being generated, but only partly through coordinated efforts. It was noted that at least 5 different groups are developing regular global seasonal flux maps, all using different techniques and reporting significantly different results. Some large research programs that were supporting these observation networks will soon be coming to an end, and the continuation of those programs is uncertain. The workshop participants recognized the need for sustained funding for the global surface ocean pCO_2 network from volunteer observing ships, and suggested that an international strategy for these networks may be required.

Dataset Development - In the last few years, efforts by Dorothee Bakker (UEA), Benjamin Pfeil (Bjerknes) and Are Olsen (UiB) have led to the development of a common format global pCO_2 data base, using the IOCCP-recommended formats, and building on all the publicly available data at CDIAC and including the database developed from the Carbon in the Atlantic (CARINA) activity. The data set includes approximately 1.3 million data points of various carbon parameters from 300 cruises from 1972 to 2005. This dataset has undergone primary QC, including corrections for missing values, data outliers, and calculation of fCO_2 in the water column at SST and 100% humidity from various reported variables (xCO_2, fCO_2, pCO_2). This work was carried out in a transparent and traceable manner, with all original data files and Matlab scripts available on-line, including detailed metadata documentation for each cruise. A full data report will be published at CDIAC as soon as the dataset has been completed (later this year). Some issues still remain to be dealt with, including systematic naming (expocodes) for all historic cruises, re-calculating atmospheric CO_2 parameters, inclusion of more recent non-EU VOS line data, and secondary QC. In addition, the EU CARBOOCEAN program data will also soon be publicly released, and inclusion of these data with the current dataset would generate a dataset with approximately 3 million measurements (with 1.6 million measurements in the Atlantic Ocean alone) from over 550 cruises covering a period from 1972 – 2007. The CARBOOCEAN data adopted the IOCCP-recommended formats for data and metadata reporting, and is thus largely compatible with the current CDIAC/CARINA dataset.

The workshop participants expressed great enthusiasm over these developments and the impending release of this valuable tool for the community, and noted that this type of activity must be prioritized and sustained.

Status Summary - Over the last few years, we have seen an expansion in the number of observing programs, although these activities are not yet coordinated globally in terms of an agreed global observing strategy or dataset / data product development. However, some national and regional programs have been well-coordinated and sustained for a number of years now, in many cases through research programs, and these programs have demonstrated that we can meet stated goals using current technology. In addition, the community has made significant advances in cooperation in dataset development that will form the basis of a global standard dataset upon which the international community can build as the observing system develops.

The workshop participants agreed that we must urgently coordinate these ongoing efforts to demonstrate that we can meet the goals set by the UNFCCC and Member States, as well as the goals of the research community, with appropriate and sustained data coverage, as has been demonstrated in some regions. With the past several years serving as a proof-of-concept period, the community has demonstrated the ability to generate the requested products at the required level of certainty using current technology, and it is time to consider transitioning the support for these activities towards a more sustained mechanism outside the traditional 5-10 year research program systems. The participants also agreed that we must use this opportunity to highlight where coverage is currently inadequate and address methods, techniques, and observation strategies to fill those gaps.

Group Discussions and Decisions

Based on presentations and discussions, the workshop participants agreed to undertake specific tasks to improve coordination on dataset and data product development, global and regional synthesis activities, and to further define the requirements for a sustained observing system required to develop the required products.

Establishment of a standard global data set - It was agreed that the first issue to address was the establishment of a standard global data set upon which the community will continue to build, based on agreed data and metadata formats and standard 1st and 2nd level Quality Control procedures. Chris Sabine (NOAA/PMEL) agreed to lead a comparison of the global data sets currently being used by different groups to generate seasonal flux maps to examine which data have been incorporated into the datasets and how those data are treated to generate the global compilation. This analysis should provide the information necessary for the community to decide which global data set should be considered the standard global community dataset on which we should continue to build. Based on this, Dorothee Bakker (UEA), Are Olsen (University of Bergen) and Benjamin Pfeil (Bjerknes Centre) will be asked to provide guidance and assistance to develop appropriate secondary QC procedures.

Evaluation of methods used to estimate flux and surface CO_2 using satellite data and proxy techniques - Along with this analysis, Chris Sabine also agreed to lead an evaluation of the methods used to generate global seasonal flux estimates to understand why there is such a significant discrepancy among them. This may also include involvement of a larger group of investigators to also examine and evaluate the various methods for estimating surface CO_2 using satellite data and proxy techniques.

Initiation of regular data product development - It was also agreed that there is a strong scientific need for gridded ocean CO_2 products for the observational and modelling communities. The participants suggested the development of an annually-updated "Surface Ocean CO_2 Atlas" that consists of a 1° x 1° grid of monthly surface pCO_2 means (including number of data points and standard deviation), with no interpolation. In discussions with the modellers present at the workshop, it was agreed that surface pCO_2 was more useful than air-sea flux estimates, since this will be generated differently according to the constructs of the individual models.

Defining needs of the atmospheric CO_2 community for ship-based CO_2 data – Collecting high-quality atmospheric CO_2 data from ships in data sparse regions has been discussed for many years in the ocean carbon community. With most on-board ocean carbon systems, the atmospheric data obtained are not of sufficient quality and contamination from the ship is difficult to detect. With dedicated atmospheric CO_2 systems on ships, however, it has been demonstrated that ships can make high-quality atmospheric CO_2 measurements of interest to the atmospheric community, but for the most part, these systems are expensive and require on-board technicians to run the systems. One suggestion was that flask sampling may be cheaper and produce better results. The workshop participants noted, however, that for such a sampling system to be initiated on key repeated lines, the atmospheric community would need to provide input into the design of this system and ensure that there is sufficient interest in the data to justify the added expense and effort. Colm Sweeney (ESRL, NOAA) agreed to work with the atmospheric community to determine the interests, requirements, and guidelines for atmospheric CO_2 measurements from ships that will allow the ocean carbon community to determine if this is feasible on specific lines.

Establishment of regional groups to identify key process-related questions that require large-scale joint synthesis efforts - The workshop established surface CO_2 synthesis groups and agreed on chairs for the following regions:

- North Atlantic (including Arctic) – Ute Schuster (UEA, UK)
- Pacific – Richard Feely (NOAA/PMEL, USA)
- Southern Ocean – Bronte Tilbrook (CSIRO, Australia) and Nicolas Metzl (UPMC, France)
- Indian Ocean – V.V.S.S. Sarma (NIO, India)
- Coastal Ocean – Arthur Chen (National Sun Yat-sen University, Taiwan) and Alberto Borges (U. Liege, Belgium)

Scientists active in the Equatorial and South Atlantic may join the Atlantic synthesis group or create another regional group. These groups were asked to identify key science questions in their regions that require regional and global datasets. The international agreement on a standard global data set should be reached by the 3rd quarter of 2007. Following this decision, the synthesis groups will decide what new data should be added to the global data set from their regions, and will aim to send the data to the dataset developers (either Alex Kozyr at CDIAC or Benjamin Pfeil at Bjerknes Centre) no later than December 2007. Synthesis groups will be encouraged to establish the key scientific questions and collaborators that will participate in the synthesis activities by November 2007.

5. Summary of Working Group Outcomes and Action Items

Vulnerability Section

- **Action item V1**: Finish the regional trend map. Check against original published work. Compare with expected trends in a constant climate scenario with the oceanic pCO_2 change driven solely by the increase in atmospheric CO_2. [*Responsible: Corinne Le Quéré, timeframe: immediate*]
- **Action item V2**: Finish the vulnerability map. Open for discussion. [*Responsible: Corinne Le Quéré, timeframe: immediate*]
- **Action item V3**: Write synthesis paper on observed trends and potential vulnerabilities of the ocean carbon cycle on the basis of 1 and 2. [*Responsible: Corinne Le Quéré to take lead, Nicolas Gruber to assist, timeframe: deadline end of August for SOCOV papers*]

Carbon Sources and Sinks

- **Action item C1**: Establish a standard global data set: Carry out a comparative analysis of global seasonal flux maps being generated by different groups using different data sets to identify major sources of discrepancies. Results from this analysis will provide the basis for the community to decide which global data set should be considered the global standard data set. Develop appropriate secondary quality control procedures for the data set. [*Responsible: Chris Sabine, Dorothee Bakker, Are Olsen, Benjamin Pfeil (IOCCP to support); timeframe: analysis completed by 3rd quarter 2007*]
- **Action item C2**: Evaluation of methods used to estimate flux and surface CO_2: Along with the analysis from Action C1, carry out an evaluation of the methods used to generate global seasonal flux estimates, including use of satellite data and proxy techniques. [*Responsible: Chris Sabine Cyril Moulin (IOCCP to support), timeframe: early 2008*]
- **Action item C3**: Surface Ocean CO_2 Atlas: Initiate the development of a global 1°x1° grid of monthly surface pCO_2 means (including number of data points and standard deviation), with no interpolation. This will build on the global standard data set from Action C1.
- **Action item C4**: Defining needs of atmospheric community for ship based CO_2 data: Work with the atmospheric community to determine their needs for ship-based atmospheric CO_2 data, examining differences between CO_2 from underway systems and flasks. [*Responsible: Colm Sweeney with input from TransCom, timeframe: immediate.]*
- **Action item C5**: Establishment of the regional surface CO_2 working groups. Establish regional groups to identify data sets not yet included in the global standard data set, to provide guidance on secondary QC, and to examine the underlying causes for the variability and trends detected in each region. [*Responsible: Group leaders (see section 4 of this report); timeframe: groups formed, data identified, and key scientific issues identified by November 2007*].

6. Observing System Update

This section documents the presentations made for the major ocean basins, and following are the complete tables and maps for the underway, hydrography and time series networks. These tables and maps are updates of the IOCCP and CDIAC maps based on the national reports provided prior to the meeting by national representatives. These reports are provided in Annex IV of this report.

North Atlantic and Arctic

Ute Schuster and Truls Johannessen reported on the activities in the North Atlantic and Arctic Ocean. The Atlantic is the best sampled ocean basin with at least 19 ships on which underway pCO_2 measurements are routinely made now. The highest density of measurements is made in the North Atlantic, including 12 commercial vessels crossing the Atlantic on at least monthly to seasonal frequency, 2 annual lines, and 5 research vessels on random routes. Additionally there are time series station near Bermuda and the Canary Islands. Countries involved in monitoring carbon in the Atlantic include Norway, Iceland, UK, Bermuda, Germany, USA, Canada, Spain, France, Netherlands, Argentina, and Brazil. Since 2005, the density of measurements in the North Atlantic is sufficient to create basin wide estimations of sea surface pCO_2 and air-sea fluxes of CO_2 with unprecedented confidence. A significant synthesis activity is underway for measurements in the Atlantic, lead by CARBOOCEAN with with collaboration from all contributing nations, which will be joined with synthesis activities from the Pacific, Indian, and Southern Oceans, to create one rigorously quality controlled global dataset.

North Pacific

Masao Ishii reported on activities in the North Pacific. He showed that VOS lines are established among Japan, US, and New Zealand/Australia covering western and eastern subtropical zone and subarctic zone, that there are well established long term time series stations and lines (e.g. HOT, OSP and 137E) continuing more than two decades and in recent years the number of permanent moorings has increased. A workshop to synthesis the data in the area was held in 2004 in Seattle (*J. Geophys. Res., 111, 2006*). For the post-WOCE hydrography work, several lines have been done and are planned for the coming year and that data synthesis needs to be done incorporating these data.

Equatorial and South Pacific

Richard Feely reported that the NOAA VOS network currently includes 7 outfitted ships plus an additional 7 ships with which NOAA has a full data exchange policy. He detailed the analysis system aboard the Columbus Waikato which has collected 13 transects in the Pacific since 2004. The system is automated and returns data to the laboratory daily. In the Equatorial and South Pacific region key VOS lines are the Albert Rickmers (USA/Australia), Ka'imimoana (USA), Transfuture 5 (JP) and the Pacific Celebes (UK). For repeat hydrography, the USA program has completed 8 or 18 lines and is on schedule to complete the global survey by 2012. Completed cruises in the Equatorial and South Pacific include P16 (USA), P06 (Japan) and P15S (Australia), with P18 (US), P14 (Japan) and P15S (Australia) planned in the next 3 years. In the tropical and southern Pacific, there are now 5 TAO moorings and 1 Stratus mooring equipped with carbon instruments, and this number is growing.

Indian and Southern Ocean

According to global maps of VOS lines, the northern tropical Indian Ocean is monitored by 2 VOS lines. On another hand, no VOS line visits the southern Indian tropics north of 25S. South of 30°S, several VOS lines provide coverage over various longitudes in the Southern Indian Ocean. The coverage of the centre of the southern Pacific Ocean is weaker due to its wide area very far from land. Similarly, the coverage of the centre of the Southern Atlantic Ocean by regular VOS lines is poor. This situation slightly improves during the 2005-2007 period in the Southern Atlantic as 5 CARIOCA drifters have been deployed and as a OISO cruise crossed the subtropical and subantarctic zones of the Southern Atlantic. The repeat hydrography coverage is much less than the one of the VOS lines and similarly, monitoring of centre longitudes of the Southern Pacific and Atlantic Oceans is missing. With respect to other oceans, very few moorings are installed in the Indian Ocean and in the Southern Ocean.

Coastal Areas

Arthur Chen reported on the coastal observing network for carbon, noting that for most of the world the coastal areas are very poorly sampled. The exceptions are the east and west coasts of the USA, the west coast of Canada, the shelf and coastal areas of northern Europe and the Mediterranean, the coastal zones of East and South East Asia, and the coasts of India where sampling is reasonable. The lack of observations makes estimating of the role of the coastal zone in the carbon system very difficult.

Underway Tables

Track/Ship name	Dates of operation	Area	Brief description (ship track)	Frequency	PI	Nation
Southern Ocean						
l'Astrolabe	2002-	Southern	Hobart – Terre Adelie (Antarctica.)	3/austral summer	B. Tilbrook (joint project with C; Goyet)	Australia/ France
Aurora Australis	2006-	Southern	Hobart -Mawson Base/ Hobart - Casey Base	4/year	B. Tilbrook	Australia
JARE by Icebreaker Shirase	On going	Southern	Fremantle – Syowa Stn. (Lützow-Holm Bay, Antarctica) Syowa Stn. – Sydney	Annual Dec. *Feb-Mar	G. Hashida S. Nakaoka	Japan
Xuelong	Nov-Mar	Southern	Leaving from Shanghai, pass northern and southern Pacific, investigate in Prydz Bay and tracks between Zhongshan St (East Antarctica) and Changcheng St (Antarctic Peninsular).	Yearly except for modification year.	L. Chen,	China
RRS James Clark Ross	2006-2009	Southern	Variable but mainly Falklands-South Georgia-Signy-Rothera	Variable	N. Hardman-Mountford	UK
RV Umitaka Maru	Dec 2007- Feb 2008	Southern	Cape Town – Fremantle - Hobart (Off of Lützow-Holm Bay, 110ºE, 140ºE)		G. Hashida S. Nakaoka	Japan
RV Hakuho Maru	Feb 2008	Southern	Port Elizabeth – Fremantle (near Kerguelene, Off of Lützow-Holm Bay)		H. Y. Inoue	Japan
Pacific Ocean						
R/V Ka'imimoana	1998-	Pacific	San Diego-Honolulu-Samoa	2/year	R. Feely	USA
Columbus Waikato/ Albert Rickmers	2005-	Pacific	Long Beach – New Zealand – Australia	6/year	R. Feely (joint project with Australia)	USA
Line P / John P Tully	1974 -	Pacific	Sidney BC – Station P	3/ year	C. S. Wong	Canada
Pyxis	2002-	Pacific	Nagoya – Portland – L.A. – Toyohashi	Monthly	Y. Nojiri	Japan

RV Tangaora	2009 -	Pacific, Southern	SW Pacific, mainly New Zealand EEZ	Continuous	K. Currie	New Zealand
M/S Transfuture 5	2005-	Western Pacific	Tokyo – Brisbane-Melbourne-Christchurch (NZ)	Monthly	Y. Nojiri	Japan
JMA's monitoring program by RV Ryofu Maru and RV Keifu Maru	On going	North and Eq Pacific	137ºE, 34ºN – 3ºN 137ºE, 34ºN – 2ºS*	Seasonal Jan-Feb*, April-May, June-July*, Oct-Nov	T. Midorikawa S. Minato	Japan
JMA's monitoring program by RV Ryofu Maru and RV Keifu Maru	On going	North Pacific	Tokyo – 50ºN ,165ºE – 28ºN ,165ºE	Annual June-July	T. Midorikawa S. Minato	Japan
JMA's monitoring program by RV Ryofu Maru and RV Keifu Maru	On going	North and Eq Pacific	165ºE, 28ºN – 5ºS	Biannual Jan-Feb, June-July	T. Midorikawa S. Minato	Japan
JMA's monitoring program by RV Ryofu Maru and RV Keifu Maru	On going	Eq Pacific	142ºE – 165ºE, Equator	Biannual Jan-Feb, June-July	T. Midorikawa S. Minato	Japan
RV Ocean Researcher	2003-	North Pacific (South China Sea)	Underway pCO_2 survey is conducted along the following cruise track in the northern South China Sea:from Kaoshiung (~120.3°E; 22.6°N) to the SEATS site (115.7°E; 18.3°N)	Seasonal	C.-M. Tseng	China (Taiwan)
RV Ocean Researcher	2001-	North Pacific (East China Sea)	Underway pCO_2 survey is conducted in the area among ~123°E; 31.5°N, ~127°E; 30°N, ~120°E; 26°N, ~121.5°E; 25°N.	Annual	C.-M. Tseng	China (Taiwan)
R/V Tamyang	2006-2009	East/Japan Sea	Annual Ulleung Basin Survey	1/year	T. Lee	Korea
Project with irregular tracks (difficult/impossible to plot)						
Southern Surveyor	2007-	SW Pacific / E Indian	Various research cruise East Indian Ocean/Coral Sea/Tasman Sea	8/yr	B. Tilbrook	Australia

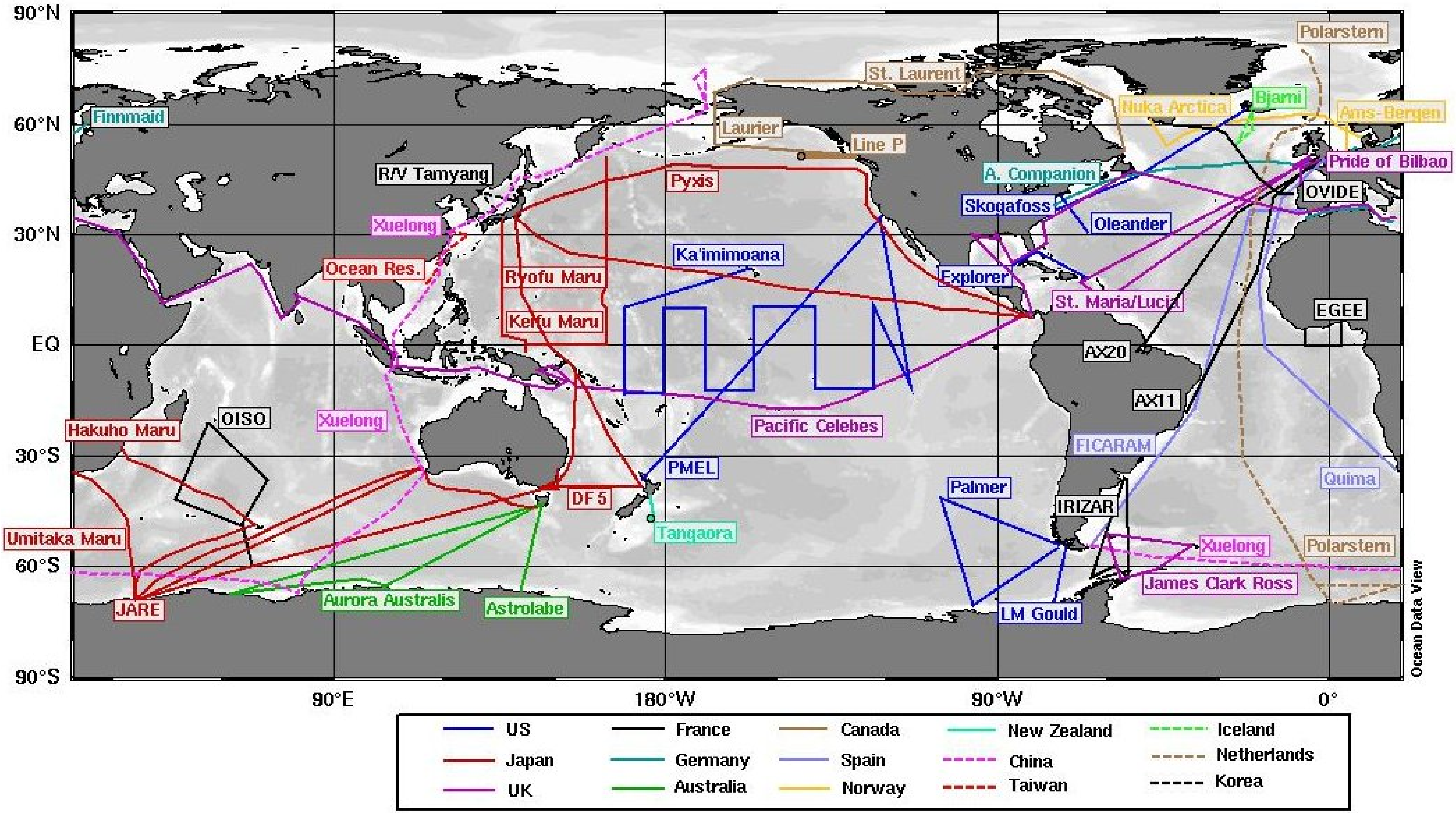
Palmer	2000-	Pacific/ Southern Ocean	Various	Random	T. Takahashi	USA
David Starr Jordan	2006 -	N/Tropical Pacific	San Diego-San Diego	Random	R. Feely	USA
MacArthur II	2006-	NE Pacific	Seattle -San Diego	Random	R. Feely	USA
R/V Mirai	1998-	Pacific, Arctic	Depending on cruises	Irregular	A. Murata	Japan
Future plans						
JMA's monitoring program by RV Ryofu Maru and RV Keifu Maru	2010-	N Pacific	40ºN, to the west of date line	Biannual	future planning	Japan
JMA's monitoring program by RV Ryofu Maru and RV Keifu Maru	2010-	N Pacific	24ºN(P3) to the west of date line	Biannual	future planning	Japan
JMA's monitoring program by RV Ryofu Maru and RV Keifu Maru	2010-	N Pacific	9Nº (P4), to the west of date line	Biannual	future planning	Japan
No longer current						
Skaugran VOS	1995-2005	Pacific	Vancouver, Tokyo. Surface measurements of DIC etc., some pCO_2 surveys with Japan	~10/yr	C.S. Wong	Canada
Atlantic Ocean						
Ams-Bergen	2005-2009	North Sea	Amsterdam-Bergen; collaboration Norway-Netherlands in CarboOcean	weekly	A. M. Omar T. Johannessen	Norway
Finnpartner Finmaid	2003-	Baltic Sea	Leubeck-Helsinki	150/year	B. Schneider	Germany
Bjarni Saemundsson	2006 and 2007	Atlantic	Repeat hydrographic sections across the Iceland shelf and into open Atlantic	4/year	J. Olafsson	Iceland

