The Southern Ocean Observing System (SOOS)

Interim Report (v2)

Bremen, October 1-3 2007

Table of Contents

1. Summary

The Southern Ocean is an integral and key component of the global climate system. The large extent of sea ice in the region has a profound influence on the radiation budget. It is also home to the Antarctic Circumpolar Current, which connects all the major ocean basins and permits a global-scale overturning (thermohaline) circulation to exist. The Southern Ocean supports unique food webs with strong feedbacks and linkages to biogeochemical cycles that affect carbon cycling and atmospheric CO_2 exchanges. The region is vast, remote and logistically difficult to access and thus is one of the least sampled regions on Earth. Design and implementation of an observing system that encompasses physical, biogeochemical and ecological processes is therefore a formidable challenge.

Building on the discussions in the Scientific Committee on Oceanic Research (SCAR)/ the Scientific Committee on Antarctic Research (SCOR) Oceanography Expert Group and the Climate Variability and Predictability (CLIVAR)/Climate and Cryosphere/SCAR Southern Ocean Implementation panel as well as results from an earlier meeting in Hobart, Tasmania in August 2006 (see http://www.clivar.org/organization/southern/expertgroup/SOOS.htm), this workshop was intended to more fully develop the plans for such an observing system (see Appendix 1 for original agenda). As such, please note that this is very much an ***interim progress report*** and does not represent what will be in the final planning document –there will be many more opportunities for consultation.

Thirty-two participants (see Appendix 2) from diverse backgrounds that ranged across scientific disciplines of physical oceanography and ecosystem studies, as well as relevant agencies involved in the planning of ocean observation systems and potential users or contributors, such as the tourist industry, discussed various aspects of the observing system during the three-day workshop. The first day consisted of summary lectures and discussion about the SOOS structure. The second and third days saw attendees split into various groups to tackle different (though interconnected) aspects of the SOOS, for example (i) marine physics and surface meteorology, (ii) ecosystems/biology, (iii) biogeochemisty/carbon and (iv) the marine cryosphere. These groups focused on defining and refining the main science questions that any hypothetical observing system should aim to answer and the types of measurements that would be needed in order to do so. The state of the observing system and gaps were also examined. Cross group interaction was actively realized and each group reported back on progress at regular intervals.

A plan for production of a SOOS document, which identified suggested lead authors and contributors for specific sections, was drawn up. This will be developed over the next few months, with a near final draft document anticipated for open discussion at the SCAR/International Arctic Science Council (IASC) Open Science Conference scheduled for St Petersburg, Russia in July 2008 (http://www.scar-iasc-ipy2008.org/).

The SOOS is a key component of the SCAR Pan Antarctic Observing System (PAntOS, see: http://www.scar.org/researchgroups/physicalscience/PAntOS_Plan_Rev1.pdf) and the need for sustained observing system in the Antarctic and Southern Ocean is recognised by the parties to the Antarctic Treaty (see Appendix 3). SOOS is co-sponsored by SCAR, SCOR, the Census of Antarctic Marine Life (CAML), the Partnership for Observation of the Global Oceans (POGO) and the Global Ocean Observing System (GOOS). Other organisations, in particular the National Oceanic and Atmospheric Administration (NOAA), provided significant funding for the workshop.

2. Introduction and aims:

The three-day SOOS workshop was hosted by the Alfred Wegener Institute at the Haus der Wissenschaften in Bremen on 1-3 of October 2007. The workshop started with Eberhard Fahrbach welcoming everyone to Bremen and giving a brief introduction about the meeting location and the work of the Alfred Wegener Institute. He also thanked the sponsors of the meeting and reminded the meeting participants of the main aim of the meeting, which was to produce a document that demonstrates:

(i) why sustained observations are needed in the Southern Ocean and what science/policy questions they address,
(ii) what mix of observations are required to address these questions,
(iii) what is presently done and possible,
(iv) a vision for the future

Victoria Wadley briefly summarised the 1st SOOS meeting held in Hobart, Tasmania in August 2006. She also emphasised the importance of the connections between the different disciplines such as physics, biology etc. The interdisciplinary nature of the SOOS is key to its success.

3. The need for a SOOS:

Steve Rintoul presented an overview of the scientific rationale for a SOOS. He summarized the many reasons why observations in the Southern Ocean are needed, for example:

- The significant role of the Southern Ocean in the global overturning circulation due the shallow and deep meridional circulation cells and the way it connects the three ocean basins
- Oceanic heat storage (84% of "global" warming since 1955 is found in the ocean and the change in zonally-integrated ocean heat content since 1955 is largest in the Southern Ocean)
- The importance of the Southern Ocean to carbon uptake, particularly in the Mode Water and Antarctic Intermediate Water masses
- The connections to the rapid warming of the Antarctic Peninsula
- Possible sea ice decline since the 1950s from ice core proxies and whaling records
- Possible "regime shifts" in East Antarctica (e.g. in penguin populations)
- Changing phytoplankton distributions (e.g. coccoliths found further south than in 1970s south of Australia)
- Decline in shell weights of calcareous plankton

Changes in the Southern Ocean are of importance because of the potential for positive feedbacks influencing global climate, for example sea ice-albedo feedbacks, carbon uptake and changes in the global overturning circulation. Changes in the Southern Ocean can ultimately affect sea level. Also there are the dual impacts of climate change and ocean acidification on Southern Ocean ecosystems.

It is not possible to detect, interpret and respond to change without sustained, system-scale observations. Integrated multidisciplinary observations are necessary to understand (and ultimately predict) the response of biota to changes in physical drivers. The Southern Ocean region is relatively difficult to observe