Pride of Bilbao	2005-	Atlantic	Portsmouth (UK)-Spain	Twice per week except January	D. Hydes C. Bargeron	UK
A. Companion	2006-	Atlantic	Liverpool - Halifax	2 per 5 weeks	A. Körtzinger D. Wallace	Germany
Skogafoss	2005-	Atlantic	Charleston-Reykjavik	12/year	R. Wanninkhof Joint project France/Iceland	USA/France
Explorer of the Seas	2004-	Atlantic	Caribbean (winter) Bermuda-Newark-Caribbean (summer)	Weekly	R. Wanninkhof	USA
Santa Lucia /Santa Maria	2003-2009	Atlantic	Portsmouth (UK) - Windward Islands	35 day round trips	U. Schuster	UK
Thalassa (OVIDE)	2002-2010	Atlantic	Iberian Peninsula - Greenland	2 years	A. Rios	Spain
Oleander	2006-	NW Atlantic	Newark-Bermuda	2/week	N. Bates	USA
MN Colibri (AX20)	2006-	Atlantic	France - French Guiana	~6/ year	N. Lefèvre	France
Monte Olivia (AX11)	2007-	Atlantic	France-Brazil	~6/ year	N. Lefèvre	France
R/V Poseidon/ Merian	2007 and 2008	Mauritanian upwelling	Las Palmas-Las Palmas	1/year	A. Körtzinger	Germany
Las Palmas	2005-	Atlantic	Cartagena - Rio - Ushuaia	2/year	A. Rios	Spain
Quima VOS line	2005	Atlantic	UK - Cape Town	Monthly	M. Gonzalez	Spain
IRIZAR Project	2007-	Atlantic	Buenos Aires - Antarctica	2-4 times per year	C. Goyet (joint project with Argentina)	France
Drake Passage Time series/ LM Gould	2005-	Atlantic	Ponte Arenas - Palmer	20/year	T. Takahashi C. Sweeney	USA
Shelf/coastal lines						
Plymouth Quest	2005-2009	Atlantic (shelf)	Weekly (L4) & monthly (E1) transects in Western English Channel, other variable routes	Weekly/Monthly & other variable	N. Hardman-Mountford	UK

Prince Madog	2006-2009	Atlantic (shelf)	Regular transects between Hollyhead and Dublin, regular Liverpool Bay, other variable routes in Irish Sea	Approx. monthly & other variable	N. Hardman-Mountford	UK
ICCABA	2007	Atlantic Mediterranean	Canary Islands - Italy		M. Gonzalez	Spain
Mytilus	2006-2007	Atlantic	Coastal Zone - Gulf of Cádiz	4/year	J. Forja	Spain
RV Belgica	2001-2010	Atlantic	Continuous pCO_2 measurements on all the cruises of the RV Belgica in the Southern Bight of the North Sea	Weekly to monthly	A. Borges	Belgium
Irregular						
RV Ron Brown	1997-	Atlantic/ E Pacific	Random	Random	R. Wanninkhof	USA
R/V Atlantic Explorer	2006-	NW Atlantic	Bermuda	Random	N. Bates	USA
CARIOCA buoys	2005-2009	Atlantic	Southern Ocean	Continuous	J. Boutin L. Merlivat	France
No longer running						
RMS St Helena	1993-95	Atlantic	UK- Cape Town	Every two months	N. Lefèvre	UK
Prince of Seas	Jun 1994- Jun 1995	Atlantic	UK - Jamaica	Once per month	A. Watson	UK
Atlantic Meridional Transect	1995, 1996 (2 x), 1998	Atlantic	UK - Falkland Islands (pCO_2 for AMT-1, -2, -3, -7)	4 crossings	N. Lefèvre	UK
Atlantic Meridional Transect	2003-2004	Atlantic	UK - Falkland Islands (some, discrete TCO_2, T_{Alk} for AMT-12, -13, -14)	3 crossings	Andrew Hind	UK
Atlantic Meridional Transect	2004-2005	Atlantic	UK - South Africa (pCO_2 for AMT-15 (part), -16, -17; AMT-15 also some discrete TCO_2, T_{Alk})	3 crossings	D.C.E. Bakker A. Hind	UK

Indian Ocean						
Marion Dufresne / OISO	1998-	S Indian/ Southern Ocean	Reunion - Crozet - Kerguelen - Amsterdam Is	2/year	N. Metzl	France
Arctic Ocean						
Amundsen	2004-	Arctic	ArcticNet Domain (Arctic coastal waters)	1/year	T. Papakyriakou	Canada
St Laurent / Laurier	2005-	Atlantic & Pacific	Newfoundland-Canada basin	?	C. S. Wong	Canada
Nuka Arctica	2005-2009	N Atlantic -Arctic	Aalborg Denmark - Nuuk, West Greenland	Monthly	A. Olsen T. Johannessen	Norway
Global						
Pacific Celebes	May 2007-	global	Singapore-TAO array-Panama Canal- Houston-Halifax-Suez-Jeddah-Mumbai-Singapore	Twice per year	D. Hydes	UK
Xue Long (Snow Dragon)	2007-	Arctic/ Antarctic (Pacific)	Shanghai- PR China- Antarctic and Arctic oceans	Annual	R. Wanninkhof W.-J. Cai L. Chen (3rd inst PRC) Joint project w PRC	USA
Polarstern	2007-	both polar oceans and Atlantic transects to/from Antarctic	autonomous pCO_2 system (General Oceanics) should already have been completed and delivered. For installation and continuous operation at Polarstern.	Annual	M. Hoppema collaborative effort with Royal NIOZ	Germany/ Netherlands
Irregular						
Turmoil	2007	Global		Random	T. Takahashi	USA
RRS Discovery	2005 2006-2009	Global	One AMT route in 2005. Variable (pCO_2 collected on all research cruises)	Variable	Nick Hardman-Mountford	UK
RRS James Cook	2007-2009	Global	Variable (pCO_2 to be collected on all research cruises)	Variable	N. Hardman-Mountford	UK
R/V Langseth	2007	Global		Random	T. Takahashi	USA

Underway Map



Hydrography Tables

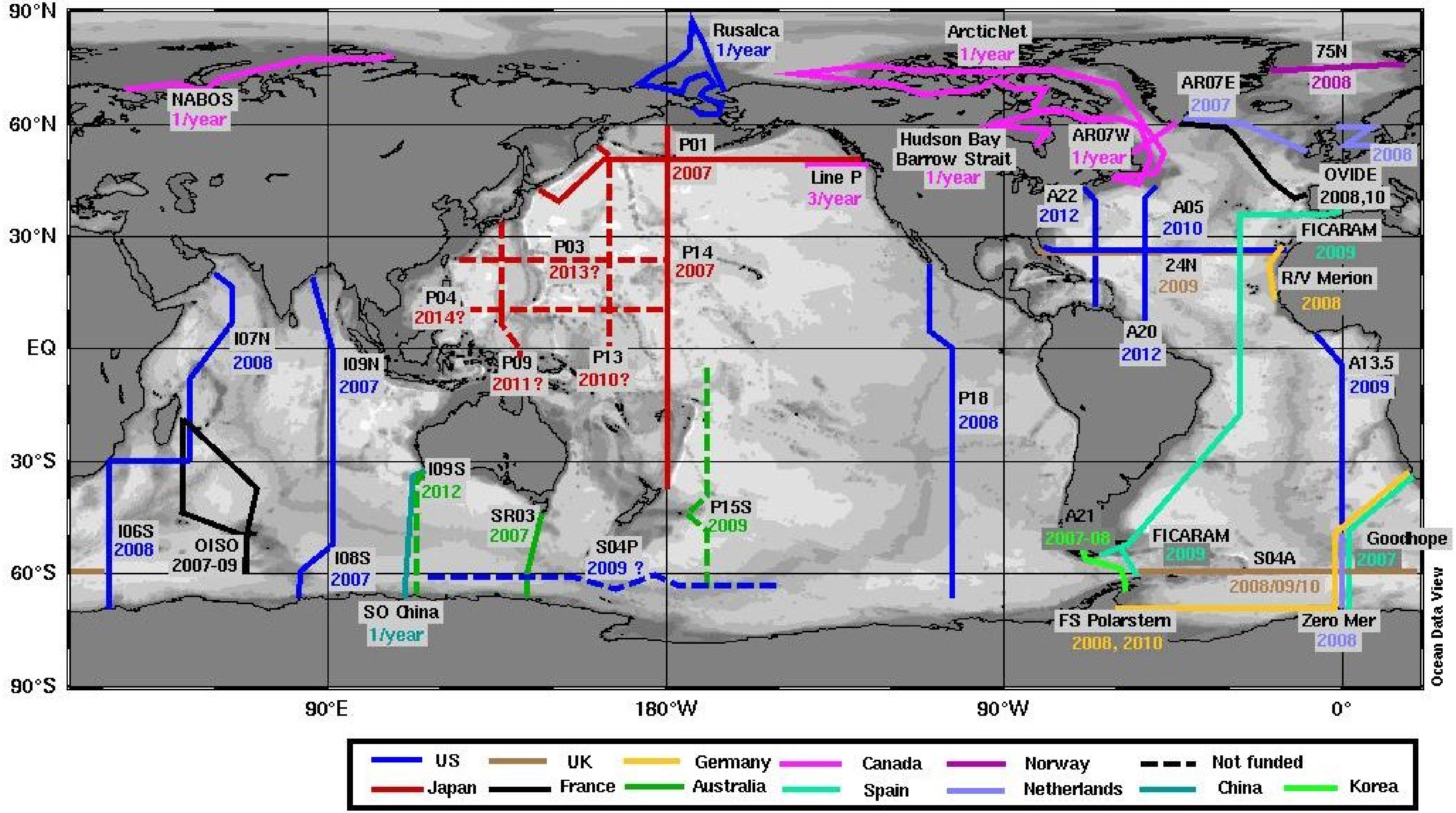
Name of the line	Area	Description (ship track)	Year planned	PI	Country
Atlantic					
A5	Atlantic	24°N	2010	R. Wanninkhof	USA
A13.5	Atlantic	0°	2009	R. Wanninkhof	USA
A20	Atlantic	52°W	2012	R. Wanninkhof	USA
A22	Atlantic	66°W	2012	R. Wanninkhof	USA
24N section	Atlantic	Reoccupation of 24N section (Funding for CO_2 + tracers uncertain)	Autumn 2009	S. Cunningham, A. Watson, U. Schuster	UK
WOCE S4A	Southern / Atlantic	Line from tip of Antarctic Peninsula to 30 E along the northern edge of the Weddell gyre (nominally 60 S)	2008/09/10 (proposal under review)	A. Naveira Garabato D. Bakker	UK
OVIDE	Atlantic	Iberian Peninsula – Greenland	2006, 2008, 2010	A.Rios	Spain
FICARAM	Atlantic	Ushuaia – Cartagena (Spain), following part of the line WOCEA A17 and from 10ºS to 36ºN along 28ºW	2009	A. Rios	Spain
Goodhope	Atlantic	South Africa - Antarctica	2007	Alvarez/Alvarez-Salgado	Spain
WOCE AR7E	Irminger Sea	repeat section WOCE by dr. Hendrik van Aken (NIOZ); past DIC data 1981 TTO, and NIOZ DIC data of 1991, 2005; thus far no underway pCO_2; next section in 2007	Sep 2005 completed; next Sep2007	S. van Heuven M.Sc. H. de Baar	Netherlands
NorthSeaSummer	Basinwide North Sea	Repeat summer (August) cruise doing ca. 92 stations and ca. 22,000 underway surface pCO_2	2001, 2005; next 2008	2008: H. Zemmelink, past 2001, 2005: H. Thomas	Netherlands
R/V Merion 07	Tropical Atlantic	Dakar- Las Palmas	2008	A. Körtzinger	Germany

FS Polarstern	S. Atlantic and Southern Ocean	Capetown – Antarctica (Prime Meridian) Weddell Sea: Kapp Norvegia – Joinville Island	2005 2008 2010	M. Hoppema	Germany
AR7W	Atlantic (Labrador Sea)	From Labrador to Greenland 53N/56W-61N/48W 1/year (spring)	1993- 1/year	K. Azetsu-Scott (DIC, TA) and G. Harrison / B. Li / P. Kepkay / E. Head (Biogenic carbon – TOC, DOC, phytoplankton, primary and secondary productivity, microbial production and respiration)	Canada
Pacific					
P18	Pacific	110°W	2008	R. Feely	USA
P01	Pacific	Sekinehama, Japan – Dutch Harbor	2007	A. Murata	Japan
P14	Pacific	Sekinehama, Japan – Auckland, New Zealand	2007	A. Murata	Japan
P13	Pacific	Not fixed	2010 not fixed	To be conducted by JMA.	Japan
P09	Pacific	Not fixed	2011 not fixed	To be conducted by JMA.	Japan
P01 to the west of the date line	N. Pacific	Not fixed	2012 not fixed	To be conducted by JMA.	Japan
P03 to the west of the date line	N. Pacific	Not fixed	2013 not fixed	To be conducted by JMA.	Japan
P04 to the west of the date line	N. Pacific	Not fixed	2014 not fixed	To be conducted by JMA.	Japan
Line P	Pacific	BC coast to 50 N, 145 W. CTD casts at 27 stations, water properties (nutrients, oxygen) at 5 to 7 stations. DIC/Alk by Lisa Miller	3/yr over next decade	M. Robert	Canada
P15S	S. Pacific	Equator – 50S 175W	2009 (not yet funded)	B. Tilbrook	Australia

Indian					
I6S	Indian	55°E	2008	C. Sabine	USA
I7N	Indian	65°E	2008	C. Sabine	USA
I8S	Indian	95°E	2007	C. Sabine	USA
I9N	Indian	88·E	2007	C. Sabine	USA
OISO	S. Indian	low resolution hydrocasts	1998-	N. Metzl	France
Southern Ocean					
S04P	Pacific	60°S	2009	R. Feely	USA
Antarctic Zero Meridian	Antarctic-Atlantic sector	Repeat section along zero meridian from Polar Front (ca. 50 S) to Antarctica; once every 2-3 years, focus on DIC in complete water column, surface pCO_2 in some but not all past cruises	since 1984 AJAX cruise onwards; next Feb-Apr 2008	M. Hoppema collaborative effort with Royal NIOZ	Netherlands
Fremantle-Prydz Bay	Southern Ocean	Leaving from Fremantle of Australia, pass southern Indian Ocean, transactions investigation between 60°S and 69°S.	Yearly except for modification year.	Z. Dong	China
P12/SR3	Southern Ocean	Hobart – Antarctica (140E)	2007	B. Tilbrook	Australia
I9S	Southern Ocean	Fremantle – Antarctica	2012 (not yet funded)	B. Tilbrook	Australia
56°S,63°W - 62°S,58°W	Southern	Drake Passage (Punta Arenas, Chile <-> King George Island, West Antarctica)	2007, 2008 (yearly continuous)	Y.C. Kang	Korea
Polarstern	S. Atlantic and Southern Ocean	Capetown – Antarctica (prime meridian), Weddell Sea, Kapp Norvegia, Joinville Island	2008, 2010	M. Hoppema	Germany
Arctic					
Barrow Strait	Canadian Arctic Archipelago	Parry Channel 1/year (summer)	2003-	K. Azetsu-Scott	Canada

Hudson Bay and Strait (MERICA)	Canadian Arctic	Hudson Bay	2003-	K. Azetsu-Scott	Canada
Joint ArcticNet/ NABOS annual cruise (I/B Kapitan Dranitsyn)	Arctic	From Murmansk to Laptev Sea (following the Arctic shelfbreak)	2003, 2004, 2005, 2006, ongoing	L. Fortier	Canada
ArcticNet annual monitoring cruise (CCGS Amundsen)	N Atlantic and Arctic	From Quebec City to Labrador Sea, Baffin Bay (NOW), Northwest Passage (trough M'Clintock Channel), Beaufort Sea (Mackenzie Shelf and Amundsen Gulf), and to Foxe Basin and Hudson Bay on the way back to Quebec City.	2003, 2004, 2005, 2006, ongoing	L. Fortier	Canada
75N	Nordic Seas	Iceland – Greenland.	2006, 2008	Truls Johannessen Are Olsen	Norway
RUSALCA	Arctic	Bering and Chukchi Seas	2004, 2008	Nick Bates	USA/Russia
Davis Strait	Atlantic (Baffin Bay)	From Baffin Island to Greenland 1/year (summer-fall)	2004-present	K. Azetsu-Scott	Canada
Scotian Shelf	NW Atlantic	Coastal monitoring program off Nova Scotia, Canada, 2-3/year 42/48N, 60/66W	2006-?	H. Thomas	Canada

Hydrography Map



Time Series Tables

Mooring/Station/ Ship name	Date of operation	Location	Description	Frequency (i.e. monthly, continuous)	PI	Country
Atlantic						
Stations monitored from ships						
Iceland Sea	1983-	68°N 12.66°W	Profile, pCO_2 and TIC, O_2 and nutrients	4/year	J. Olafsson	Iceland
Irminger Sea	1983-	64.3N,28°W	Profile, pCO_2 and TIC, O_2 and nutrients	4/year	J. Olafsson	Iceland
Labrador Sea (Bravo)	1993-	57N,53W		1/year	K. Azetsu-Scott	Canada
JetSet		53N, 4E46' Marsdiep tidal channel	DIC, Alkalinity	weekly	H. Zemmelink	Netherlands
L4/Plymouth Quest	2005-2009	W. English Channel	Time series station since 1988, pCO_2 added in 2005.	Weekly	N. Hardman-Mountford	UK
E1/Plymouth Quest	2005-2009	W. English Channel	Time series station since 1903, pCO_2 added in 2005.	Monthly	N. Hardman-Mountford	UK
NW Atlantic Hydro Station S	1983-	32N, 65W		Monthly	A. Dickson	USA
NW Atlantic BATS/OFP/BTM	1988-	32N 65W			N. Bates	Bermuda/ USA
NE Atlantic ESTOC	1995-	29N,16W	European Station for Time series in the Ocean at the Canary Islands	Monthly	M. Gonzalez/M. Santana	Spain
RV Islandia/CV	2007-	17.5°N, 24.3°W		Monthly	D. Wallace A. Körtzinger	Germany
Cariaco time series station/R.V. "Hermano Ginés"	1996-	10° 30' N, 64° 40' W (Cariaco Basin, Atlantic)	Water column core measurements up to 1310 m, including carbon measurements: POC, DOC, CO_2, TOC	Monthly, on going	Time series: F. Muller-Karger CO_2 measurements: Y.M. Astor	Venezuela

Stations monitored by moorings						
Central Irminger Sea (CIS)	2003-	59.7°N, 39.7°W		Continuous	A. Körtzinger	Germany
Baltic Sea	2000-	Östergarns-holm	SAMI pCO_2 mooring and air CO_2 flux measurements	Continuous	A. Rutgersson Owenius	Sweden
Norwegian Sea OWS Station M	1992-	66°N, 2°E (Arctic)	Water column and surface measurements	Continuous	I. Skjelvan T. Johannessen	Norway
Ste Anna	2002-2010	Upper Scheldt estuary	Fixed station for continuous measurements of pCO_2, salinity and temperature	Continuous	A. Borges	Belgium
K1	2001/2002 2004-2007	56.5°N, 52.6°W (near Bravo)	Long-term mooring	Continuous	A. Körtzinger	Germany
Porcupine Abyssal Plain (PAP)	2003-	49N, 16.5W	Long term mooring	Continuous	A. Körtzinger	Germany
MAREL-Iroise	Feb 2003-	48°22' N 4°33' W	Hourly measurements by a CARIOCA sensor (modified for coastal measurements) at 1.5m depth	Continuous	E. Bucciarelli	France
Scotian Shelf	2007-	44.68N 63.61W	CARIOCA buoy	Hourly 2007-	H. Thomas	Canada
Martha's Vineyard, MA	2002-	43°N	pCO_2	Continuous	W. McGillis	USA
MINAS	2005-	43ºN, 11ºW	Multidisciplinary Iberian North Atlantic Station. CARIOCA buoy with sensors of CO_2, O_2, S, T, Chla.	Continuous	F.F. Perez	Spain
NW Atlantic BATS/OFP/BTM	1988-	32°N 65°W			N. Bates	Bermuda/USA
Grays Reef, Georgia (NDBC 41008)	2006-	31.4°N, 80.9°W		Continuous	C. Sabine	USA
BTM	2005-	31.5°N, 64°W	MAPCO₂ system	Continuous	C. Sabine/N. Bates	USA

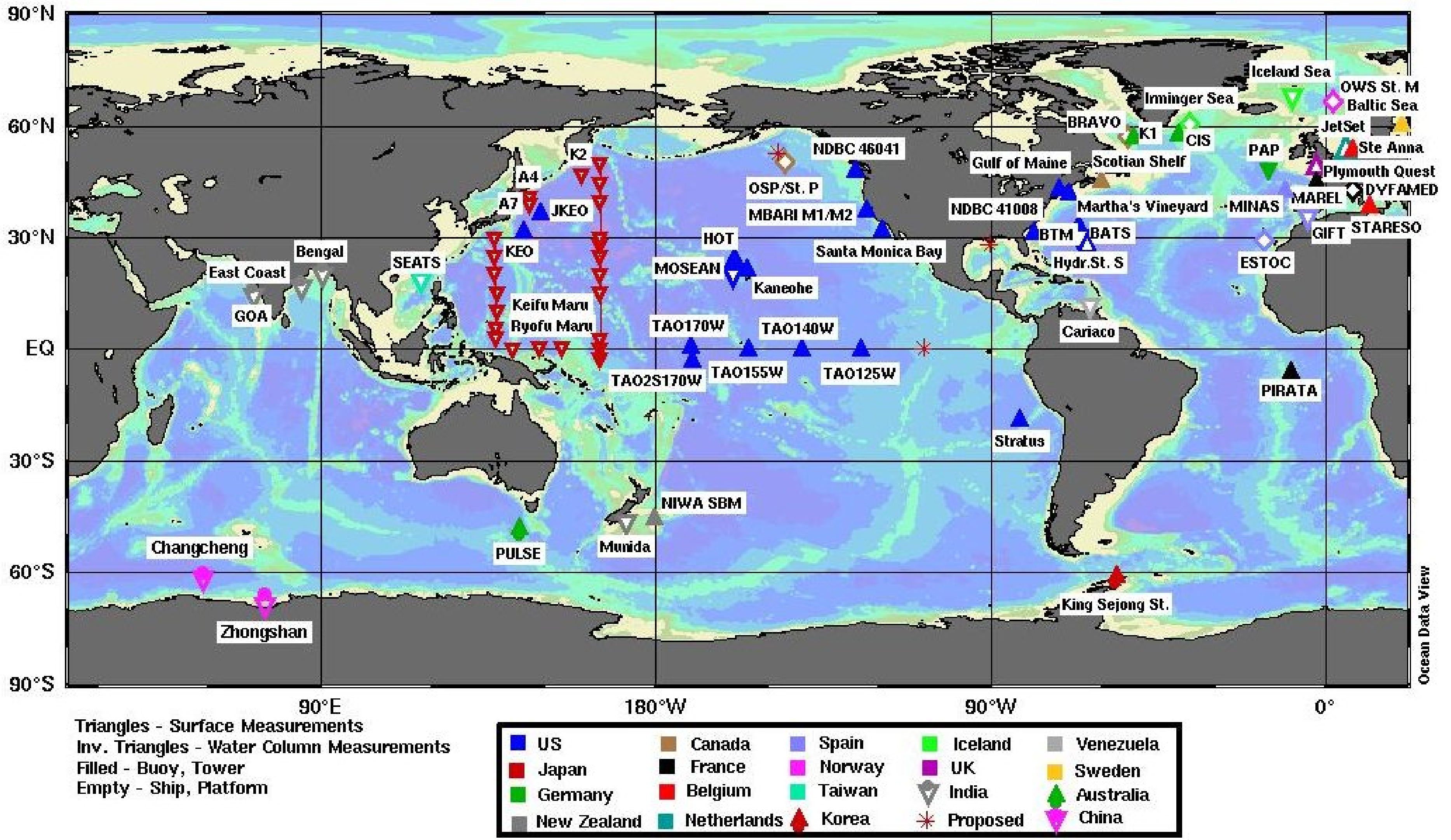
CV	2007-	17.5°N, 24.3°W		Daily	D. Wallace A. Körtzinger	Germany
Pacific						
Stations monitored from ships						
NE Pacific OSP / Line P	1970's-	50N,145W	DIC/T Alk at 5 stations along Line P (Miller). pCO_2 (Wong)	3/year	C.S. Wong L. Miller	Canada
K2	2001-	47N,160E	0 - bottom, 36 layers DIC, TA, pH, CFCs	2 – 3/year	M. Honda M. Wakita	Japan
A-line (A4, A7)	1996-	42.25ºN, 145.125ºE (A4) and 41.50ºN, 145.50ºE (A7)	DIC, TA, 13C 0 - 3000m, 12 layers *part of A-line monitoring program (http://ss.hnf.affrc.go.jp/a-line/index_e.html) *reference: Ono et al., JO 61, 1075-1088, 2005.	4-6/year	T. Ono	Japan
Santa Monica Bay, CA	2003-	33.9N, 118.7 N		Bi weekly	A. Leinweber	USA
NW Pacific HOT	1988-	22.75N,158W	shipboard cruises	Monthly	D. Karl	USA
SEATS	1999-	115.67°E 18.25°N (in the South China Sea)	Dissolved inorganic carbon and total alkalinity are measured at 25 discrete depths throughout the water column (from surface to 3500m).	Seasonal	W.-C. Chou	China (Taiwan)
Munida time series transect	Jan 1998-	SW Pacific	Surface transect (45.77S 170.72E – 45.83S 170.50E), water column measurements at 45.83S 170.50E	6 per year	K. Currie	New Zealand
JMA's monitoring program by RV Ryofu Maru and RV Keifu Maru	2003-	North Pacific 137ºE(P9), 30ºN-5ºN, mostly 5º intervals	DIC, 13C, pH, CFCs* 0 - 2000m, 22 layers * measured in selected cruises	Seasonal Jan-Feb, April-May, June-July, Oct-Nov	M. Ishii S. Minato	Japan

JMA's monitoring program by RV Ryofu Maru and RV Keifu Maru	2003-	North Pacific 165ºE(P13), 50ºN - 28ºN, mostly 2-3º intervals	DIC, TA*, CFCs* 0 - 2000m, 22 layers	Annual June-July	M. Ishii S. Minato	Japan
JMA's monitoring program by RV Ryofu Maru and RV Keifu Maru	2003-	North and Eq Pacific 165ºE(P13), 28ºN - 3ºS, mostly 2-3º intervals	DIC, 13C, pH*, CFCs* 0 - 2000m, 22 layers	Biannual Jan-Feb, June-July	M. Ishii S. Minato	Japan
JMA's monitoring program by RV Ryofu Maru and RV Keifu Maru	2003-	Eq Pacific 165ºE - 142ºE, 0º, mostly 5º intervals	DIC, pH* 0 - 2000m, 22 layers	Biannual Jan-Feb, June-July	M. Ishii S. Minato	Japan
155E Line	2002 -	North Pacific 155°E, 44°N –0°	0 - bottom, 36 layers DIC, TA, pH, CFCs	~1/year	M. Wakita	Japan
Stations monitored by moorings						
Cape Elizabeth (NDBC 446041)	2006-	47.3N, 124.8W		Continuous	C. Sabine	USA
NW Pacific JKEO	2007-	38N, 146.5E	MAPCO_2 system	Continuous	C. Sabine M. Cronin	USA
California Current MBARI M1	1996-	36.75N, 122W		Continuous	F. Chavez	USA
California Current MBARI M2	1996-	36.75N, 122W		Continuous	F. Chavez	USA
Santa Monica	2002-	33.9N, 118.7 N		Continuous	N. Gruber	USA
NW Pacific KEO	2006-	32N, 145E	MAPCO_2 system	Continuous	C. Sabine M. Cronin	USA
MOSEAN	2005-	22.75N,158W	MAPCO_2 system	Continuous	C. Sabine D. Karl	USA

Kaneohe Bay, Hawaii	2005–	21.4N, 157W		Continuous	C. Sabine	USA
TAO / TRITON	2003-	0, 125W	MAPCO_2 system	Continuous	C. Sabine	USA
TAO / TRITON	2003–	0, 140W	MAPCO_2 system	Continuous	C. Sabine	USA
TAO / TRITON	1997–	0,155W	MBARI pCO_2 system	Continuous	F. Chavez C. Sabine	USA
TAO / TRITON	2005–	0, 170W	MAPCO_2 system	Continuous	C. Sabine	USA
TAO / TRITON	1997–	2S 170W	MBARI pCO_2 system	Continuous	F. Chavez C. Sabine	USA
Stratus	2006–	85W, 20S	MAPCO_2 system	Continuous	C. Sabine R. Weller	USA
Indian						
Stations monitored from ships						
GOA time series station	2003-2012 (Funded)	15N 72E	Sampling of CO_2 parameters were started in end of 2006 and will continue until 2012.	Monthly	S. W. A. Naqvi	India
East coast time series	2007-2012 (Funded)	15-20N 80-85E	5 transects will be occupied along east coast of India between 15 to 20N and samples are collected along 5 transects of 10 kms wide.	Seasonal	M.D Kumar	India
Bay of Bengal time series	2008-2013 (Proposed)	20N, 90E	Permanent mooring and weekly sampling using automated samplers and seasonal visit to the station.	Seasonal	VVSS Sarma	India
Mediterranean						
Stations monitored from ships						
Mediterranean DYFAMED	1991-2001; 2003 – present	43N,7.9E	Water column discrete AT and CT	Monthly	C. Goyet	France

Stations monitored by moorings						
STARESO	2006-2008	Calvi (Corsica)	Shallow mooring for pCO_2 and temperature measurements (Pro-Oceanus) over a Posidonia seagrass meadow (water column depth 10m) the Mediterranean Sea	Daily	A. Borges	Belgium
GIFT	2005-ongoing	35.861N, 5.977W 35.912N, 5.746W 35.987N, -5.368W	Time series composed by three stations located in the Strait of Gibraltar aimed at assessing biogeochemical cycles between North Atlantic and Mediterranean Sea	Seasonal	E. Huertas	Spain
Southern Ocean						
Stations monitored by moorings						
PULSE time series	2008? -	47S 142E	Sub-Antarctic mooring	Continuous	B. Tilbrook (CO_2)	Australia
NIWA Southern Biophysical Mooring	March 2005–(for SAMI)	SW Pacific, sub-antarctic surface water	Permanent mooring, including SAMI-CO_2 instrument	Continuous	K. Currie S. Nodder	New Zealand
Marian Cove, King Sejong Station, King George Island	2003-	62°13´S, 58°47´W	Surface measurements	Continuous	Y.C. Kang	Korea
Stations monitored from ships						
Zhongshan Station	1984-	69°S, 75°W	Water column including DIC, pH, ^{234}Th, DO, Chl, nutrients, biomass	Annual	L. Chen	China
Changcheng Station	1984-	62°S, 59°W	Water column including DIC, pH, ^{234}Th, DO, Chl, nutrients, biomass	Annual	L. Chen	China

Time Series Map



Annex I: Participant List

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Annex II: Agenda

DAY 1 – Wednesday April 11

0900-0915	**Welcome and meeting outline** 0900-0910 Welcome and objectives for Workshop Workshop Chairs: Nicolas Metzl and Bronte Tilbrook 0910-0915 Sponsors welcome and logistics Sponsors: Maria Hood (IOCCP), Emily Breviere (SOLAS), Sylvie Roy (IMBER), Pep Canadell (GCP) Logistics & information: Roger Dargaville
	Vulnerabilities in the Ocean Carbon-Climate System **Chairs: Corinne Le Quéré and Nicolas Gruber**
0915-1000	State of knowledge on vulnerability of the oceanic CO_2 sink Speakers: Corinne Le Quéré and Nicolas Gruber
1000-1030	Possible long term impacts of anthropogenic carbon emissions on climate, ocean circulation, ecosystems and biogeochemical cycles in model simulations. Speaker: Andreas Schmittner
1030-1100	**Coffee break**
1100-1130	Results from coupled carbon-climate models. Speaker: Laurent Bopp
	What are the maximum impacts of projected environmental changes on marine biology and the carbon cycle? **Chairs: Corinne Le Quéré and Nicolas Gruber**
1130-1200	Potential impact of changes in marine ecosystems from laboratory/mesocosm experiments. Speaker: Ulf Riebesell
1200-1325	**Lunch**
1325-1355	Lessons from the geological past. Speaker: Ken Caldeira (30 min)
1355-1415	Potential impact of changes in marine ecosystems from model simulations. Speaker: Scott Doney
1415-1430	Surface Ocean CO_2 Variability and Vulnerabilities in the Southern Ocean and the Arctic Ocean. Speaker: Liqi Chen
1430-1445	CO_2 flux variability in the North Atlantic: Exploring physical and ecological drivers. Speaker: Galen McKinley
1445-1500	Exploring the impact of changes in oceanic dust deposition on CO_2 fluxes and marine productivity between 1860 and 2100. Speaker: Alessandro Tagliabue
1500-1530	**Coffee**
	Ocean Carbon Sources and Sinks session I **Chair: Nicolas Metzl**
1530-1600	Decadal changes in chlorophyll a. Speaker: David Antoine
1600-1630	Decadal Changes in ecosystems. Speaker: Gregory Beaugrand

1630-1700	Ocean CO_2 inversions on pre-industrial / contemporary air-sea flux estimates. Speaker: Sara Mikaloff-Fletcher
1700-1730	**Poster set up**
1730-2000	Poster session and welcome reception (7th floor restaurant)

DAY 2 Thursday April 12

	Ocean Carbon Sources and Sinks session II **Chair: Scott Doney**
0900-0945 0945-1000	Global Climatology of Air-Sea Fluxes. Speaker: Rik Wanninkhof Discussion
1000-1030	Regional View 1: North Atlantic. Speaker: Ute Schuster
1030-1100	Coffee Break
1100-1130	Regional View 2: Arctic Ocean and Nordic Seas. Speaker: Are Olsen
1130-1200	Regional View 3: North Pacific. Speaker: Yukihiro Nojiri
1200-1330	**Lunch**
	Ocean Carbon Sources and Sinks session III **Chair: Roger Dargaville**
1330-1400	Regional View 4: Equatorial and South Pacific. Speaker: Richard Feely
1400-1430	Regional View 5: Southern and Indian Oceans. Speaker: Nicolas Metzl
1430-1500	Regional view 6: Coastal areas. Speaker: Arthur Chen
1500-1530	Simulating interannual/decadal CO_2 flux variability; underlying mechanisms and agreement with observations. Speaker: Scott Doney
1530-1600	**Coffee**
1600-1630	Estimating decadal variability of ocean carbon fluxes from atmospheric inversions. Speaker: Christian Rödenbeck
1630-1700	Estimating ocean-atmosphere carbon fluxes from atmospheric oxygen measurements. Speaker: Mark Battle
1700-1800	Open Discussion: Can we identify from field observations and model outputs the most likely regions of the ocean where the large-scale air-sea CO_2 fluxes have changed in the recent past and are most susceptible to change in the future (i.e. most vulnerable) ? Can we identify the underlying processes? Can we assess the content and quality of the models that are used to quantify the observed and projected changes? (Plenary discussion to guide Working Group 1). Discussion Leader / WG1 leader: Corinne Le Quéré Rapporteur: Chris Sabine

1800-1900	5x10 minutes activities overview presentations based on the national program written reports (note these are to be technical, not scientific). See list of national reports at the end of this agenda. • North Atlantic and Arctic Seas (Truls Johannessen/Ute Schuster) • North Pacific (Masao Ishii) • Equatorial and South Pacific (Feely) • Indian and Southern Ocean (Jacqueline Boutin) • Coastal (Arthur Chen)

DAY 3 - Friday April 13

	Strategies to Estimate Air-Sea Fluxes of CO_2 session I **Chair: Bronte Tilbrook**
0900-0930	What do we learn from the use and/or assimilation of ocean CO_2 data in coupled models. Speaker: Reiner Schlitzer
0930-1000	Moorings: New results and new technology overview. Speaker: Chris Sabine
1000-1030	Overview of proxy techniques for data extrapolation and interpolation. Speaker: Chris Sabine
1030-1100	**Coffee**
1100-1130	Neural network approaches to data extrapolation and interpolation for surface pCO_2. Speaker: Cyril Moulin
1130-1200	Air-sea gas exchange: State of knowledge and Southern Ocean GasEx. Speaker: David Ho
1200-1330	**Lunch**
	Strategies to Estimate Air-Sea Fluxes of CO_2 session II **Chair: David Ho**
1330-1400	Combining satellite observations and *in situ* CO_2 data with models to quantify air-sea flux (CASIX work). Speaker: Nick Hardman-Mountford
1400-1430	Using surface pCO_2 decorrelation length scales to determine sampling resolution. Speaker: Joellen Russell
1430-1500	Using biogeochemical models to develop sampling strategies. Speaker: Andrew Lenton
1500-1530	**Coffee**
1530-1550	Overview of current global ocean pCO_2 observations, new data releases, and data centre / data flow issues. Speaker: Alex Kozyr

1550-1610	pCO_2 Data base and synthesis efforts. Speaker: Benjamin Pfeil
1610-1800	Open Discussion: Part I (1610-1705): Considering our largest unknowns, data and gas exchange uncertainties, interpolation / extrapolation techniques, new measurement technology, and observing system experiments, what have we learned and where do we go from here to develop observation strategies to meet research objectives? (*Plenary discussion to guide WG 2*). Discussion Leader / WG 2 Leader: Bronte Tilbrook Rapporteur: Roger Dargaville Part II (1705-1800): Considering existing projects, new results, and recent data releases, what needs are there for coordination and data synthesis activities? Should we begin developing a "GlobalView Ocean CO_2" database? Should we develop scientific synthesis groups? (*Plenary discussion to guide WG 3*). Discussion Leader / WG 3 Leader: Dorothee Bakker Rapporteur: Helmuth Thomas

DAY 4 - Saturday April 14

	Working Groups – in parallel & plenary **3 rooms – Room II (capacity of 200+ people), Room IX (80) and Room V (20)**
0900-0930	Plenary session: Overview of Working Group Goals and Assignment of Rooms (Room II)
0930-1200	Working Groups 1, 2 and 3 in parallel (2&3 combined)
1200-1400	**Lunch – extra long to allow for getting to local restaurants**
1400-1500	Working groups 1, 2 and 3 in parallel (2&3 combined)
1500-1600	Plenary discussion to report on final recommendations Working group 1 (20 minutes) Working group 2 (20) Working group 3 (20)
1600-1630	Summary and actions
1630	End of meeting

Annex III : Poster Abstracts

Detecting and understanding the decadal changes of the global ocean phytoplankton: the GLOBPHY project

D. Antoine[1], **F. D'Ortenzio**[1], A. Bricaud[1], B. Gentili[1], C. Moulin[2], L. Bopp[2]
O. Aumont[3], H. Loisiel[4], C. Jamet[4], L. Duforet[4]

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Strong uncertainties persist on the recent changes (a few decades) of the primary biomass of the global ocean, namely the phytoplankton, which are the 1st link of the food chain and a regulator of the atmospheric CO_2. A homogeneous satellite ocean colour record, expressed in terms of the chlorophyll concentration, was recently generated, through a reanalysis and a reprocessing of the archives of two sensors, namely the "Coastal Zone Colour Scanner" (CZCS, 1980's) and the "Sea Viewing Wide Field of View Sensor" (SeaWiFS, end of the 1990's, beginning of the 2000's). Strong positive as well as negative changes were shown, leading on average to an increase of ~20% for the world ocean.

Further research is needed, on the one hand to confirm the evolutions that were observed, and, on the other hand, to understand their causes. The GLOBPHY project (started in 2007 and funded by the French Research National Agency) was therefore recently set up, with the general goal of confirming the observed decadal changes in the global ocean phytoplankton, and of understanding the impact of environmental (climatic) changes on this major compartment of the planetary carbon cycle. The structure of the project is presented, and the different approaches that will be used are described.

Air-sea CO_2 fluxes at the Cariaco Basin

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Measurements of pH and alkalinity have been taken at the Cariaco Basin as part of the CARIACO oceanographic time series program. These measurements have been used to calculate total carbon dioxide (TCO_2), fugacity of CO_2 (fCO_2), and air-sea CO_2 fluxes. From January 1996 to December 2000, and from March 2002 to December 2006, measurements were taken on a monthly basis at 10° 30' N, 64° 40' W as part of the CARIACO oceanographic time series. Sharp changes in the air-sea fluxes are observed from one month to the other. High production rates, changes in temperature, upflow of TCO_2 due to upwelling, and in a few occasions a decrease in salinity have an effect on CO_2 concentrations and these factors modulate the air-sea CO_2 exchange. At the time-series station, air-sea CO_2 fluxes ranged from -65 up to 26 mmol C m^{-2} d^{-1}. Similar measurements have been made on three separate cruises (March 2004, 2006 and September 2006) to various locations within the Cariaco Basin in order to study the distribution of the CO_2 parameters along an upwelling plume. High and low fluxes values were observed around the basin. Higher values (> 60 mmol C m^{-2} d^{-1}) were observed at the core of the upwelling plume, which originates along the south-eastern margin of the basin. Along the plume, flux values ranged from -2 to 67 mmol C m^{-2} d^{-1}). Lower values (- 43 mmol C m^{-2} d^{-1}) were observed in the southwest corner of the basin, near the mouth of several local rivers. Because of this effect, fluxes in the western side of the basin increases with latitude.

Time series studies of total inorganic carbon in the Labrador Sea and in the Canadian Arctic Archipelago

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The Labrador Sea is one of two sites in the North Atlantic that produces intermediate and deep water by winter convection. Depths of deep convection are influenced by the semi-decadal atmospheric forcing, North Atlantic Oscillation (NAO), and vary from over 2000m to 500-1000m. During convection, CO_2 is taken up in the surface water and is quickly transported to the depths, and some sequestered carbon is subsequently incorporated into the meridional overturning circulation and stored in the deep ocean. It is important to understand the size and variability of this long-term CO_2 sink associated with deep convection in the Labrador Sea to assess the global carbon cycle. Channels in the Canadian Arctic Archipelago region provide the main pathway for the flow of freshwater to the North Atlantic Ocean from the Arctic Ocean. Changes in the freshwater from the Arctic Ocean through the Canadian Arctic Archipelago have a possible implication for the deep convection regime in the Labrador Sea, as well as carbon transport from the Arctic to the North Atlantic. Time series studies of Total Inorganic Carbon, Alkalinity and auxiliary measurements along the Labrador Sea repeat section (AR7W line) since 1993, in the Davis Strait since 2004, and in the Barrow Strait since 2003 will be presented.

More pieces of the shelf sea CO_2 flux jigsaw puzzle

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The most straightforward and robust way to estimate air-water CO_2 fluxes is from pCO_2 field data. High latitude open shelf waters appear to be significant sinks, but there is a paucity of data (Borges, 2005). We are now sampling shelf-ocean hydrographic regions with high temporal and spatial variability, with a frequency that allows resolution of the sources and sinks of atmospheric CO_2 along the route year round.

Our VOS system on the P&O ferry between Portsmouth to Bilbao includes a non-dispersive gas analyser with equilibrator system (Cooper et al., 1998) and Optode (Tenberg et al., 2006), to measure xCO_2 and dissolved oxygen autonomously at a 30 sec frequency. Bulk seawater temperature is measured with in-line, towed, and hull-mounted sensors while skin temperature is measured radiometrically (ISAR) to provide the needed temperature corrections. Fluorescence and conductivity are measured at 1Hz. The ship crosses open continental shelves on the eastern margin of the North Atlantic, which can be subdivided hydrographically into well-mixed, tidal-frontal and shelf-slope regions, in addition to the ocean waters of the Bay of Biscay. The xCO_2 data reduction sequence has been validated within a CarboOcean inter-comparison exercise. Simultaneous O_2 and CO_2 fluxes are calculated using the most appropriate local wind data sources (spatial and temporal calculation of k, the piston velocity). The area is well served with wind data products; QuikSCAT scatterometer (12-hourly), corrected ship's anemometer (1 sec), three regional buoys (hourly), coastal stations (3-hourly) and Met Office model data (hourly). Preliminary results will be presented.

Inter-annual variability of the carbon dioxide oceanic sink south of Tasmania

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We compiled a large data-set from 22 cruises spanning from 1991 to 2003, of the partial pressure of CO_2 (pCO_2) in surface waters over the continental shelf (CS) and adjacent open ocean (43 to 46°S; 145 to 150°E) south of Tasmania. Sea surface temperature (SST) anomalies (as intense as 2°C) are apparent in the subtropical zone (STZ) and subantarctic zone (SAZ). These SST anomalies also propagate on the CS, and seem to be related to large scale coupled atmosphere-ocean oscillations such as the Antarctic circumpolar wave (ACW) or the southern annular mode (SAM). Overall, anomalies of pCO_2 normalized to a constant temperature are negatively related to SST anomalies. This seems to be related to a depressed winter-time vertical input of dissolved inorganic carbon (DIC) during phases of positive SST anomalies, in relation to a poleward shift of westerly winds, and concomitant local decrease in wind stress. We investigate the potential effect of SST anomalies on air-sea CO_2 exchange. The general trend is an increase of the sink for atmospheric CO_2 associated with positive SST anomalies, although strongly modulated by inter-annual variability of wind speed. Assuming that phases of positive SST anomalies are indicative of the future evolution of regional ocean biogeochemistry under global warming, we show using a purely observational based approach that some provinces of the Southern Ocean could provide a potential negative feedback on increasing atmospheric CO_2.

Surface ocean CO_2 variability and vulnerabilities in the Southern Ocean and the Arctic Ocean

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The polar oceans, with the Arctic Ocean in the north and Southern Ocean in the south, cover 20-25% of the total area of the global ocean. The Arctic Ocean is rapidly changing with thinning and retreating of the sea ice due to its sensitivity to global warming. In addition, the Arctic Ocean has and will receive more terrestrial organic materials due to the thawing of permafrost. These changes in ice cover and input of terrestrial organic carbon are thought to alter the absorption of the atmospheric carbon dioxide. The Southern ocean also exerts a major control on atmospheric carbon dioxide content.

The data collected during the CHINARE (Chinese National Arctic and Antarctic Research Expeditions) cruises reveal distinctive differences between both regions. In the Southern Ocean, CO_2 levels are different between the southern India Ocean and the southern Atlantic Ocean sectors because of different biological production as manifested by different chlorophyll-a levels. In the Western Arctic Ocean, the exchange area between Pacific and Arctic oceans, which is influenced by Bering inflow water, the melting ice zone, and the pack ice zone, respectively.

Therefore, it is of paramount importance to increase observations in the polar oceans. A program of 'Comparison of Air-Sea Fluxes of CO_2 in the Southern Ocean and the Western Arctic Ocean (CFCSOA, EoI #1017)' will be carried out during the international polar year (IPY) in 2007/2008. This work will be conducted on R/V Xuelong cruises and researches will focus on the distributions of

pCO_2, air-sea carbon fluxes and their controlling factors. There are three overarching objectives: (1) to install a high-resolution underway pCO_2 systems on the ship; (2) to achieve a quantitative understanding of the variability of sources and sinks of CO_2 in the polar and sub-polar regions from underway measurements of atmospheric and surface water pCO_2 and related chemical, physical, meteorological parameters; and (3) to provide observational information for evaluating the role of the polar regions in global change.

Influence of the South China Sea subsurface water outflow on the carbon chemistry of Kuroshio waters

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Measurements of dissolved inorganic carbon (DIC), $\delta^{13}C$ of DIC, dissolved oxygen, and other pertinent chemical parameters were carried out at 12 hydrographic stations around the Luzon Strait during the cruises in July 2002, August 2003, and October 2005 to attest whether the South China Sea (SCS) subsurface water outflow could act like a "shelf pump" to export the carbon from the interior of the SCS into the open Pacific. Result shows that the outflow is capable of transporting 17.6±9.0 Tg C yr-1 in the DIC form out from the SCS to the western Pacific, a quantity equivalent to ~35±18% of annual export production of the entire SCS. Furthermore, owing to the input of this SCS outflow, the subsurface waters of the Kuroshio Current become enriched in DIC/TA ratio but depleted in $\delta^{13}C$ DIC. Such a change in seawater carbon chemistry may further attenuate the capacity of CO_2 sequestration and result in an overestimate of CO_2 uptake rate in seawaters around the Kuroshio main path. More importantly, since these modifications can make all their ways northward along with the Kuroshio Current, the effect may reach even as far as to the higher latitude region in the north-western Pacific.

The South West Pacific Ocean – sink for atmospheric carbon dioxide

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The Southern Ocean is recognised as a sink for carbon dioxide, low pCO_2 in the surface waters and high transfer velocity characterised by high wind speeds combine to give large CO_2 fluxes into the seawater. The uptake is variable on both spatial and temporal scales, and the mechanisms affecting the variability are still not well known. pCO_2 in the surface waters of the South West Pacific Ocean has been measured on five voyages, as part of the NIWA led Drivers and Mitigators Of Global Change programme. The area sampled includes the Tasman Sea, sub-Antarctic surface water, and subtropical water masses, plus the subtropical and sub Antarctic frontal systems.

We present the combined data set, and make an estimate of the air-sea carbon flux for the New Zealand region. In general, water south of the sub Antarctic front (T < 7 °C) has the highest pCO_2 measured: 360 – 380 μatm; sub Antarctic water (8 < T < 12 °C) has pCO_2 between 330 and 360 μatm, and the subtropical water (T > 14 °C) varies from 350 ± 5 μatm in the Tasman Sea, to 340 ± 10 μatm north of Chatham Rise in the Pacific Ocean. Future plans include the installation of an autonomous pCO_2 system on the NIWA research vessel, RV Tangaroa, to increase both temporal and spatial

coverage of measurements, thereby further constraining the estimate of oceanic uptake of carbon in the South West Pacific region.

Spring CO_2 dynamics within sea ice: abiotical vs biological control.

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High latitude oceans are major sinks for atmospheric carbon dioxide (CO_2) but so far the extensive sea ice cover has been considered inert with respect to gas exchange with the atmosphere. There are growing observations that sea ice exchanges CO_2 directly with the atmosphere, highlighting the need in understanding CO_2 dynamics within sea ice. In spring ice, at least 6 processes can affect CO_2 dynamics, namely: (1) temperature change and (2) related melting of ice crystal, (3) biological activity, (4) dissolution of carbonate minerals, (5) internal convection and (6) air-ice gases exchanges. Each process can significantly impact inorganic carbon dynamics with opposing and compensating effects.

To explore the relationships between sea ice-specific biogeochemical processes and spring CO_2 dynamics, we carried out three surveys in Antarctic land fast sea ice, and first year and multiyear pack ice. We tried to assess the role played by none-transport processes and give some clues of the impact of the others.

In sea ice, intense growth of microalgae is commonly observed and acts to significantly decrease the partial pressure of CO_2 (pCO_2) and promote the uptake of atmospheric CO_2 by Antarctic sea ice. Biological mediated decrease of pCO_2 is significantly enhanced by superimposed none-transport abiotic processes (temperature change and related melting of ice crystals, dissolution of carbonate minerals) while transport processes (internal convection and air-ice gas exchange) counteract the observed decrease of pCO_2. Independent and indirect estimates of the potential CO_2 fluxes driven by these processes are consistent with available chamber measurements of air-ice CO_2 exchanges

Ecosystem functions in the Equatorial Pacific Ocean

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The equatorial Pacific Ocean is the largest oceanic source of CO_2 to the atmosphere, with significant impacts on the global carbon cycle. The elevated pCO_2 and flux of upwelled CO_2 to the atmosphere at the equator is due to incomplete use of the available NO_3. The ecosystem of the upwelling region approximates a chemostat, a type of continuous culture systems in which one nutrient is limiting and all others are in excess. In the Pacific equatorial upwelling system, the limiting nutrient is $Si(OH)_4$ which diatoms require for their shells. Diatoms are the major users of NO_3 in this system and the amount they can assimilate is limited by the low amount of $Si(OH)_4$ available. As a consequence NO_3 is left in the surface waters along with unused CO_2 This poster describes how the ecosystem functions and discusses the question of how a minority population of diatoms controls the biogeochemistry of the surface equator, especially the surface pCO_2 concentration. The source of the low $Si(OH)_4$ in this system is found in the Southern Ocean, where diatom growth results in low $Si(OH)_4$ Antarctic Mode

Water (AMW). These results suggest the importance of $Si(OH)_4$ and diatoms in the global carbon cycle. The role of Fe in the equatorial upwelling system is as a secondary limitation affecting the $Si(OH)_4$ uptake kinetics of the diatoms.

Continuous pCO_2 measurements under the sea ice in Arctic and Antarctic waters onboard an icebreaker

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High-frequency underway pCO_2 measurements were successfully performed in the Arctic Ocean in 2005, and in the Antarctic Southern Ocean in 2006 onboard the Swedish I/B Oden. We traversed in both open water and heavy sea ice conditions. The seawater intake was placed at the bow of the ship at approximately 8 meters depth, which enabled immediate under ice measurements in ice covered areas. In both studies, preliminary data showed rapid changes in the pCO_2 and oxygen values in the ice zones, which was related to physical fronts and changing sea-ice conditions. However, the under-ice pCO_2 levels differed in the two high-latitude oceans, likely due to different ecosystem dynamics involving ice-algae versus pelagic phytoplankton production. Future participation in expeditions to Antarctic Southern Ocean, and a long-term study in the Arctic Ocean in 2007/2008 will enable us to further investigate the biogeochemical dynamics in both Polar seas.

The impact of anthropogenic atmospheric nitrogen and sulfur deposition on ocean acidification and inorganic carbon system

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Fossil-fuel combustion and agriculture result in large atmospheric emissions of reactive sulfur and nitrogen, about a third to half of which are deposited to the coastal and open-ocean near major source regions in North America, Europe and South and East Asia. Atmospheric inputs of strong acids (H_2SO_4 and HNO_3) and bases (NH_3) are altering surface seawater alkalinity, pH and inorganic carbon storage. We quantify the geochemical and biogeochemical impacts using atmosphere and ocean models. The direct alkalinity flux to the ocean is predominately negative (acidic) in the temperate Northern Hemisphere and positive in the tropics because of ammonia inputs. However, most of the excess ammonia is nitrified to nitrate (NO^{-3}) in the upper ocean, and the effective net atmospheric alkalinity input is negative almost everywhere. The decrease in surface alkalinity drives a net air-sea efflux of CO_2, reducing surface dissolved inorganic carbon (DIC) and damping the size of the initial negative alkalinity driven decline in surface pH. Additional biogeochemical feedbacks arise from anthropogenic nitrogen eutrophication, leading to elevated primary production and enhanced biological DIC drawdown that reverses in some places the sign of the surface pH and air-sea CO_2 flux perturbations. On a global scale, the alterations in surface water chemistry from anthropogenic nitrogen and sulfur deposition are a few percent of acidification and DIC increases due to the oceanic uptake of anthropogenic CO_2. However, the impacts are more substantial in coastal waters, with

implications for ecosystem responses to ocean acidification and to the design of ocean observing systems.

An operational UK air-sea carbon flux observation capability (CARBON-OPS)

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We describe a new project CARBON-OPS which will demonstrate a 'supply chain' for automated measurement of pCO_2 in the surface of the ocean, its processing and its use in providing information to government bodies. Data is gathered by five new pCO_2 measurement systems on UK research ships in the Southern Ocean, Atlantic Ocean and NW European shelf seas. These send the measurements in near-real time, via satellite communication systems, to the British Oceanographic Data Centre, where they will be automatically processed, quality controlled and archived. The data will then be delivered to the Met Office for use in testing predictions from its ocean models. These models will assist the UK government by providing information on the amount of CO_2 taken up by the oceans and the related impacts on global climate, ocean alkalinity and the health of marine ecosystems. Data from the South Atlantic, Southern Ocean and Irish Sea will be presented.

Strong fCO_2 undersaturation after ice melt in the eastern Weddell Gyre

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The ice covered Weddell Gyre is a highly dynamic region within the global carbon cycle. We present fCO_2 data from Polarstern cruise ANT XX/2 carried out early in the austral summer, when the Weddell Sea was still largely ice covered. Generally, CO_2 was highly supersaturated under the ice, caused by entrainment of high-CO_2 intermediate water into the surface layer. In the coastal polynya at 0 8°W a dramatic undersaturation was observed, hinting that as soon as the ice disappears, biological drawdown of CO_2 takes over. Similarly, along a transect at 23°E strong undersaturations of CO_2 were found after the meltdown of the ice pack. This undersaturation was accompanied by very high chlorophyll levels, indicating high levels of phytoplankton productivity in the eastern Weddell Gyre. Interestingly, the chlorophyll maximum was not found at the sea surface but around 50 m depth, suggesting that satellite chlorophyll data for this region underestimate the productivity level. The spatial variation of fCO_2 in this most eastern part of the Weddell Gyre was quite high. Lowest fCO_2 values were observed in a region with low salinities after the ice melt. Hence surface layer stratification seems to support biological CO_2 drawdown. The phytoplankton growth with accompanying CO_2 uptake, changing the supersaturated ice covered surface layer into strongly undersaturated open water, appears to be the mechanism that makes the Weddell Gyre an annual CO_2 sink – confirming independent surface layer budget studies.

Fine and global scale measurements of pCO_2 and dissolved oxygen in relation to biological processes and gas exchange

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Since 2005, VOS measurements have been made on a shelf-sea-to-ocean route between Portsmouth and Bilbao, measuring pCO_2 (non-dispersive gas analyser with equilibrator system), dissolved oxygen (Optode), fluorescence, temperature and salinity. In addition, and unusually, regular monthly manual sampling of TA, DIC, oxygen (Winkler), nutrients, chlorophyll a, HPLC pigments and plankton species is done. It has a high data repeat rate (4 - 72 hours) enabling short time scale events to be observed for 11 moths of the year. Bargeron et al., (2006, Estuar Coast Mar Sci 69, 478-490) demonstrated the value of the oxygen anomaly measurements with calculations of gas exchange for the estimation of net productivity. We are co-operating with Swire Shipping (Hong Kong), to fit a pCO_2 system on a global 160-day route (Singapore, Panama Canal, Houston, Halifax, Suez Canal, Mumbai). To be robust and serviceable by the ships crew, it uses a Pro-Oceanus CO_2-Pro and a GTD (total dissolved gas pressure) instrument, in a tank with Aanderaa conductivity, temperature and dissolved oxygen (Optode) sensors - GPS, Vaisala atmospheric pCO_2, humidity and temperature sensors are at bridge level. Data will be transmitted to NOC every four hours using an Iridium link. At NOC, data will be transferred automatically to a public web page. Installation will take place in Singapore in May 2007. Results from trials against the non-dispersive gas analyser with equilibrator system on the Portsmouth-Bilbao route will be presented.

CO_2 profile in the lower atmosphere and CO_2 flux by the gradient method

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Micrometeorological methods are expected as crucial for the direct measurement of air-ocean exchange of carbon dioxide (CO_2). Micrometeorological methods are able to observe temporally and spatially small-scaled CO_2 flux. These methods will serve for the study on processes controlling air-ocean CO_2 exchange. The aerodynamic gradient method is plain and simple compared with the eddy-covariance method. We developed a fine buoy system for the measurement of CO_2 concentration profile in the lower atmosphere. Observations were performed in the Arctic Ocean and Bering Sea during the MR06-K04 leg 2 cruise aboard JAMSTEC R/V Mirai in 2006.

In the arctic and sub-arctic region, air-ocean differences of pCO_2 (ΔpCO_2 = pCO_2 sea - pCO_2 air) almost showed large negative values between -180 and -30μatm, and atmospheric CO_2 concentration was smaller at the lower levels. Difference in CO_2 concentration between 0.1m and 8m above sea surface was up to 0.4 μatm. Further more, vertical gradients of CO_2 concentration showed ideal semi-logarithmic profile and clear dependency on ΔpCO_2 . Half-hour CO_2 flux calculated by the gradient method showed downward flux between -80 and 20 mmol $m^{-2}d^{-1}$. The gas transfer velocity derived from CO_2 fluxes and ΔpCO_2 showed closer fit to Liss and Merlivat (1986) or Wanninkhof (1992).

It is said that the aerodynamic gradient method is applicable for air-ocean CO_2 flux measurements as well as the eddy-covariance method. The micrometeorological CO_2 fluxes will help to understand processes which control the air-ocean exchange such as surface conditions, water temperature, pH, bubble effect, wave breaking and so on.

Atmospheric constraints on the ocean carbon cycle

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There are few places in the open ocean where long time series of carbon data have been collected. These records are very informative about changes in time near the stations, but their extrapolation to regional and basin scales is limited. Ocean time series stations are preferentially located near land and in the northern hemisphere, leaving gaps in large areas of the open oceans, especially in the South Pacific, Indian, and Southern Oceans. Surveys with comprehensive spatial coverage are rare, and repeat cruises are episodic. In contrast, the network of atmospheric carbon observations is about an order of magnitude larger. This network has a more uniform spatial coverage, and records already extend over multiple decades. Historically, atmospheric CO_2 stations have been sited to sample the well-mixed marine boundary layer and to avoid signals from local terrestrial fluxes, meaning that their observations can contain significant information about air-sea fluxes. We use transport simulations and inversions to evaluate the extent to which atmospheric

CO_2 observations can inform us about three topics: the size of the ocean sink, both globally and in the Southern Ocean; whether coastal fluxes might be confounding the interpretation of atmospheric CO_2 mixing ratios; and the detection horizon for changes in air-sea exchange of carbon.

Observing the linked changes in nitrate, oxygen and inorganic carbon with *in situ* sensors in the coastal ocean

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Understanding the linkage between ecosystem processes and the carbon cycle in the presence of a changing climate requires long-term observations at a temporal resolution that is comparable to the rates of ecosystem change (hours to days). Here, it's shown that chemical sensors can be used in the coastal zone to track ecosystem rates and biomass on a daily basis. Chemical sensors for nitrate, oxygen and carbon dioxide partial pressure have been deployed simultaneously on moorings offshore of Monterey Bay on the Central California coast since April 2006. These moorings report data in real time. Diel cycles in the chemical properties are apparent on most days. It has been shown previously that diel cycles of nitrate concentration are created by photosynthetic production of organic matter during the daytime and respiration and mixing at night (Johnson et al., Deep-Sea Research I, **53**, *561-573*, 2006). The diel cycles in nitrate, oxygen and total inorganic carbon, which was estimated from carbon dioxide partial pressure after assuming an appropriate value for titration alkalinity, are compared here. The amplitudes of each of these cycles provide a different perspective on community production. These amplitudes can be used to predict the accumulation and loss of phytoplankton biomass with a high degree of fidelity to *in situ* observations. Thus, we now have the tools to directly observe ecosystem rates and their response to climate forcing.

Remote sensing as a tool for quantifying oceanic carbon dioxide sinks and sources in the Atlantic Sector of the Southern Ocean

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The global oceans act as buffers for the anthropogenic carbon dioxide released into the atmosphere. The air-sea exchange of CO_2 varies across each oceanic region with additional seasonal variations due to temperature and biological activity. The area of the Southern Ocean between The Falkland Islands, the Antarctic Peninsular and South Georgia is thought to be a strong CO_2 sink region although sparse shipboard measurements have made it difficult to accurately quantify this sink zone. This project aims to combine shipboard carbon dioxide measurements and satellite observations in order to help quantify carbon dioxide air-sea gas exchange in the Atlantic sector of the Southern Ocean. A CASIX (Centre of Observation of Air-Sea Interactions and Fluxes) underway pCO_2 (partial pressure of carbon dioxide) instrument was installed on the British Antarctic Survey research ship RRS James Clark Ross to provide an additional pCO_2 data set that will be added to existing data sets for surface pCO_2 to increase the overall spatial and temporal coverage of this region. Shore based support will be provided for this instrument and the data obtained will be co-located with satellite data of chlorophyll and sea surface temperature, parameters that can be used to inform on processes affecting pCO_2 in the surface ocean. It is hoped that the spatial and temporal variation of both the satellite and shipboard data will help to unravel the processes that drive the CO_2 air-sea transfer in this region.

Air-Sea CO_2 flux by eddy covariance technique in the Equatorial Indian Ocean

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The eddy covariance (correlation) technique is the only direct measurement of the CO_2 flux across the air-sea interface. This technique can evaluate the CO_2 flux on a shorter time scale than the traditional bulk CO_2 flux estimated by mass balance techniques using as tracers the natural and bomb-produced ^{14}C, $^{222}Rn/^{226}Ra$, and $SF_6/^3He$. We report the direct measurement of CO_2 fluxes evaluated by the eddy covariance technique in areas of small ΔfCO_2 and low wind speed over the equatorial Indian Ocean, and compares these fluxes with the bulk CO_2 fluxes estimated using the gas transfer velocity by mass balance techniques. The power spectra of the temperature or water vapour density fluctuations followed a -5/3 power law, although that of the CO_2 density fluctuation showed white noise in the high frequency range. However, the cospectrum of the vertical wind velocity and CO_2 density was well closed with those of the vertical velocity and temperature or water vapour density in this frequency range, and the CO_2 white noise did not influence the CO_2 flux. The raw CO_2 fluxes by the eddy covariance technique showed a sink from the air to the ocean, and had almost the same value as the source CO_2 fluxes due to the mean vertical flow, corrected by the sensible and latent heat fluxes (called the Webb correction). The total CO_2 fluxes including the Webb correction terms showed a source from the ocean to the air, and were larger than the traditional bulk CO_2 fluxes estimated by mass balance techniques.

North Atlantic fCO_2 variability in time and space

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Data from the research vessel G.O.Sars, and additional datasets from the North Atlantic north of 45°N have been used to make estimates of temporal and spatial changes of surface fCO_2. Using the cubic fit

between fCO_2, normalized to 5°C, and SST that was developed by Olsen et al. (2003), fCO_2^{95} has been calculated and used to estimate the annual change in fCO_2 after 1995. These results show substantial increases in most areas. In addition the trends in the actual data, fCO_2 vs year, have been analyzed and these results were compared to differences from the Olsen et al. (2003) equation. Finally, we have looked at the relationship and trends between annual change in fCO_2 after 1995 and salinity.

Observational strategy to better estimate the variability of fCO_2 in the tropical Atlantic

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An observational network is being setup in the tropical Atlantic to better estimate the seasonal variability of the air-sea CO_2 flux, its long-term trend, and the underlying processes dominating the variability of the fugacity of CO_2 (fCO_2) in the mixed layer. The tropical Atlantic includes two main large-scale currents: the South Equatorial Current (SEC), flowing westward and transporting upwelled waters, and the North Equatorial Counter Current (NECC) affected by the presence of the Inter Tropical Convergence Zone (ITCZ). The observational strategy consists of sampling these two main current systems. Two merchant ships (France-French Guiana and France-Brazil routes) are being equipped with an autonomous fCO_2 system based on infrared detection. In addition, a CARIOCA sensor is being installed on two instrumented moorings (6°S, 10°W and 8°N, 38°W) to monitor surface fCO_2. Data from the France-French Guiana line, from the mooring at 6°S, 10°W and from a cruise in the Gulf of Guinea will be presented in order to provide some insights on the processes affecting the spatial variability of the surface fCO_2 in the tropical Atlantic.

Response of Mediterranean benthic coralline algae and corals to elevated pCO_2 and temperature

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The CO_2 partial pressure (pCO_2) and temperature are two important factors that control the rates of calcification of benthic organisms but very few studies have investigated their interactive effects. The effect of increases of pCO_2 and temperature similar to those expected at the end of this century were investigated in the temperate coralline alga Lithophyllum cabiochae and the zooxanthellate scleractinian coral Cladocora caespitosa. Specimens were collected in the NW Mediterranean Sea (Bay of Villefranche, France) in summer and grown for one month at a temperature of 22°C (normal temperature) or 25°C (elevated temperature) and pCO_2 of ca. 400 µatm (normal pCO_2) or ca. 700 µatm (elevated pCO_2). Calcification rates were measured in incubation chambers using the alkalinity anomaly technique in the light and dark. The rate of calcification of L. cabiochae increased with increasing temperature under normal pCO_2 both in the light and dark, and with increasing pCO_2 under normal temperature only in the light. The rate of calcification of C. caespitosa did not change with increasing temperature under normal pCO_2 but decreased significantly with increasing pCO_2. There is a strong interaction between temperature and pCO_2 in L. cabiochae with a decrease in daily net calcification of 10% when both parameters were elevated. There is no such interaction in C. caespitosa as daily net calcification decreased by about 30% irrespective of the temperature level considered.

CO_2 flux variability in the North Atlantic: Exploring physical and ecological drivers

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Prediction of future vulnerability in ocean carbon uptake requires better understanding of current flux variability and its relationship to changing carbon storage. The North Atlantic is of particular interest because it is region of large net sink (Sabine et al. 2004). Atmospheric inversions employing the standard large-region approach (Baker et al. 2006) suggest relatively large flux changes from year to year for this region, but general circulation models and small-region inversions (Rödenbeck et al. 2003, McKinley et al. 2004) suggest only small variability. The region clearly warrants additional attention. In this paper, recent variability in fluxes and storage are studied using a moderately high resolution (0.5o) North Atlantic model that incorporates the ecosystem model of Dutkiewicz et al. (2005) and carbon cycling. Here we focus on the relative importance of physical and ecosystem processes, contrasting the subpolar and subtropical regions. In the subtropics, CO_2 flux anomalies are physically-dominated. In the subpolar gyre, the air-sea flux is impacted by both variability in convective mixing, and also the timing and magnitude of the spring bloom and subsequent carbon export.

The CO_2-Pro Sensor and Preliminary Intercomparisons

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The recently developed *PSI* CO_2*-Pro™* sensor uses a self-calibrating NDIR module and a long thin coiled PDMS membrane equilibrator. The sample volume is continuously re-circulated through the equilibrator and optical cell. The optical cell is warmed to a prescribed temperature (typically 40−55 °C) to prevent condensation. The NDIR module has an automatic zero-point calibration system that makes use of a CO_2 absorbent cell to provide CO_2-free air for periodic calibrations. The system is autonomous, originally designed to operate in profiling- or moored-mode over a depth range of 0−1000 m. Preliminary results of inter-comparisons in underway-mode, made during the UK SOLAS DOGEE-I experiment in the NE Atlantic during Nov/Dec 2006 using an earlier proto-type, show promise that the sensor is also capable of making stable underway pCO_2 measurements on ships of opportunity. Details of calibrations and raw data conversions are presented and discussed.

Summertime CO_2 sources and sinks in the eastern Bering Sea shelf

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In the summers of the years 1998 to 2002, 2004 and 2006, we conducted shipboard observations of atmospheric and surface seawater pCO_2 in the eastern Bering Sea shelf. At latitudes 57 – 63°N, surface seawater pCO_2 was elevated up to about 450 μatm, meaning that the area acted as a source for atmospheric CO_2. South of 57°N, however, surface seawater pCO_2 was reduced to be 150 μatm, meaning a strong sink for atmospheric CO_2. The reduced surface seawater pCO_2 was associated with depleted nitrate and reduced silicate, suggesting diatom activity. Although the depletion of nitrate and reduction of silicate were observed also at latitudes 57 – 63°N, surface seawater pCO_2 (total CO_2 also) was elevated. Since the pCO_2 elevation corresponded with blooms of coccolithophorid Emiliania huxleyi, it was expected that the pCO_2 was elevated by the blooms. The fact that the pCO_2 elevation was found also in the years when the bloom did not occur demonstrates that there are no cause-and-effect relationships between the blooms and the pCO_2 elevation. We chiefly attributed the pCO_2 elevation to river discharge. In the presentation, we intend to discuss carbon budget in the eastern Bering Sea shelf.

A new simple pCO_2 sensor with compact drifting buoy system for long term observation

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A lot of observations to obtain the fate of CO_2 in the atmosphere which is related with long term climate change have been carried in the world. However, the sea surface pCO_2 observations on research vessels and commercial ships concentrated in the North Atlantic and North Pacific. To obtain the spatial and temporal variation of surface pCO_2 in the whole ocean, new simplified automated pCO_2 measurement system is needed.

We have been developing newly small and simple *in situ* system for pCO_2 measurement using spectro-photometric technique. The pCO_2 is calculated from pH of indicator solution equilibrated with seawater through a gas permeable membrane. In this study we decided to use AF Teflon tube as an equilibrium membrane because this material is well suited to pCO_2 measurements due to its high gas permeability. This measuring system was constructed from LED light source, optical fibre, beam selector, CCD detector, micro pump, TS sensor and downsized PC. The new simple system is attached in aluminium drifting buoy with satellite communication system, which size is about 300 mm diameter and 450 mm length and weight is about 20 kg. A Li-ion battery for 1 year measurement is occupied about one third of the drifting buoy. In the laboratory experiment, we obtained high response time (less than 2 minutes) and precision within 2 μatm.

An underway pCO_2 system designed for volunteer observing ships

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An overall goal of the international ocean carbon cycle community is to constrain the global air-sea CO_2 fluxes on seasonal timescales. This requires a large increase in surface ocean water pCO_2 observations. A pCO_2 underway system was designed that could be utilized on volunteer observing ships (VOS). The system presented here is, in principle, similar to previous NDIR-based underway pCO_2 systems that use shower equilibrators (Wanninkhof and Thoning, 1993; Feely et al., 1998), but it is packaged in a relatively compact format and includes features that allow it to run unattended for weeks or months at a time in (hostile) engine room or bow chamber environments. Several unique features facilitate complete unattended operation: a self-cleaning water filter prevents the equilibrator spray heads from clogging. A hybrid, cold trap and naphion tube, air drying system dries the equilibrator and atmospheric air streams to a dew point of -20° C without using consumables. The control software supports additional sensors such as a thermosalinograph, an oxygen optode and/or a fluorometer. All data can be transmitted to shore daily by iridium satellite modem. Shoreside software allows one PC to receive data from multiple pCO_2 systems and includes automated range checking of pCO_2 and diagnostic sensor data to check for instrument malfunction. Aside from automation, the system also provides highly accurate data as manifested in intercomparison exercises. Using 4 gas reference standards every 2 to 3 hours, the calibration curve can be fully constrained and drift can be accounted for. A two-stage shower equilibrator ensures full equilibration. Data are presented showing the equilibrator's response time and reproducibility between multiple systems.

Regional and temporal variability of surface pCO_2 in the North Atlantic near Iceland

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The ocean around Iceland is characterized by sharp fronts between warm and saline Atlantic Water and lower salinity, colder Polar or Arctic Water. Air-sea fluxes of CO_2 differ significantly between these water-masses. Atlantic Water is characterized by pCO_2 values that are close to saturation with the atmosphere during the winter months and a significant biological draw-down of pCO_2 during spring/summer. Polar or Arctic water-masses have undersaturated pCO_2 values relative to the atmosphere throughout the year and exhibit considerably greater uptake of CO_2. Conditions in the Iceland Sea, north of Iceland, are especially sensitive to the proportions of these water-masses, which has a strong effect on the surface distribution of pCO_2. Results will be presented for underway measurements of surface pCO_2 during four cruises from May 2006 through February 2007.

fCO_2sw variability in the Bay of Biscay during ECO cruises

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The Bay of Biscay is part of the North Atlantic Ocean, the most important sink of CO_2, and a subduction zone of mode waters that favours the entry of carbon to the ocean interior. To investigate the seasonal and interannual variability of CO_2 uptake, continuous underway measurements of the

partial pressure of CO_2 in surface waters were performed along a commercial route between Vigo (Spain) and St. Nazaire (France). An unattended pCO_2 measuring system, with meteorological station, and temperature, salinity, oxygen and fluorescence sensors, was installed on board of ships of opportunity RO-RO L'Audace and Surprise.

The shipboard measurements show the temporal variations of surface seawater fugacity of CO_2 (fCO_2sw), temperature (SST), salinity (SSS), chlorophyll and nutrients (nitrate (NO_3), phosphate (PO_4) and silicate ($Si(OH)_4$). The gathered dataset throughout the two seasonal cycles reported an important interannual variability; mainly for the winter season. The noticeable increase of fCO_2sw during the winter fertilization of year 2004 was associated to subsequent biogeochemical differences related to nutrient ratios, phytoplankton activity and atmospheric CO_2 uptake. The fCO_2sw distribution throughout the seasonal cycle was correctly predicted from three empirical relationships in spite of the high interannual variability. The highest disagreement were found for fCO_2sw levels lower than 10 µatm The seasonal variability was mainly controlled by nutrients and chlorophyll during pre--bloom and bloom periods whereas SST was the key parameter during post-bloom period. Nevertheless surface waters of Bay of Biscay showed atmospheric CO_2 uptake for all the periods ranging from -2±2 to -0.4±0.6 $molC \cdot m^{-2} \cdot yr^{-1}$. Using the regular wind speed sources of CO_2 fluxes estimation ranged from -1.3 to -2.4 $molC \cdot m^{-2} \cdot yr^{-1}$ at annual scale, exceeding the sink capacity of the nearby regions of the North Atlantic Ocean.

fCO_2 in the Equatorial and North Subtropical Atlantic

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The FICARAM project aims to evaluate the air-sea CO_2 fluxes along meridional transects in the Atlantic Ocean. Underway measurements of seawater CO_2 fugacity (fCO_2), sea surface temperature and salinity were performed during 9 cruises spanning from 2000 through 2006. The transects were divided into 4 zones according to the spatial fCO_2 distribution and mean physical structures, namely: Subtropical Gyre (SG; from 35ºN to 17ºN), North Equatorial Current (NEC; from 17ºN to 5ºN), Equatorial Region (ER; from 5ºN to 5ºS) and Brazil Current (BC; 5ºS to 10ºS). In order to normalize the fCO_2 observations, the measurements were recalculated to a common constant temperature (25ºC), and the interannual increase of atmospheric CO_2 was also corrected. Empirical algorithms of normalized CO_2 were estimated for every region by cubic regression fits using SST, SSS and geographical position. Subsequently the estimations of normalized fCO_2 for each observation were converted to *in situ* temperature and the respective atmosphere conditions. A high percentage of the fCO_2 variability was explained with these expressions. The RMS errors are 8, 12, 5 and 12 µatm for SG, NEC, ER and BC, respectively. The predicted fCO_2 distribution along FICARAM V yielded a slightly overestimation of 2±8 µatm. The air-sea CO_2 flux differences associated with the use of the estimated empirical algorithms were also studied. Discrepancies of -0.2±0.2, 0.3±0.2, 0.1±0.2 and -0.1±0.1 $mol \cdot m^{-2} \cdot y^{r-1}$ were found for the SG, NEC, ER and BC, respectively. The seasonal variability and the source/sink behaviour of the region are adequately predicted for any of the considered regions.

Recommendations on underway pCO_2 data reduction.

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In October of 2005, a workshop was organized in Miami, FL to deal with the issue of uniformity in the underway pCO_2 data reduction. It has been recognized that the same data set could lead to significant differences in the calculated pCO_2 and fCO_2 due to differences in the treatment of the data. The participants of the workshop were mostly from the NOAA VOS program and partly from the

European CARBOOCEAN program. The results of this workshop are presented here and consist of recommendations on the collection, quality control and reduction of the data. Excel® and Matlab® programs have been written to help in that effort.

The partial pressure of carbon dioxide and air-sea fluxes in the coastal zone of the Gulf of Cadiz in summer and autumn

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The distribution of the partial pressure of CO_2 (pCO_2) in the surface waters of the Gulf of Cadiz (southwestern Spain) was examined and air-sea CO_2 fluxes also were calculated during two seasons: early summer and autumn. The studied area covers down to 15 nautical miles and could be divided in two zones: Bay of Cadiz, where the main input is anthropogenic carbon and Estuary of Guadalquivir, where continental inputs are predominant.

Data were obtained from 17th to 29th June and 19th to 30th November 2006 on board R/V Mytilus (CSIC, Vigo). Underway partial pressure of CO_2 was measured using an autonomous home-made equipment, following the design of Körtzinger et al. (1996). The carbon flux between the atmosphere and the ocean was calculated using the k-wind parameterization given by Wanninkhof, 1992 and Ho et al., 2006. The wind speed was obtained from the meteorological station on board.

The highest values of pCO_2 have been observed in the Estuary of Guadalquivir and they are up to 1000 µatm in summer and in autumn. In contrast, in the Bay of Cadiz values were roughly 500 µatm in summer and even lower in autumn. pCO_2 decreases while distance to the coast increases. The equilibrium atmospheric value is reached in the Bay of Cadiz closer to the coast than in Estuary of Guadalquivir. Calculations of average CO_2 fluxes indicated that the sampled coastal sector of the Gulf of Cadiz behaved as a net source for atmospheric CO_2 during the period studied.

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Carbon dioxide fluxes in the Benguela coastal province

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In the frame of the CARBOOCEAN Project the QUIMA-ULPGC group is studying the variability of fCO_2 in the Benguela region. The near-coastal South East Atlantic Ocean off Africa is a unique and highly dynamic environment influenced by the Angola coastal upwelling, the Benguela upwelling and the Western Agulhas Bank. The QUIMA-VOS line has been crossing the Benguela current coastal province (BENG) between 15ºS and 35ºS since July 2005 having a set of data in the area in winter and spring.

Benguela is one of the eastern boundary regimes of the World Ocean. In the region, apart from the equatorward and poleward boundaries, zonal oriented fronts tend to develop equatorward of the major upwelling cells and four areas can be distinguished. Between 14ºS and 20ºS, where the Cumene cell (16ºS) and Northern Namibia cell (19ºS) are located, the highest values of fCO_2sw in the area are obtained (460 µatm in July 2005 at 19ºS) acting this area as a source of CO_2.

Between 20ºS and 25ºS, the fCO_2 sw values are lower than fCO_2 atm and the area is a light sink of CO_2 affected by the wind field. Around 27ºS the influence of the Lüderitz cell is observed and higher seawater fCO_2 than in the surrounded area are obtained result of rich and not totally depleted CO_2 upwelled water. The seawater fCO_2 values fluctuates between 410 µatm (July 2005) and 360 µatm (November 2005). South of 27ºS and until 34ºS the lowest values of fCO_2 in the area (320 µatm) are found, acting in the period studied as a sink of CO_2.

Two well defined areas can be distinguished in the Benguela province during the period studied. Northern of 20ºS (14ºS-20ºS) the system acts as a source of CO_2 with an average flux ranging from 0.15 mol m^{-2} yr^{-1} to 1.5 mol m^{-2} yr^{-1}, affected by the wind stress. South of 20ºS (20ºS-33ºS) the average fluxes are negative, being a sink of CO_2 with values between -0.71 and -2.43 mol m^{-2} yr^{-1}.

Measurements of the CO_2 partial pressure in the North Atlantic Ocean – Does the ΔpCO_2 change?

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As part of the European FP6 IP "CarboOcean" three cruises with continuous pCO_2 measurements were conducted in 2005 on the M/V Falstaff across the North Atlantic between Europe and North America. In January 2006, we installed another pCO_2 system on board the commercial vessel M/V Atlantic Companion that produces reliable pCO_2 results since June 2006 with two North Atlantic crossings every 5 weeks. In addition to the continuous pCO_2 measurements, discrete samples are taken at regular intervals (~ every 7 weeks in 2006) for DIC/AT, ^{13}C, nutrients, POC/PON, TOC/TN and chlorophyll.

Here we compare the newly acquired CarboOcean pCO_2 data with data that were collected within the European FP5 project "CAVASSO" in 2002/2003 on nearly the same route. The region between 35°N and 55°N is divided in 4 grid bands of 10° width between 10°W and 50°W, where we exclude the shelf areas. The average ΔpCO_2 is calculated for each grid band. It shows a consistent annual cycle with a high variability on shorter time scales. The direct comparison of the "CAVASOO" data with the more recent ones shows no significant change of the ΔpCO_2 during the observed time period.

Constraining global air-sea gas exchange for CO_2 with recent bomb ^{14}C measurements and multiple wind products

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The $^{14}CO_2$ released into the stratosphere during bomb testing in the early 1960s provides a global constraint on air-sea gas exchange of soluble atmospheric gases like CO_2. Using the most complete database of dissolved inorganic radiocarbon, $DI^{14}C$, available to date and a suite of ocean general circulation models in an inverse mode we find a 33 % lower globally averaged air-sea gas transfer velocity for CO_2 compared to previous estimates (Wanninkhof, 1992). Unlike some earlier ocean radiocarbon studies, the implied gas transfer velocity finally closes the gap between small-scale deliberate tracer studies and global-scale estimates. Additionally, the total inventory of bomb produced radiocarbon in the ocean is now in agreement with global budgets based on radiocarbon measurements made in the stratosphere and troposphere. Combining our estimated gas transfer velocity with wind speed, and standard partial pressure difference climatology we obtain an ocean uptake estimate of 1.3±0.5 $PgCyr^{-1}$ for 1995. After accounting for the carbon transferred from rivers to the deep ocean, this estimate compares well with estimates based on ocean inventories, ocean transport inversions using ocean concentration data, and model simulations. While the globally averaged air-sea gas transfer velocity is independent of wind speed products currently available, the resulting flux calculated is not. The difference in global CO_2 air-sea flux calculated using different wind speeds products normalized by bomb $DI^{14}C$ inventory is a function of large regional variations in wind speed.

Factors driving the interannual variability of surface pCO_2 in the Drake Passage

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As of January 2007, we have completed over 90 transects of the Drake Passage covering three basic routes from the tip of South America to Palmer Peninsula, Antarctic. During these cruises the primary measurement made on the R/VIB L.M. Gould determine the partial pressure of CO_2 (pCO_2) at the surface by equilibrating air in a closed container with water taken from the uncontaminated seawater system. Additionally, we have collected and analyzed discrete samples of total CO_2 (TCO_2), the $^{13}C/^{12}C$ of TCO_2 (C-13), the $^{14}C/^{12}C$ of TCO_2 (C-14), phosphate (PO_4), nitrate (NO_3), silicate (SiO_4), oxygen and salinity on these transects 6-8 times a year. In collaboration with Janet Sprintall (SIO), the discrete measurements are done coincident with expendable bathythermographs (XBTs) which enables us to identify eddies and the approximate location of the mixed layer along our sampling track. These measurements provide a unique opportunity to not only describe the full seasonal cycle of nutrients, oxygen and CO_2 in the Drake Passage but also to see the inter-annual variability in these fields over the last five years. The surface water surveys have also been supplemented by one hydrographic cruise during the austral summer (March, 2006) which seeks to understand how observed increases in wind speeds might change the wintertime surface ocean CO_2 concentrations. While net annual air-sea fluxes are close to zero in the Drake Passage moderate biological production and sea surface temperature act together to produce a strong seasonal cycles.

Neural networks as a technique for reconstructing marine pCO_2 fields in the North Atlantic using data gathered within 2005 by VOS, buoys, moorings and research vessels.

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Artificial neural networks are useful alternatives to traditional statistical modelling techniques used in environmental sciences. We show preliminary basin-wide maps of the North Atlantic pCO_2 for 2005 computed using neural networks. We compare our parameterizations with other contemporary work available. The data set consists of underway measurements of sea surface pCO_2 collected on four vessels of opportunity (VOS), regularly crossing the North Atlantic throughout 2005, as a part of the IP CARBOOCEAN (http://dataportal.carboocean.org). We hypothesize that seawater pCO_2 may be

parameterized as a function of globally available parameters: sea surface temperature (SST), mixed layer depth (MLD), and chlorophyll-a concentrations, plus two variables containing the indirectly related information, month (MTH) and position (POS).

We propose using two types of neural networks. Initially we use Self Organizing Maps (SOM) in order to pre-process the in-situ data. SOM are designed for processing multidimensional data with non-linear behaviour, which is a characteristic of pCO_2 fields. Kohonen's maps, as they are also called, are unsupervised learning algorithms. They can be used for the visualisation of multidimensional databases. Such maps will help us to better understand the links between five variables (SST, MLD, chlorophyll, MTH and POS) and the pCO_2. The algorithm partitions available data into clusters (each corresponding to a neuron on the map) that exhibit some similarity (Dreyfus, 2005). As a result of the neighbourhood function, nearby neurons on the map are nearby in the data-space. Hence the map, which is a quantization of the original data-space, allows an easier visualisation of the relationships between variables of the original database. We present the visualisation of the map with our interpretation of relationships linking the variables of the database. With the information provided by the SOM, we will process the database using another type of neural network called Multilayer Perceptron (MLP). It has been shown (Hornik et al., 1989), that the MLP can be trained to approximate virtually any smooth, measurable function. It can model non-linear functions and can be trained to accurately generalise when presented with new unseen data (Gardner and Dorling, 1998). Hence we will train an MLP in order to model the $pC0_2$ (on a basin scale) which is considered as a non linear function of SST, MLD, chlorophyll, POS and MTH.

References:

CARBOOCEAN Integrated Project, 2005 internal data set http://dataportal.carboocean.org (2005)

Dreyfus, G. Neural Networks: Methodology and Applications, 386, (Springer, Berlin, 2005).

Temporal variability of dissolved inorganic carbon in the western North Pacific subarctic region

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The dissolved inorganic carbon (DIC) and related chemical species have been measured from 1992 to 2006 at Station KNOT (44°N, 155°E) and K2 (47°N, 160°E) in the western North Pacific subarctic region. DIC and apparent oxygen utilization (AOU) in the subsurface water (26.7-27.2σθ) appeared not to increase and showed a declining tendency from 2001 to 2006, while potential alkalinity (PA) remained constant. Temporal variability of DIC and AOU at KNOT were more scattered than those at K2, and decreased with increasing density. In general, observed DIC along an isopycnal surface is the sum of the changes of DIC due to the gas exchange of CO_2 at the air-sea interface ($DIC_{air\text{-}sea}$), the decomposition of organic matter (DIC_{org}) and the dissolution of calcium carbonate (DIC_{Ca}). DIC_{org} and DIC_{Ca} have positive relationships to AOU and PA, respectively. $DIC_{air\text{-}sea}$ can be calculated by using DIC, AOU and the stoichiometric ratio of carbon to oxygen at the organic matter decomposition (117/170, Anderson and Sarmiento, 1994), as following,

$$DIC_{air\text{-}sea} = DIC - 117/170 * AOU$$

$DIC_{air\text{-}sea}$ at KNOT and K2 has increased in the intermediate water (26.7-27.2σθ) for the period from 1992 to 2006 (0.6-1.9 μmol/kg/yr). This rate decreased with increasing density. DIC in the mixed layer at Station KNOT increased from 1998 to 2003 at rate of 1.0 $\mu mol\ kg^{-1} yr^{-1}$ [Tsurushima, 2004]. The water column inventory of CO_2 in the western North Pacific subarctic region was estimated to be 0.63 mol $m^{-2} yr^{-1}$, which is almost the same as that previous reported [e.g., Ono et al., 2000].

Annex IV: National Reports

National reports were requested from 20 nations, to detail their current and planned activities. These reports were synthesised into the tables in section 6.

Nation: Australia

Lead author: Bronte Tilbrook

Ocean Carbon Observations:

Underway pCO_2/VOS (Voluntary Observing Ships)

Track/Ship name	Dates of operation	Basin	Brief description (ship track)	Frequency	PI
l'Astrolabe	2002 -	Southern Ocean	Hobart – Terre Adelie (Antarctica.)	3/austral summer	B. Tilbrook (joint project with France)
Aurora Australis	2006 -	Southern Ocean	Hobart -Mawson Base/ Hobart - Casey Base	4/year	B. Tilbrook
Southern Surveyor	2007 -	South West Pacific/ East Indian	Various research cruise East Indian Ocean/Coral Sea/Tasman Sea	8/yr	B. Tilbrook

Time Series (permanent moorings and repeat visit by ships)

Mooring/ Station	Date of operation	Location	Description	Frequency	PI
PULSE time series	2008 -	47S 142E	Sub-Antarctic mooring	Continuous	B. Tilbrook

Repeat Hydrography

Name of the line	Basin	Description (ship track)	Year planned	PI
P12/SR3	Southern Ocean	Hobart – Antarctica (140E)	2007	B. Tilbrook
P15S	South Pacific	Equator – 50S 175W	2009 (not yet funded)	B. Tilbrook
I9S	Southern Ocean	Fremantle – Antarctica	2012 (not yet funded)	B. Tilbrook

Ocean carbon research programmes:

Research project	Description	Dates of operation	PI
SAZ-Sense	Sub-Antarctic biogeochemistry in South Tasman Sea including CO_2 enrichment experiments	Jan – Feb, 2007	B. Tilbrook

Nation: Belgium
Lead author: Alberto Borges

Ocean Carbon Observations:

Underway pCO_2/VOS (Voluntary Observing Ships)

Track/Ship name	Dates of operation	Basin	Brief description (ship track)	Frequency	PI
RV Belgica	2001-2010	Atlantic	Continuous pCO_2 measurements on all the cruises of the RV Belgica in the Southern Bight of the North Sea	Weekly to monthly	A. Borges alberto.borges@ulg.ac.be

Time Series (permanent moorings and repeat visit by ships)

Mooring/ Station	Date of operation	Location	Description	Frequency	PI
Ste Anna	2002-2010	Upper Scheltd estuary	Fixed station for continuous measurements of pCO_2, salinity and temperature	Continuous	A. Borges
STARESO	2006-2008	Calvi	Shallow mooring for pCO_2 and temperature measurements (Pro-Oceanus) over a Posidonia seagrass meadow (water column depth 10m) the Mediterranean Sea	Daily	A. Borges

Ocean carbon research programmes:

Research project	Description	Dates of operation	PI
PEACE : Role of Pelagic cAlcification and export of CarbonatE production in climate change (Belgian Federal Science Policy Office)	pCO_2, DIC, pH and total alkalinity measurements in conjunction with process measurements (primary production, calcification, respiration, organic and inorganic matter export) during coccolithophorid blooms in the Gulf of Biscay http://www.co2.ulg.ac.be/peace/	June 2006 May 2007 May-June 2008	A. Borges
SESAME : Southern European Seas: Assessing and Modelling Ecosystem changes (FP6 IP)	pCO_2, DIC, pH and total alkalinity measurements in the Eastern Mediterranean and Black Sea http://www.ncmr.gr/sesame/	March 2008 September 2008	A. Borges
Sea Ice Biogeochemistry in a climate change perspective SIBCLIM (Action de Recherche Concertée - ARC)	pCO_2, DIC, pH and total alkalinity measurements in sea-ice (Bellingshausen Sea) http://dev.ulb.ac.be/glaciol/projects/sibclim.htm	September - October 2007	B. Delille Bruno.delille@ulg.ac.be
	modelling of CO_2 in Antarctic seaice		C. Lancelot lancelot@ulb.ac.be

BELCANTO : Assessing the sensitivity of the Southern Ocean's Biological Pump to Climate Change (Belgian Federal Science Policy Office)	pCO_2, DIC, pH and total alkalinity measurements in the Southern Ocean (0° Meridian) http://www.co2.ulg.ac.be/belcanto/	February – March 2008	B. Delille
	3D modelling of CO_2 in the Southern Ocean http://www.co2.ulg.ac.be/belcanto/		C. Lancelot
BELCOULOR-2 : Optical remote sensing of marine, coastal and inland waters (Belgian Federal Science Policy Office)	pCO_2, DIC, pH and total alkalinity measurements in the Southern Bight of the North Sea to establish remote sensing algorithms for coastal environments http://www.mumm.ac.be/BELCOLOUR/	Several cruises in 2007, 2008 and 2009	A. Borges
Towards an integrated marine Carbon sources and sinks assessment CARBO-OCEAN (FP6 IP)	Continuous pCO_2 measurements on all the cruises of the RV Belgica in the Southern Bight of the North Sea http://www.carboocean.org/	2001-2010	A. Borges
	Fixed station for continuous measurements of pCO_2, salinity and temperature in the Upper Scheltd estuary http://www.carboocean.org/	2002-2010	A. Borges
	0D and 3D modelling of CO_2 in the Southern Bight of the North Sea http://www.carboocean.org/		C. Lancelot
MIS FNRS n° F.4513.06	Shallow mooring for pCO_2 and temperature measurements (Pro-Oceanus), and O_2 over a Posidonia seagrass meadow (water column depth 10m) in the Mediterranean Sea (Corsica, Calvi) http://www.co2.ulg.ac.be/posidonia.htm	2006-2008	A.Borges

Nation: Brazil

Lead author: Rosane Ito

Ocean carbon research programmes:

Research project	Description	Dates of operation	PI
PATEX: PAtagonian EXperiment	A multidisciplinary fieldwork (physics, nutrients, bio-optics, primary production, CO_2, DMS) to investigate the strong occurrence of phytoplankton blooms and its role in the sea-air CO_2 fluxes along the Patagonian shelf-break region (South Atlantic, 40-50°S).	2006-2007 (Nov and Mar)	rgito@io.usp.br
SOS-CLIMATE: Southern Ocean Studies for Understanding Global-CLIMATE Issues	The study of the seasonal and interannual variability of sea-air carbon flux, along the Patagonian shelf-break region (South Atlantic, 40-50°S), based on satellite data analyses and *in situ* data collection.	2007-2009 (Nov and Feb)	rgito@io.usp.br

Nation: Canada
Lead author: Helmuth Thomas

Ocean Carbon Observations:

Underway pCO_2/VOS (Voluntary Observing Ships)

Track/Ship name	Dates of operation	Basin	Brief description (ship track)	Frequency	PI
St Laurent / Laurier	2005-	Atlantic & Pacific	Newfoundland-Canada basin	Not stated	C. S. Wong
Line P / John P Tully	1974 -	Pacific	Sidney BC – Station P	3/ year	C. S. Wong
Amundsen	2004 -	Arctic	ArcticNet Domain (Arctic coastal waters)	1/year	T. Papakyriakou (papakyri@cc.umanitoba.ca)
Skaugran VOS	1995-2005	Pacific	Vancouver, Tokyo. Surface measurements of DIC etc., some pCO_2 surveys with Japan	~10/yr	CS Wong

Time Series (permanent moorings and repeat visit by ships)

Mooring/ Station	Date of operation	Location	Description	Frequency	PI
Labrador Sea	1993-present	57N,53W		1/year	K. Azetsu-Scott
NE Pacific OSP / Line P	1970's – present	50N,145W		4/year	L. Miller millerli@dfo-mpo.gc.ca
Scotian Shelf	2007-	44.68N 63.61W	CARIOCA buoy	Hourly 2007-	H. Thomas, helmuth.thomas@dal.ca
ArcticNet Beaufort Sea moorings (CA04, CA08, CA05, CA18)	2003 - ongoing	71°N, 133°W 71°N, 127°W 71°N, 126°W 70°N, 123°W	4 moorings equipped with sequential sediment traps	Continuous	L. Fortier (louis.fortier@bio.ulaval.ca)
ArcticNet Baffin Bay moorings (BA01, BA03)	2005 - ongoing	76°N, 71°W 76°N, 77°W	2 moorings equipped with sequential sediment traps	Continuous	L. Fortier)
ArcticNet Hudson Bay moorings (AN01, AN03)	2005 - ongoing	60°N, 92°W 55°N, 78°W	2 moorings equipped with sequential sediment traps	Continuous	L. Fortier
ArcticNet Laptev Sea mooring (M3)	2004 - ongoing	80°N, 142°E	1 mooring equipped with sequential sediment traps	Continuous	L. Fortier

NE Pacific OSP / Line P	1970's – present	50N,145 W	DIC/T Alk at 5 stations along Line P (Miller). pCO_2 (Wong)	3/year	CS Wong, L. Miller
OSP	1982-2006	50N, 145W	Sediment trap moorings redeployed annually	continuous	CS Wong

Repeat Hydrography

Name of the line	**Basin**	**Description (ship track)**	**Year planned**	**PI**
AR7W	Atlantic (Labrador Sea)	From Labrador to Greenland 1/year (spring)	1993-present	K. Azetsu-Scott Azetsu-Scottk@mar.dfo-mpo.gc.ca
Davis Strait	Atlantic (Baffin Bay)	From Baffin Island to Greenland 1/year (summer-fall)	2004-present	K. Azetsu-Scott
Barrow Strait	Canadian Arctic Archipelago	Parry Channel 1/year (summer)	2003-present	K. Azetsu-Scott
Hudson Bay and Strait	Hudson Bay	MERICA	2003-present	K. Azetsu-Scott
AR7W	Atlantic	53N/56W-61N/48WBiogenic carbon (TOC, DOC, phytoplankton, bacteria, zooplankton) inventories. Primary and secondary productivity, microbial production and respiration.	1/year	G. Harrison / B. Li / P. Kepkay / E. Head HarrisonG@mar.dfo-mpo.gc.ca
Scotian Shelf	NW Atlantic	Coastal monitoring program off Nova Scotia, Canada, 2-3/year 42/48N, 60/66W	2006-?	H. Thomas
ArcticNet annual monitoring cruise (CCGS Amundsen)	North Atlantic and Arctic	From Quebec City to Labrador Sea, Baffin Bay (NOW), Northwest Passage (trough M'Clintock Channel), Beaufort Sea (Mackenzie Shelf and Amundsen Gulf), and to Foxe Basin and Hudson Bay on the way back to Quebec City.	2003, 2004, 2005, 2006, ongoing	L. Fortier
Joint ArcticNet/ NABOS annual cruise (I/B Kapitan Dranitsyn)	Arctic	From Murmansk to Laptev Sea (following the Arctic shelfbreak)	2003, 2004, 2005, 2006, ongoing	L. Fortier
Line P	Pacific	BC coast to 50 N, 145 W. CTD casts at 27 stations, water properties (nutrients, oxygen) at 5 to 7 stations. DIC/Alk by Lisa Miller	3/yr over next decade	M. Robert robertM@dfo-mpo.gc.ca

Ocean carbon research programmes:

Research project	**Description**	**Dates of operation**	**PI**
Canadian Arctic Shelf Exchange Study (CASES)	CASES was the largest field program ever initiated to decipher the functioning of the arctic shelf system. The main objective is to understand how the	2002-2007	L. Fortier

	atmospheric, oceanic and hydrologic forcing of sea ice variability dictates the nature and magnitude of biogeochemical carbon fluxes in the Mackenzie Shelf and Amundsen Gulf ecosystem (Beaufort Sea). (http://www.cases.quebec-ocean.ulaval.ca)		
CASES cont.:	Measurements of DIC, total alkalinity and pH throughout the water column on the Mackenzie Shelf and slope, Beaufort Sea during the ice-free season and throughout the year in Franklin Bay. Calculation of pCO_2 in surface mixed layer and estimation of fluxes across the air-sea and ice-air interface from meteorological data.	September 2003-October 2004	A. Mucci., L. Miller L. and T. Papakiriakou
CFL: Canadian Flow Lead Study	Measurements of DIC, total alkalinity and pH throughout the water column in the Bathurst Polynia, east coast of Banks Island, Beaufort Sea. Calculation of pCO_2 in surface mixed layer and estimation of fluxes across the air-sea and ice-air interface from meteorological data.	2007-2008	L. Miller, A. Mucci, T. Papakiriakou, H. Thomas.
GEOTRACES	Measurements of DIC, total alkalinity and pH throughout the water column in the Canadian basin during the ice-free season and throughout the year in Franklin Bay. Measurement of pCO_2 in surface mixed layer and estimation of fluxes across the air-sea and ice-air interface	2 weeks? in 2008, 2009 & 2010.	A. Mucci and H. Thomas
C-ICE02	air-sea ice CO_2 flux, Barrow Strait	Spring/02	T. Papakyriakou L. Miller
ArcticNet	Hudson Bay & CASES region	Fall/05	T. Papakyriakou
ArcticNet	North Water & Archipelago & CASES region	Fall/06	T. Papakyriakou
SERIES	Iron enrichment in HNLC waters of the NE Pacific	July 2002	CS Wong
Canadian Archipelago Throughflow Studies	Baffin Bay and Nares Strait	2003	K. Azetsu- Scott
Irminger Sea Circulation and Convection	East Greenland shelf and slope	2004	K. Azetsu-Scott

Nation: China (Taiwan)

Lead author: **Wen-Chen Chou**
Other contributors: **Chen-Tung Arthur Chen, Kon-Kee Liu, and Chun-Mao Tseng**

Ocean Carbon Observations:

Underway pCO_2/VOS (Voluntary Observing Ships)

Track/Ship name	Dates of operation	Basin	Brief description (ship track)	Frequency	PI
RV Ocean Researcher	2003~present	North Pacific (South China Sea)	Underway pCO_2 survey is conducted along the following cruise track in the northern South China Sea: from Kaoshiung (~120.3°E; 22.6°N)to the SEATS site (115.7°E; 18.3°N)	Seasonal	C.-M. Tseng cmtseng99@ntu.edu.tw
RV Ocean Researcher	2001~present	North Pacific (East China Sea)	Underway pCO_2 survey is conducted in the area among ~(123°E; 31.5°N), ~(127°E; 30°N), ~(120°E; 26°N), ~(121.5°E; 25°N).	Annual	C.-M. Tseng

Time Series (permanent moorings and repeat visit by ships)

Mooring/ Station	Date of operation	Location	Description	Frequency	PI
SEATS	1999~present	115.67°E 18.25°N (in the South China Sea)	Dissolved inorganic carbon and total alkalinity are measured at 25 discrete depths throughout the water column (from surface to 3500m).	Seasonal	W.-C. Chou wcjou@mail.nsysu.edu.tw
Sediment-trap mooring/ SEATS	2004~present	115.67°E 18.25°N (in the South China Sea)	The mooring system consists of 3 sediment traps at the water depths of 500m, 1000m, and 3500m, respectively. The exported carbon fluxes in particulate form are measured at these three depths.	Continuous (each sample represents a collecting duration of two weeks)	W.-C. Chou

Repeat Hydrography

Name of the line	Basin	Description (ship track)	Dates of operation	PI
PR20, and PR21	North Pacific	The hydrography, including temperature, salinity, dissolved oxygen, nitrite, nitrate, phosphate, silicate, pH, alkalinity, and dissolved inorganic carbon, of the two lines was repeatedly investigated during the World Ocean Circulation Experiment (WOCE) by the ROC WOCE team. PR20: across 21°45'N from the southern tip of Taiwan (~121°30'E) to 130°E. PR21: across 120°42'E from the southern tip of Taiwan (~21°N) to the northern tip of Luzon (~19°30'N).	Oct., Nov., and Dec. 1990 Jun. 1991 May 1992 Oct. 1993 May 1994 Oct. 1994 May 1995 Oct. 1995 Sep. 1996 Jul. 2004	A. Chen ctchen@ mail.nsysu.edu.tw

Ocean carbon research programmes:

Research project	Description	Dates of operation	PI
Carbonate Chemistry in Waters Surrounding Taiwan	In order to investigate the carbonate chemistry in waters surrounding Taiwan, dissolved inorganic carbon, alkalinity and pH were measured during 9 research cruises around Taiwan.	Aug. 1988~Jul. 2001	A. Chen
Kuroshio Edge Exchange Processes-Marginal Sea Studies (KEEP-MASS)	The overall objective of this project is to quantify the oceanic penetration of anthropogenic CO_2, and to better understand the carbon cycle in the marginal seas. Dissolved inorganic carbon, alkalinity and pH were measured in the water samples collected from the western marginal seas of the North Pacific, including the western Philippine Sea, the East China Sea, the southern Yellow sea, the Sea of Japan, and the Okhotsk Sea during the KEEP-MASS expedition.	7/10/1992~ 8/5/1992	A. Chen
2006 Joint Hydrographic Survey	In order to investigate the hydrographic characteristics around Taiwan, a joint survey with 4 research vessels was conducted. Dissolved inorganic carbon, alkalinity and pH were measured in the water samples collected from the West Philippine Sea and the northern South China Sea during this joint cruise.	May. 2006	W.-C. Chou
Strait Watch on the Environment and Ecosystem with Telemetry (SWEET)	In order to investigate the circulation in the Taiwan Strait, 22 research cruises were conducted. Dissolved inorganic carbon, alkalinity and pH were measured in the water samples collected from each SWEET cruise in the Taiwan Strait.	Aug. 2001~Jul. 2007	A. Chen

Carbon cycles in the fluvial and oceanic system of Southeast Asia (CASA)	The objective of CASA project is to develop theories regarding carbon cycle dynamics and fisheries productivity in the South China Sea region, with a focus on biogeochemical dimensions and fisheries along with their interactions and feedback. Dissolved inorganic carbon, alkalinity and pH were measured in the water samples collected from the South China Sea during each CASA cruise.	Aug. 2003~Jul. 2007	A. Chen
Long-term observation and Research of the East China Sea (LORECS)	A sub-project in LORECS, entitled "Distribution and Air-Sea Exchange Fluxes of CO_2 in the East China Sea" is designed to investigate the cycling and air-sea exchange of carbon dioxide (CO_2) and related controlling processes in the East China Sea (ECS) and further to examine the role of East China Sea margins in the global carbon cycling. The observational study is devoted to carry out the underway pCO_2 measurements in the ECS. The results will be used to derive the air-sea exchange fluxes of CO_2, to understand the carbon dynamics of the East China Sea and further to evaluate the controlling mechanisms and impacts of Changjiang runoff and Kuroshio upwelling and atmospheric forcings on the CO_2 biogeochemistry of the ECS. Over the long-term observation, we expect to incorporate these multi-media data into a coupled physical-biogeochemical model for the ECS. The results will finally allow to be applicable to other similar coastal environments.	Aug. 2006~Jul. 2008	C.-M. Tseng
Coupled Physical-biogeochemical study of the upper water column in the South China Sea: isotopic analyses and numerical modeling	The South China Sea (SCS) is the largest marginal sea in southeast Asia. This project is a part of the SEATS study and aims to explore the possible linkage between variation of carbon and nitrogen isotopic compositions of particulate organic matter in the South China Sea and the marine carbon cycle. We propose two approaches: (1) Using carbon and nitrogen isotopic compositions of particulate organic matter as tracers to examine the intrusion of the Kuroshio water masses into the South China Sea and other water mass movement, such as upwelling, and (2) Using 3-D coupled physical-biogeochemical model to explore how physical forcing, including wind and irradiance, may control the sinking fluxes of particulate organic matter and its carbon and nitrogen isotopic compositions.	Aug. 2006~Jul. 2007	K.-K. Liu kkliu@ncu.edu.tw

Development of coupled physical-biogeochemical model for the western Pacific marginal seas	This project is a part of LORECS. The project is built upon an existing hydrodynamic model based on the Regional Ocean Model System (ROMS). The model is capable of simulating the western North Pacific Ocean with a resolution of 1/4 degree. In the geochemical aspect, we have improved estimates of the East China Sea carbon budget based on a two-box model of the East China Sea shelf. In the future, we propose to perform the following items: 1. Improve the existing biogeochemical module by including carbon in the compartments, by experimenting with new ecosystem structures and by incorporating observational findings to the model from LORECS as well as other regional studies. 2. Develop a pelagic-benthic coupled module and advocating observations of diagenetic processes in the benthic layer of the East China Sea.	Aug. 2006~Jul. 2009	K.-K. Liu

Nation: China

Lead author: Liqi Chen

Ocean Carbon Observations:

Underway pCO_2/VOS (Voluntary Observing Ships)

Track/Ship name	**Dates of operation**	**Basin**	**Brief description (ship track)**	**Frequency**	**PI**
Xuelong	Jun-Sep, 2008 and 2009	Bering Sea, Chukchi Sea and Canadian Basin	Leaving from Shanghai, pass East China Sea, Japan Sea, Bering Abyssal Plain, Bering Strait, Chukchi Sea, Canadian Basin, en route undertway observations of air-sea fluxes of CO_2 and back to Shanghai.	2008, 2009 and couple of years interval	L. Chen, lqchen@soa.gov.cn
Xuelong	Nov-Mar	Southern Ocean	Leaving from Shanghai, pass northern and southern Pacific, investigate in Prydz Bay and tracks between Zhongshan St(East Antarctica) and Changcheng St(Antarctic Peninsular).	Yearly except for modification year.	L. Chen

Time Series (permanent moorings and repeat visit by ships)

Mooring/ Station	**Date of operation**	**Location**	**Description**	**Frequency**	**PI**
Zhongshan Station/Xuelong	Nov-Mar	Prydz Bay, Southern Ocean		Yearly except for modification year.	L. Chen
Changcheng Station/Xuelong	Nov-Mar	Fields Bay. Southern Ocean		Two-yearly except for modification year.	L. Chen

Repeat Hydrography

Name of the line	Basin	Description (ship track)	Year planned	PI
Fremantle-Prydz Bay	Southern Ocean	Leaving from Fremantle of Australia, pass southern Indian Ocean, transactions investigation between 60°S and 69°S.	Yearly except for modification year.	Z. Dong Dongzahoqian@pric.gov.cn

Ocean carbon research programmes:

Research project	Description	Dates of operation	PI
Carbon Cycles and Response of Bering Sea and the western Arctic Ocean to the Arctic Rapid Changes	Due to its sensitivity to global warming. the Arctic Ocean rapidly changing with thinning and retreating of the sea ice and the thawing of permafrost, changes in ice cover and input of terrestrial organic carbon are whether to alter the absorption of the atmospheric carbon dioxide.	Jul-Sep, 2008 and 2009	L. Chen
Comparison of Air-Sea Fluxes of CO_2 in the Southern Ocean and the western Arctic Ocean (CFCSOA)	The goals of this program are: 1) to develop a high-resolution underway pCO_2 system; 2) from underway measurements of atmospheric and surface water pCO_2 and related chemical, physical, meteorological parameters, to achieve a quantitative understanding of the variability of sources and sinks of CO_2 in the Polar and Sub-polar Regions, and of the processes control the pCO_2 variations; and 3) to provide observational information for evaluating the role Polar regions plays in global change.	Jul-Sep, 2008 and 2009, Nov-Mar, 2007,2008,2009,and 2010	L. Chen, R. Wanninkolf, Rik.Wanninkhof@noaa.gov Weijun Cai, wcai@uga.edu Zhongyong Gao,benbengao@263.net

Nation: France

Lead author: Jacqueline Boutin

Ocean Carbon Observations:

Underway pCO_2/VOS (Voluntary Observing Ships)

Track/Ship name	Dates of operation	Basin	Brief description (ship track)	Frequency	PI
IRIZAR Project	2007-???	Atlantic	Buenos Aires – Antarctica	2-4 times per year	C. Goyet (joint project with Argentina)
Minerve Project / Astrolab	2002-	Pacific / Southern Ocean	Hobart – Terre Adelie (Antarctica.)	3/austral summer	C. Goyet
CARIOCA buoys	2005-2009	Atlantic	Southern Ocean	Continuous	J. Boutin /L. Merlivat
Marion Dufresne / OISO	1998-	South Indian/Southern Ocean	Reunion – Crozet – Kerguelen – Amsterdam Is	2/year	N. Metzl

Skogafoss	1993-	North Atlantic	Island-New Foundland	3-4/year	G. Reverdin/N. Metzl/R. Wanninkhof
MN Colibri	2006-present	Atlantic	France_French Guiana	~6/ year	N. Lefèvre
Monte Olivia	2007-present	Atlantic	France-Brazil	~6/ year	N. Lefèvre

Time Series (permanent moorings and repeat visit by ships)

Mooring/ Station	Date of operation	Location	Description	Frequency	PI
Mediterran-ean DYFAMED	1991-2001; 2003 – present	43N,7.9E	Water column discrete A_T and C_T	Monthly	C. Goyet
PIRATA	2006-pres. 2007-	6S-10W 8^{o}N, 38^{o}W	Hourly measurements of pCO_2 by a CARIOCA sensor at 1.5m depth	Continuous	N. Lefèvre
MAREL-Iroise	Feb. 2003-present	48°22' N 4°33' W	Hourly measurements by a CARIOCA sensor (modified for coastal measurements) at 1.5m depth	Continuous	E. Bucciarelli

Repeat Hydrography

Name of the line	Basin	Description (ship track)	Year planned	PI
OISO	South Indian	low resolution hydrocasts	1998-	N. Metzl

Ocean carbon research programmes:

Research project	Description	Dates of operation	PI
EGEE 3/ AMMA	Research cruise with underway pCO_2	June 2006	N. Lefèvre
EGEE 1 to 6/ AMMA	2 research cruises (June, Sep.) with DIC, TA samples	2005, 2006, 2007	N. Metzl
CarboOcean-WP5	Measurements related to and understanding of air-sea CO_2 fluxes in the Southern Ocean	2005-2010	J. Boutin-N. Metzl
CarboOcean-WP4	Measurements related to and understanding of air-sea CO_2 fluxes in the northern and tropical Atlantic Ocean	2005-2010	N. Lefèvre-N. Metzl
CarboOcean-WP9	Anthropogenic carbon in the ocean	2005-2010	C. Goyet-N.Metzl
CarboOcean-WP13	Penetration of carbon in the Mediterranean Sea (measurements (BOUM, ARCHIMED) and modeling)	2005-2010	C. Goyet
French CYBER/ $FLAMENCO_2$ program	Decadal CO_2 variability: measurements, models and atmospheric inversions	2006-2008	N. Metzl

Nation: Germany
Lead author: Tobias Steinhoff

Ocean Carbon Observations:

Underway pCO_2/VOS (Voluntary Observing Ships)

Track/Ship name	**Dates of operation**	**Basin**	**Brief description (ship track)**	**Frequency**	**PI**
Finnpartner Finnmaid	2003- ongoing	Baltic Sea	Luebeck- Helsinki	150/year	B. Schneider (bernd.schneider @ io-warnemuende.de)
M/V Falstaff	2002 - 2003	North Atlantic	Southampton – New York	18/year	A. Körtzinger (akoertzinger@ifm-geomar.de), D. Wallace (dwallace@ifm-geomar.de)
M/V Falstaff	2005	North Atlantic	Southampton – New York	3/year	A. Körtzinger, D. Wallace
M/V Atlantic Companion	2006 – ongoing	North Atlantic	Liverpool – Halifax	2 per 5 weeks	A. Körtzinger D. Wallace
R/V Meteor 45/2	1999	Northeast Atlantic	Lisbon – St. John's	4 weeks research cruise	D. Wallace
R/V Meteor 45/3	1999	Labrador Sea	St. John's – St. John's	4 weeks research cruise	D. Wallace
R/V Meteor 50/1	2001	Labrador Sea/North Atlantic	Halifax – St. Johns	4 weeks research cruise	D. Wallace
R/V Meteor 50/4	2001	Labrador Sea/North Atlantic	Reykjavik – Hamburg	4 weeks research cruise	D. Wallace
R/V Meteor 55	2002	Tropical Atlantic	Curacao – Douala	5 weeks	A. Körtzinger
R/V Meteor 59/2	2003	Subpolar North Atlantic	Reykjavik – St. John's	4 weeks research cruise	D. Wallace
R/V Meteor 59/3	2003	Subpolar North Atlantic	St. John's - Bremerhaven	5 weeks research cruise	A. Körtzinger
R/V Charles Darwin 162	2004	Subpolar North Atlantic	St. John's – Reykjavik	2 weeks research cruise	A. Körtzinger
R/V Thalassa WNA-05	2005	Labrador Sea	St. John's – Vigo	4 weeks research cruise	A. Körtzinger

R/V Poseidon 320/1	2005	Mauretanian upwelling	Las Palmas – Mindelo	3 weeks research cruise	A. Körtzinger
R/V Meteor 68/3	2006	Mauretanian upwelling	Mindelo – Las Palmas	4 weeks research cruise	A. Körtzinger
R/V Poseidon 347	2007	Mauretanian upwelling	Las Palmas – Las Palmas	3 weeks research cruise	A. Körtzinger
R/V Poseidon 348	2007	Mauretanian upwelling	Las Palmas – Las Palmas	3 weeks research cruise	A. Körtzinger
R/V M.S. Merian 07	2008	Mauritanian upwelling	Dakar – Las Palmas	4 weeks research cruise	A. Körtzinger
FS Polarstern	2007 and ongoing	Arctic and Southern Ocean	Arctic Ocean and Atlantic sector of Southern Ocean	All cruise legs ARK and ANT	M. Hoppema (mario.hoppema @awi.de)

Time Series (permanent moorings and repeat visit by ships)

Mooring/ Station	Date of operation	Location	Description	Frequency	PI
CIS	2003 – ongoing	59.7°N, 39.7°W	Long-term mooring	Continuous	A. Körtzinger
CV, R/V Islandia	From 2007	17.5°N, 24.3°W	Monthly ship visits / profiling float	Monthly / Daily	D. Wallace A. Körtzinger
K1	2001/2002 2004 – 2007	56.5°N, 52.6°W (near Bravo)	Long-term mooring	Continuous	A. Körtzinger
PAP	2003 – ongoing	49°N, 16.5°W	Long-term mooring	Continuous	A. Körtzinger

Repeat Hydrography

Name of the line	Basin	Description (ship track)	Year planned	PI
R/V Meteor 55	Tropical Atlantic	Curacao – Douala	2002	A. Körtzinger
R/V Meteor 68/3	Tropical Atlantic	Mindelo – Las Palmas	2006	A. Körtzinger
R/V M.S. Merion 07	Tropical Atlantic	Dakar – Las Palmas	2008	A. Körtzinger
FS Polarstern	South Atlantic and Southern Ocean	Capetown – Antarctica (Prime Meridian) Weddell Sea: Kapp Norvegia – Joinville Island	2005 2008 2010	M. Hoppema

Ocean carbon research programme

Research project	Description	Dates of operation	PI
CarboOcean	WP4: North Atlantic VOS line	2005-2009	A. Körtzinger
CarboOcean	WP8+9: Atlantic carbon storage	2005-2009	D. Wallace
CarboOcean	WP10: Atlantic oxygen floats	2005-2009	A. Körtzinger
CarboOcean	WP16: Mesocosm/biological feedbacks	2005-2009	U. Riebesell (uriebesell@ifm-geomar.de)
SOPRAN	WP3.5: CO_2 and O_2 fluxes in tropical northeast Atlantic, CV site	2007-2009	A. Körtzinger
TENATSO	Cape Verde Ocean Observatory	2006-2008	D. Wallace
CarboOcean	WP5: pCO_2 Southern Ocean	2005-2009	M. Hoppema

Nation: Iceland

Lead author: Jon Olafsson

Ocean Carbon Observations:

Time Series (permanent moorings and repeat visit by ships)

Mooring/ Station	Date of operation	Location	Description	Frequency	PI
Irminger Sea	1983-present	64.3N,28° W	Profile, pCO_2 and TIC, O_2 and nutrients	4/year	J. Olafsson jon@hafro.is
Iceland Sea	1983-present	68°N 12.66°W	Profile, pCO_2 and TIC, O_2 and nutrients	4/year	J. Olafsson

Ocean carbon research programmes:

Research project	Description	Dates of operation	PI
Iceland Sea Ecolology	Iceland Sea and Denmark Strait area. Hydrography, nutrients, oxygen and carbon system, plankton and pelagic fish with emphasis on capelin,	2006-2007 3/yr	O. K. Palsson, okp@hafro.is
CARBOOCEAN	FP6 programme	2005-2009	

Nation: India
Lead author: VVSS Sarma

Ocean Carbon Observations:

Time Series (permanent moorings and repeat visit by ships)

Mooring/ Station	Date of operation	Location	Description	Frequency	PI
GOA time series station	2003-2012 (Funded)	15N 72E	Sampling of CO_2 parameters were started in end of 2006 and will continue until 2012.	Monthly	S. W. A. Naqvi naqvi@nio.org
East coast time series	2007-2012 (Funded)	15-20N 80-85E	5 transects will be occupied along east coast of India between 15 to 20N and samples are collected along 5 transects of 10 kms wide.	Seasonal	M.D Kumar dileep@nio.org
Bay of Bengal time series	2008-2013 (Proposed)	20N, 90E	Permanent mooring and weekly sampling using automated samplers and seasonal visit to the station.	Seasonal	VVSS Sarma vvsarma@yahoo.com

Nation: Japan
Lead author: Masao Ishii

Ocean Carbon Observations:

Underway pCO_2/VOS (Voluntary Observing Ships)

Track/Ship name	Dates of operation	Basin	Brief description (ship track)	Frequency	PI
JMA's monitoring program by RV Ryofu Maru and RV Keifu Maru	On going	North and Eq Pacific	137ºE, 34ºN – 3ºN 137ºE, 34ºN – 2ºS*	Seasonal Jan-Feb*, April-May, June-July*, Oct-Nov	T. Midorikawa midorika@mri-jma.go.jp S. Minato sminato@met.kishou.go.jp
JMA's monitoring program by RV Ryofu Maru and RV Keifu Maru	On going	North Pacific	Tokyo – 50ºN ,165ºE – 28ºN ,165ºE	Annual June-July	T. Midorikawa S. Minato sminato@met.kishou.go.jp
JMA's monitoring program by RV Ryofu Maru and RV Keifu Maru	On going	North and Eq Pacific	165ºE, 28ºN – 5ºS	Biannual Jan-Feb, June-July	T. Midorikawa S. Minato

JMA's monitoring program by RV Ryofu Maru and RV Keifu Maru	On going	Eq Pacific	142ºE – 165ºE, Equator	Biannual Jan-Feb, June-July	T. Midorikawa S. Minato
JARE by Icebreaker Shirase	On going	Southern	Fremantle – Syowa Stn. (Lützow-Holm Bay, Antarctica) Syowa Stn. – Sydney *	Annual Dec. *Feb-Mar	G. Hashida gen@nipr.ac.jp S. Nakaoka nakaoka@nipr.ac.jp
RV Umitaka Maru	Dec. 2007 – Feb. 2008	Southern	Cape Town – Fremantle - Hobart (Off of Lützow-Holm Bay, 110ºE, 140ºE)		G. Hashida S. Nakaoka nakaoka@nipr.ac.jp
RV Hakuho Maru	Feb. 2008	Southern	Port Elizabeth – Fremantle (near Kerguelene, Off of Lützow-Holm Bay)		H. Y. Inoue hyoshika@ees.hokudai.ac.jp
Pyxis	2002-	Pacific	Nagoya – Portland – L.A. – Toyohashi	Monthly	Y. Nojiri nojiri@nies.go.jp
R/V Mirai	1998 -	Pacific, Arctic	Depending on cruises	Irregular	A. Murata
JMA's monitoring program by RV Ryofu Maru and RV Keifu Maru	2010?-	North Pacific	40ºN, to the west of date line	Biannual	future planning
JMA's monitoring program by RV Ryofu Maru and RV Keifu Maru	2010?-	North Pacific	24ºN(P3), to the west of date line	Biannual	future planning
JMA's monitoring program by RV Ryofu Maru and RV Keifu Maru	2010?-	North Pacific	9°N (P4), to the west of date line	Biannual	future planning

Time Series (permanent moorings and repeat visit by ships)

Mooring/ Station	**Date of operation**	**Location**	**Description**	**Frequency**	**PI**
JMA's monitoring program by	2003- On going	North Pacific 137ºE(P9)	DIC, ^{13}C, pH, CFCs* 0 - 2000m, 22 layers	Seasonal Jan-Feb,	M. Ishii mishii@mri-jma.go.jp

RV Ryofu Maru and RV Keifu Maru		, 30ºN-5ºN, mostly 5º intervals	* measured in selected cruises	April-May, June-July, Oct-Nov	S. Minato
JMA's monitoring program by RV Ryofu Maru and RV Keifu Maru	2003- On going	North Pacific 165ºE (P13), 50ºN - 28ºN, mostly 2-3º intervals	DIC, TA*, CFCs* 0 - 2000m, 22 layers	Annual June-July	M. Ishii S. Minato
JMA's monitoring program by RV Ryofu Maru and RV Keifu Maru	2003- On going	North and Eq Pacific 165ºE (P13), 28ºN -3ºS, mostly 2-3º intervals	DIC, ^{13}C, pH*, CFCs* 0 - 2000m, 22 layers	Biannual Jan-Feb, June-July	M. Ishii S. Minato
JMA's monitoring program by RV Ryofu Maru and RV Keifu Maru	2003- On going	Eq Pacific 165ºE - 142ºE, 0º, mostly 5º intervals	DIC, pH* 0 - 2000m, 22 layers	Biannual Jan-Feb, June-July	M. Ishii S. Minato
A-line (A4, A7)	1996- On going	North Pacific 42.25ºN, 145.125ºE (A4) and 41.50ºN, 145.50ºE (A7)	DIC, TA, ^{13}C 0 - 3000m, 12 layers *part of A-line monitoring program (http://ss.hnf.affrc.go.jp/a-line/index_e.html) *reference: Ono et al., JO 61, 1075-1088, 2005.	4-6/year	T. Ono tono@fra.affrc.go.jp
K2	2001 -	North Pacific 160°E, 47°N	0 - bottom, 36 layers DIC, TA, pH, CFCs	2 – 3/year	M. Honda hondam@jamstec.go.jp M. Wakita mwakita@jamstec.go.jp
155E Line	2002 -	North Pacific 155°E, 44°N –0o	0 - bottom, 36 layers DIC, TA, pH, CFCs	~1/year	M. Wakita
JMA's monitoring program by RV Ryofu Maru and RV Keifu Maru	2010?-	40°N to the west of date line	DIC, pH, (TA) 0 - 2000m, 22 layer	Biannual	Future planning
JMA's monitoring program by	2010?-	24N(P3) to the west of	DIC, pH, (TA) 0 - 2000m, 22 layers	Biannual	Future planning

RV Ryofu Maru and RV Keifu Maru		date line			
JMA's monitoring program by RV Ryofu Maru and RV Keifu Maru	2010?-	9N(P4) to the west of date line	DIC, pH, (TA) 0 - 2000m, 22 layers	Biannual	Future planning

Repeat Hydrography

Name of the line	Basin	Description (ship track)	Year planned	PI
P17N	Pacific	Sekinehama, Japan – Dutch Harbor	2001	A. Murata akihiko.murata@ jamstec.go.jp
P06	Pacific	Brisbane, Australia – Papeete, Tahiti – Valparaiso, Chile	2003	A. Murata
A10	Atlantic	Santos, Brasil – Cape Town, South Africa	2003	A. Murata
I03/I04	Indian	Cape Town, South Africa – Tamatave, Madagascar – Port Louis, Mauritius – Fremantle, Autralia	2003/2004	A. Murata
P10	Pacific	Sekinehama, Japan – Guam, USA	2005	A. Murata
P03	Pacific	San Diego, USA – Sekinehama, Japan	2005	A. Murata
P01	Pacific	Sekinehama, Japan – Dutch Harbor	2007	A. Murata
P14	Pacific	Sekinehama, Japan – Auckland, New Zealand	2007	A. Murata
P13	Pacific	Not fixed	2010? not fixed	To be conducted by JMA.
P09	Pacific	Not fixed	2011? not fixed	To be conducted by JMA.
P01 to the west of the date line	N. Pacific	Not fixed	2012? not fixed	To be conducted by JMA.
P03 to the west of the date line	N. Pacific	Not fixed	2013? not fixed	To be conducted by JMA.
P04 to the west of the date line	N. Pacific	Not fixed	2014? not fixed	To be conducted by JMA.

Ocean carbon research programmes:

Research project	Description	Dates of operation	PI
Development of CO_2 sensor	A CO_2 sensor, which can be installed on a drifting buoy, is under development.	FY2005 – FY2009	S. Watanabe swata@jamstec.go.jp Y. Nakano ynakano@jamstec.go.jp

Development of Advanced System for Measuring CO_2 in the Ocean	A dual-beam coulometer and a small spectrophotometer with optical fibre connections for high precision DIC, TA, and pH analyses now under development.	FY2005 – FY2007	M. Ishii A. Murata

Nation: Korea
Lead author: Kitack Lee

Ocean Carbon Observations:

Time Series (permanent moorings and repeat visit by ships)

Mooring/ Station	Date of operation	Location	Description	Frequency	PI
Marian Cove, King Sejong Station, King George Island	2003-ongoing	62°13´S, 58°47´W	Surface measurements	Continuous	Y.C. Kang (yckang@kopri.re.kr)

Repeat Hydrography

Name of the line	Basin	Description (ship track)	Year planned	PI
56°S,63°W 62°S,58°W	Southern	Drake Passage (Punta Arenas, Chile King George Island, West Antarctica)	2007, 2008 (yearly continuous)	Y.C. Kang

Ocean carbon research programmes:

Research project	Description	Dates of operation	PI
National Research Laboratory Program-mesocosm experiment	Examine the effect of CO_2 concentration on phytoplankton	Jan.-Feb. 2007 (yearly continuous)	Kitack Lee ktl@ postech.ac.kr
PECOECS: Prediction of the marine Ecosystem variation in the East China Sea due to the long term climate change	As part of the PECOECS, surface water pCO_2 and water column TA will be measured at the northern East China Sea as well as other biogeophysical factors. The major process for the surface pCO_2 distribution and the amount of air/sea CO_2 flux will be discussed as an area of continental shelf pump.	Aug. 2003, Apr. 2004, Oct. 2004, Oct. 2005, Jul. 2006, ???	C.H. Kim chkim@ kordi.re.kr

Nation: Netherlands
Lead author: Hein de Baar (debaar@nioz.nl)

Ocean Carbon Observations:

Underway pCO_2/VOS (Voluntary Observing Ships)

Track/Ship name	Dates of operation	Basin	Brief description (ship track)	Frequency	PI
Ams-Bergen	2005-2009	North Sea	Amsterdam-Bergen; collaboration Norway-	Weekly	T. Johannesen (Norway)

			Netherlands in CarboOcean		truls@gfi.uib.no H. van der Strate h.j.van.der.strate @rug.nl
Polarstern	end of 2007 ? and onwards	both polar oceans and Atlantic transects to/from Antarctic	autonomous pCO_2 system (General Oceanics) should already have been completed and delivered. For installation and continuous operation at Polarstern.		M. Hoppema Mario.Hoppema @awi.de collaborative effort with Royal NIOZ (debaar@nioz.nl)

Time Series (permanent moorings and repeat visit by ships)

Mooring/ Station	Date of operation	Location	Description	Frequency	PI
Platform F3 Atmospheric measurements	2006-2009	North Sea (54°51' N, 4°44' E)	NAM oil&gas platform F3. Continuous atmospheric CO_2 and O_2 concentration monitoring. Flask samples are being taken regularly (typically once a week) since early September 2006. Joint CarboEurope/CarboOcean activity.	Continuous; weekly flasks	H.Meijer, Centre h.a.j.meijer@rug .nl I. Luykx i.t.luijkx@rug.nl
Dyfamed Atmospheric measurements	2006-2009	Mediterranean 43° 25' N, 7° 52' E	atmospheric flask sampling	Monthly	H. Meijer Ingrid Luijkx
GriendFlux Atmospheric measurements	mid-2007 onwards	Wadden Sea; island of Griend 53°15'05" N, 5°15'15"E .	eddy correlation CO_2 fluxes at tower ca. 10m above intertidal flats Griend is a small (0.1Km2) island and is part of the Vlie tidal basin, located in center of the western part of the Wadden Sea national park		H. Zemmelink zemmelink@nio z.nl
Lutjewad Atmospheric measurements	2006-2009	boundary Wadden Sea and land 53N24'18" 6E21'13"	Tower height ca. 60 m above land and sea, positioned at boundary, trace gas signal of land or sea depending on wind direction; CO_2 (Carbon Dioxide), CH_4 (Methane), N_2O (Nitrous Oxide), SF_6 (Sulphur Hexafluoride) and CO (Carbon Monoxide); since April 2006 eddy covariance CO_2 fluxes linked also to ^{222}Rn Future activities (end of 2007 onwards): continuous O_2 measurements	Continuous, weekly flasks (CO_2 + isotopes, O_2) Monthly mean delta-$^{14}CO_2$, wind direction dependent (North Sea vs. Continental Sector vs full-continuous)	H.Meijer h.a.j.meijer@rug .nl S. van der Laan s.van.der.laan@r ug.nl R.E.M. Neubert r.e.m.neubert@ rug.nl

Lutjewad	2006 onwards	Wadden Sea tidal flat	CO_2 fluxes using flux chambers at various locations	Monthly	W. Klaassen W.Klaassen@rug.nl
JetSet	Marsdiep tidal channel	53N, 4E46'	DIC, Alkalinity	Weekly	H Zemmelink

Repeat Hydrography

Name of the line	**Basin**	**Description (ship track)**	**Year planned**	**PI**
WOCE AR7E	Irminger Sea	repeat section WOCE by dr. Hendrik van Aken (NIOZ); past DIC data 1981 TTO, and NIOZ DIC data of 1991, 2005; thus far no underway pCO_2; next section in 2007	Sept. 2005 completed; next Sept 2007	S. van Heuven svheuven@gmail.com H. de Baar debaar@nioz.nl
Antarctic Zero Meridian	Antarctic-Atlantic sector	Repeat section along zero meridian from Polar Front (ca. 50 S) to Antarctica; once every 2-3 years, focus on DIC in complete water column, surface pCO_2 in some but not all past cruises	since 1984 AJAX cruise onwards; next Feb-Apr 2008	M. Hoppema Mario.Hoppema@awi.de long term collaborative effort with Royal NIOZ (debaar@nioz.nl)
NorthSea Summer	Basinwide North Sea	Repeat summer (August) cruise doing ca. 92 stations and ca. 22,000 underway surface pCO_2	2001, 2005; next 2008	H. Zemmelink, H. Thomas, helmuth@phys.ocean.dal.ca

Ocean carbon research programmes:

Research project	**Description**	**Dates of operation**	**PI**
Time series measurements of Dimethylsulfide dynamics at BATS.	high vertical resolution (mm scale) depth sampling of major sulphur and carbon compounds	2005-2009, spring cruises at BATS	H. Zemmelink
SeaSurface Microlayer 2006-2007, The UKSOLAS Deep Ocean Gas Exchange Experiment (DOGEE)	rotating disk sampler of sea surface microlayer; and high vertical resolution (mm scale) depth sampling by fine tubings pumps system; millimeter scale vertical gradients strongly affect air/sea fluxes	June-July 2007	H. Zemmelink
Ocean Acidification	Impact of ocean acidification on bentic calcifiers		F. Gazeau f.gazeau@nioo.knaw.nl

Ocean Acidification	Impact of ocean acidification on phytoplankton of the Southern Ocean; lab studies and 2008 research cruise		P. Boelen P.Boelen@rug.nl I. Neven I.A.Neven@rug.nl B. Bontes bontes@nioz.nl H. de Baar

Nation: New Zealand

Lead author: Kim Currie

Ocean Carbon Observations:

Time Series (permanent moorings and repeat visit by ships)

Mooring/ Station	Date of operation	Location	Description	Frequency	PI
Munida time series transect	Jan 1998 - ongoing	SW Pacific	Surface transect (45.77S 170.72E – 45.83S 170.50E), water column measurements at 45.83S 170.50E	6 per year	K. Currie k.currie@niwa.co.nz
NIWA Southern Biophysical Mooring	March 2005 – ongoing (for SAMI)	SW Pacific, sub-antarctic surface water	Permanent mooring, including SAMI-CO_2 instrument	Continuous	K. Currie S. Nodder s.nodder@niwa.co.nz

Ocean carbon research programmes:

Research project	Description	Dates of operation	PI
SAGE -SOLAS Air_sea Gas Experiment	Iron-fertilisation experiment, in subantarctic surface water, with ^3He / SF_6 measurements of piston velocity	March 2004	m.harvey@niwa.co.nz
Boundary Conditions voyage	Tasman Sea voyage, measuring air-sea CO_2 flux, and C parameters throughout water column. Will inform boundary conditions of model for NZ region.	July 2005	k.currie@niwa.co.nz
Air-sea flux / dispersal in coastal environment	Air-sea exchange and gas dispersal processes in coastal environment	Feb 2008	c.law@niwa.co.nz
Air-Sea- Ice interaction	Ross Sea – dynamics of climatically important gases	Dec 2008	c.law@niwa.co.nz

Nation: Norway
Lead author: Ute Schuster/Truls Johannessen

Ocean Carbon Observations:

Underway pCO_2/VOS (Voluntary Observing Ships)

Track/Ship name	Dates of operation	Basin	Brief description (ship track)	Frequency	PI
Nuka Arctica	2005-2009	Arctic	Aalborg Denmark – Nuuk, West Greenland	Monthly	T. Johannessen
Ams-Bergen	2005-	Atlantic	Amsterdam-Bergen	Weekly	T. Johannessen

Time Series (permanent moorings and repeat visit by ships)

Mooring/ Station	Date of operation	Location	Description	Frequency	PI
Norwegian Sea OWS Station M	1992-ongoing	66°N, 2°E (Arctic)	Water column and surface measurements	4/year	T. Johannessen

Repeat Hydrography

Name of the line	Basin	Description (ship track)	Year planned	PI
75N	Arctic	Iceland – Greenland.	2006, 2008	T. Johannessen

Ocean carbon research programmes:

Research project	Description	Dates of operation	PI
CABANERA: Carbon Flux and Ecosystem Feedback in the Northern Barents Sea in an Era of Climate Change	Part of the AOSB Shelf-Basin Exchange Initiative (SBE), CABANERA will for the first time measure air/sea fluxes in the Barents Sea ice edge. The air/sea exchange effect on the inorganic carbon budget will be investigated considering mixing processes and biological productivity	2003-????	P. Wassman

Nation: Spain
Lead author: Aida F. Ríos (CSIC-IIM, Vigo)

Ocean Carbon Observations:

Underway pCO_2/VOS (Voluntary Observing Ships)

Track/Ship name	Dates of operation	Basin	Brief description (ship track)	Frequency	PI
Thalassa	2002-2010	Atlantic	Iberian Peninsula – Greenland	2 years	A. Rios (aida@iim.csic.es)
Las Palmas	2005-	Atlantic	Cartagena – Rio – Ushuaia	2/year	A. Rios

Quima VOS line	2005	Atlantic	UK – Cape Town	Monthly	M. Gonzalez (mgonzalez@dqui.ulpgc.es)
	2007	Atlantic Mediterranean	Canary Islands – Italy		M. Gonzalez
Mytilus	2006-2007	Atlantic	Coastal Zone – Gulf of Cádiz	4/year	J. Forja (jesus.forja@uca.es)

Time Series (permanent moorings and repeat visit by ships)

Mooring/ Station	Date of operation	Location	Description	Frequency	PI
NE Atlantic ESTOC	1995 – present	29N,16W	European Station for Time series in the Ocean at the Canary Islands	Monthly	M. Gonzalez M. Santana
MINAS	2005 -	43ºN, 11ºW	Multidisciplinary Iberian North Atlantic Station. CARIOCA buoy with sensors of CO_2, O_2, S, T, Chla.	Continuous	F.F. Perez (fiz.perez@iim.csic.es)
GIFT	2005-ongoing	35.861N, 5.977W 35.912N, 5.746W 35.987N, -5.368W	Time series composed by three stations located in the Strait of Gibraltar aimed at assessing biogeochemical cycles between North Atlantic and Mediterranean Sea	Seasonal	E. Huertas (emma.huertas@icman.csic.es)

Repeat Hydrography

Name of the line	Basin	Description (ship track)	Year planned	PI
OVIDE	Atlantic	Iberian Peninsula – Greenland	2006, 2008, 2010	A. Rios
FICARAM	Atlantic	Ushuaia – Cartagena (Spain), following part of the line WOCEA A17 and from 10ºS to 36ºN along 28ºW	2009	A. Rios
Goodhope	Atlantic	South Africa - Antarctica	2007	Alvarez/ Alvarez-Salgado (xsalgado@iim.csic.es)

Ocean carbon research programmes:

Research project	Description	Dates of operation	PI
CRIA	Short term cruises with high spatial and temporal resolution in the Ria de Vigo, to evaluate the coupling between residual currents and air-sea CO_2 fluxes.	2006-2007	A. Rios
GOLFO	Short term monthly intensive cruises in the continental shelf of the Gulf of Cadiz to evaluate the air/sea CO_2 fluxes	2003-2008	E. Huertas

Other comments:
Research project: ROMIAT
Description: Cultures of Mediterranean Corals in aquaria at varying pH
Dates of operation: 2007-2009
Name and email of the PI: Carles Pelejero (pelejero@cmima.csic.es)

Research project: RODA
Description: Oceanic eddies and atmospheric deposition in the Canary current: biological and biogeochemical effects, and CO_2 fluxes to the ocean interior
Dates of operation: 2006-2008
Name and email of the PI: Javier Arístegui (jaristegui@dbio.ulpgc.es)

Research project: Plankton-CO_2 feedbacks
Description: The effect of high CO_2 levels on the structure and functioning of marine bacterioplankton and phytoplankton communities
Dates of operation: 2007-2009
Name and email of the PI: Emilio Marañon (em@uvigo.es)

Nation: Sweden

Lead author: Melissa Chierici

Ocean Carbon Observations:

Time Series (permanent moorings and repeat visit by ships)

Mooring/ Station	Date of operation	Location	Description	Frequency	PI
Baltic Sea	Start in Year 2000	Östergarn s-holm	SAMI pCO_2 mooring and air CO_2 flux measurements	Continuous	A. Rutgersson Owenius, anna.rutgersson @met.uu.se

Ocean carbon research programmes:

Research project	Description	Dates of operation	PI
Beringia 2005 onboard I/B Oden, Leg 1 and 2	Continuous pCO_2, Oxygen in the Arctic Ocean. Northwest Passage (Can. Archipelago) to the Chuckhi Sea and the Bering Strait. Also collected discrete samples for DIC and AT, pH.	5 July -20 August 2005	A.Fransson, (agneta@ gvc.gu.se)
Beringia 2005 onboard I/B Oden, Leg 3	Watercoulmn measurements across the Arctic Ocean(Barrow to Svalbard). DIC, pH and AT.	22/8 to 20/9 2005	L. Anderson (leifand@ chem.gu.se)
CO_2 in the EcoFOCI 2006	AT and DIC in surface water, water column and sea ice, Bering Sea shelf	5 April to 5 May 2006	M. Chierici (melissa@ chem.gu.se)
Oden Southern Ocean 2006	Continuous pCO_2, Oxygen and chlorophyll a in the Antarctic Southern Ocean. Punta Arenas, Chile to McMurdo Station, Ross Sea, Antarctica. Also collected discrete samples for DIC and AT.	6/12 to 28/12 2006	A. Fransson, M. Chierici

CO_2 in the BEST 2007	Arctic Ocean (Bering and Chuckhi Sea) AT, DIC in seawater and sea ice	April-May 2007	M. Chierici
Oden Southern Ocean 2007	pCO_2 continuous, oxygen, chlorophyll a. Also sampling for DIC, AT, pH in seawater and sea ice.	Dec07/Jan08	A. Fransson, M. Chierici

Nation: United Kingdom
Lead author: Dorothee Bakker

Ocean Carbon Observations:

Underway pCO_2/VOS (Voluntary Observing Ships)

Track/Ship name	Dates of operation	Basin	Brief description (ship track)	Frequency	PI
RMS St Helena	1993-95	Atlantic	UK- Cape Town	Every two months	N. Lefèvre (Nathalie.lefevre@locean-ipsl.upmc.fr)
Prince of Seas	06/1994-06/1995	Atlantic	UK - Jamaica	Once per month	A. Watson (a.j.watson@uea.ac.uk)
Santa Lucia /Santa Maria	2003-2009	Atlantic	Portsmouth (UK) – Windward Islands	35 day round trips	U. Schuster (u.schuster@uea.ac.uk)
Atlantic Meridional Transect	1995, 1996 (2 x), 1998	Atlantic	UK – Falkland Islands (pCO_2 for AMT-1, -2, -3, -7)	4 crossings	N. Lefèvre
Atlantic Meridional Transect	2003-2004	Atlantic	UK – Falkland Islands (some, discrete TCO_2, TAlk for AMT-12, -13, -14)	3 crossings	A. Hind Andrew.hind@uea.ac.uk; a.j.watson@uea.ac.uk
Atlantic Meridional Transect	2004-2005	Atlantic	UK – South Africa (pCO_2 for AMT-15 (part), -16, -17; AMT-15 also some discrete TCO_2, T_{Alk})	3 crossings	D.C.E. Bakker (d.bakker@uea.ac.uk); A.Hind
Pride of Bilbao	2005-	Atlantic	Portsmouth (UK)-Spain	Twice per week except January	D. Hydes (djh@noc.soton.ac.uk) C. Bargeron (cpb103@noc.soton.ac.uk)
Pacific Celebes	05/2007-	global	Singapore-TAO array-Panama Canal- Houston-Halifax-Suez-Jeddah-Mumbai-Singapore	Twice per year	D. Hydes
RRS James Clark Ross	2006-2009	Southern	Variable but mainly Falklands-South Georgia-Signy-Rothera	Variable	N. Hardman-Mountford (nhmo@pml.ac.uk)

RRS Discovery	2005 2006-2009	Global	One AMT route in 2005. Variable (pCO_2 collected on all research cruises)	Variable	N. Hardman-Mountford
RRS James Cook	2007-2009	Global	Variable (pCO_2 to be collected on all research cruises)	Variable	N. Hardman-Mountford
Plymouth Quest	2005-2009	Atlantic (shelf)	Weekly (L4) & monthly (E1) transects in Western English Channel, other variable routes	Weekly/Monthly & other variable	N. Hardman-Mountford
Prince Madog	2006-2009	Atlantic (shelf)	Regular transects between Hollyhead and Dublin, regular Liverpool Bay, other variable routes in Irish Sea	Approx. monthly & other variable	N. Hardman-Mountford

Time Series (permanent moorings and repeat visit by ships)

Mooring/ Station	Date of operation	Location	Description	Frequency	PI
L4/Plymouth Quest	2005-2009	W. English Channel	Time series station since 1988, pCO_2 added in 2005.	Weekly	N. Hardman-Mountford
E1/Plymouth Quest	2005-2009	W. English Channel	Time series station since 1903, pCO_2 added in 2005.	Monthly	N. Hardman-Mountford

Repeat Hydrography

Name of the line	Basin	Description (ship track)	Year planned	PI
24N section	Atlantic	Reoccupation of 24N section (Funding for CO_2 + tracers uncertain)	Autumn 2009	S. Cunningham (s.cunningham@noc.soton.ac.uk), A. Watson U. Schuster
WOCE S4A	Southern / Atlantic	Line from tip of Antarctic Peninsula to 30 E along the northern edge of the Weddell gyre (nominally 60 S)	2008/09/10 (proposal under review)	A. Naveira Garabato (acng@noc.ac.uk), D. Bakker

Ocean carbon research programmes:

Research project	Description	Dates of operation	PI
CARBON-OPS	Establishing an operational air-sea carbon flux observation capability for the UK	01/03/2007-28/02/2009	N. Hardman-Moutford
CARBOOCEAN	CARBOOCEAN IP Marine carbon sources and sinks assessment (EU funded)	01/01/2005-31/12/2009	C. Heinze (heinze@gfi.uib.no), A. Watson D. Hydes

CASIX	EO Centre of Excellence: Centre for the observation of Air-Sea Interactions and fluxes. Goal is to reduce the uncertainties on air-sea CO_2 flux using a combination of EO data, *in situ* data and models. (NERC funded)	01/03/2003-28/02/2008	J. Aiken (casix_dir@pml.ac.uk)
CROZEX	CROZet natural iron bloom and EXport experiment (NERC funded)	03/11/2004-21/01/2005 (2004-2006)	R. Sanders (rics@noc.soton.ac.uk); D. Bakker
EUROCEANS	European Network of Excellence for Oceans Ecosystems Analysis (EU funded)	01/2005-12/2008	P. Tréguer, L. Legendre, E. Murphy
FAASIS	Fellowships in Antarctic Air-Sea Ice Science, Marie Curie early stage training network (EU funded)	2005-2008	W. Sturges (w.sturges@uea.ac.uk)
Greencycles	Marie Curie early stage training network (data interpretation, modelling) (EU funded)	01/2005-12/2008	A. Friend (Andrew.Friend@cea.fr) A. Watson
Microbial Metagenomics	Bergen Metagenomics mesocosm experiment (NERC funded)	05/2006	I. Joint (IRJ@pml.ac.uk) D. Bakker
QUEST	Quantifying and understanding the earth system (NERC funded)	10/2005-2010	C. Prentice (colin.prentice@bris.ac.uk)
MARQUEST	Marine ecosystems and biogeochemistry - improving the linkages between modelling and observational data (NERC funded)	10/2005-09/2008	A. Watson
QUEST Deglaciation:	Climate and Biogeochemical Cycles during the last deglaciation (NERC funded)	2006-2009	P. Valdes (p.j.valdes@bristol.ac.uk)
Quaternary Quest	Quaternary QUEST: Regulation of atmospheric carbon dioxide on glacial-interglacial timescales and its coupling to climate change (NERC funded)	05/2006-05/2009	T. Lenton (t.lenton@uea.ac.uk)
Quest ESM	Quest Earth System Modelling (NERC funded)	2006-2009	J. Gregory (j.m.gregory@reading.ac.uk)

Nation: USA

Lead authors: Richard Feely, Rik Wanninkhof and Christopher Sabine

Ocean Carbon Observations:

Underway pCO_2/VOS (Voluntary Observing Ships)

Track/Ship name	Dates of operation	Basin	Brief description (ship track)	Frequency	PI
Skogafoss	2005-ongoing	Atlantic	Charleston-Reykjavik	12/year	R. Wanninkhof Joint project France/Iceland

Drake Passage Time series/ LM Gould	2005-ongoing	Atlantic	Ponte Arenas – Palmer	20/year	T. Takahashi/ C. Sweeney
RV Ron Brown	1997-ongoing	Atlantic/ Eastern Pacific	Random	Random	R. Wanninkhof
Explorer of the Seas	2004-ongoing	Atlantic	Caribbean (winter) Bermuda-Newark-Caribbean (summer)	Weekly	R. Wanninkhof
R/V Ka'imimoana	1998-ongoing	Pacific	San Diego-Honolulu-Samoa	2/year	R. Feely
Palmer	2000-ongoing	Pacific/Southern Ocean	Various	Random	T. Takahashi
Columbus Waikato	2005-2006	Pacific	Long Beach – New Zealand – Australia	6/year	R. Feely (joint project with Australia)
Oleander	2006-ongoing	NW Atlantic	Newark-Bermuda	2/week	N. Bates
David Starr Jordan	2006-ongoing	N &tropical Pacific	San Diego-San Diego	Random	R. Feely
MacArthur II	2006-ongoing	NE Pacific	Seattle -San Diego	Random	R. Feely
R/V Atlantic Explorer	2006-ongoing	NW Atlantic	Bermuda	Random	N. Bates
R/V Langseth	2007	Global		Random	T. Takahashi
Turmoil	2007	Global		Random	T. Takahashi
Xue Long (Snow Dragon)	2007	Arctic/AntArtic (Pacific	Shanghai- PR China- antArtic station		R. Wanninkhof W.-J. Cai L. Chen (3rd inst PRC) Joint poject w PRC

Time Series (permanent moorings and repeat visit by ships)

Mooring/ Station	**Date of operation**	**Location**	**Description**	**Frequency**	**PI**
NW Atlantic Hydro Station S	1983 – present	32N, 65W		Monthly	A. Dickson
NW Pacific HOT	1988 - present	22.75N,158W	shipboard cruises	Monthly	D. Karl
MOSEAN	2005-present	22.75N,158W	MAPCO2 system	Continuous	C. Sabine/ D. Karl
BATS	1988 - present	31.5N, 64W	shipboard cruises	20/year	N. Bates

BTM	2005 - present	31.5N, 64W	MAPCO2 system	Continuous	C. Sabine/N. Bates
TAO / TRITON	0,155W	1997 – present	MBARI pCO_2 system	Continuous	F. Chavez / C. Sabine
TAO / TRITON	2S 170W	1997 – present	MBARI pCO_2 system	Continuous	F. Chavez / C. Sabine
TAO / TRITON	0, 170W	2005 – present	MAPCO2 system	Continuous	C. Sabine
TAO / TRITON	0, 140W	2003 – present	MAPCO2 system	Continuous	C. Sabine
TAO / TRITON	0, 125W	2003 - present	MAPCO2 system	Continuous	C. Sabine
NW Pacific KEO	32N, 145E	2006 – present	MAPCO2 system	Continuous	C. Sabine/M. Cronin
Stratus	85W, 20S	2006 – present	MAPCO2 system	Continuous	C. Sabine/R. Weller
NW Pacific JKEO	38N, 146.5E	2007- present	MAPCO2 system	Continuous	C. Sabine/M. Cronin

Repeat Hydrography

Name of the line	**Basin**	**Description (ship track)**	**Year planned**	**PI**
A5	Atlantic	24°N	2010	R. Wanninkhof
A13.5	Atlantic	0°	2009	R. Wanninkhof
A20	Atlantic	52°W	2012	R. Wanninkhof
A22	Atlantic	66°W	2012	R. Wanninkhof
S04P	Pacific	60°S	?	R. Feely
P16N	Pacific	152°W	2006	R. Feely
P18	Pacific	110°W	2008	R. Feely
I6S	Indian	55°E	2008	C. Sabine
I7N	Indian	65°E	2008	C. Sabine
I8S	Indian	95°E	2007	C. Sabine
I9N	Indian	88·E	2007	C. Sabine

Ocean carbon research programmes:

Research project	**Description**	**Dates of operation**	**PI**
West Coast North America	Canada - United States - Mexico	May – June 2007	R.Feely
East Coast North America	GOMECC, Gulf of Mexico to Maine	July 2007	R.Wanninkhof
Washington Mooring 47N, 125W	MAPCO2 system on NDBC mooring 46041	2006-present	C. Sabine

Georgia Mooring 31N, 81W	MAPCO2 system on NDBC mooring 41008	2006-present	C. Sabine
New Hampshire Mooring 43N, 70W	MAPCO2 system on UNH mooring	2006-present	C. Sabine/D. Vandermark
Hawaii Mooring 21.4N, 157.8W	MAPCO2 mooring in Kaneohe Bay	2006-present	C. Sabine/F. Mackenzie
Monterey Bay	MBARI moorings and time series cruises	1997- present	F. Chavez
Santa Monica Bay, CA	Bi-weekly cruises and mooring with MBARI pCO_2 system	2003 – present	A. Leinweber
Oregon Coast	OSU process study	2005-2006	B. Hales
Sabsoon	Shipboard transects, towers and process study	2004- present	W.-J. Cai
LEO-15	Intermittent C work on Shipboard transects and mooring	1998-present	O. Schofield
Martha's Vineyard Coastal Observatory	CO_2 flux tower	2002- present	W. McGillis/C. Sweeney
Gulf of Maine	Carbon surveys by UNH	2005-present	D. Vandermark

Nation: Venezuela

Lead author: Yrene Astor

Ocean Carbon Observations:

Time Series (permanent moorings and repeat visit by ships)

Mooring/ Station	Date of operation	Location	Description	Frequency	PI
Cariaco time series station/R.V. "Hermano Ginés"	Since January 1996	10° 30' N, 64° 40' W (Cariaco Basin, Atlantic)	Water column core measurements up to 1310 m, including carbon measurements: POC, DOC, CO_2, TOC	Monthly, on going	Time series: F. Muller-Karger: carib@ seas.marine.usf.edu CO_2 measurements: Y. M. Astor: yastor@edimar.org

Ocean carbon research programmes:

Research project	Description	Dates of operation	PI
Cohro 2	Measurements of the air-sea fluxes in the upwelling plume located in the eastern sub-basin of the Cariaco Basin, Atlantic	15-19 March 2004	Y. M. Astor
Casep 1	Measurements of the air-sea fluxes in the western sub-basin of the Cariaco Basin, Atlantic	19-22 March 2006	Y. M. Astor
Casep 2	Measurements of the air-sea fluxes in the eastern sub-basin of the Cariaco Basin during non-upwelling conditions, Atlantic	26-30 September 2006	Y M. Astor: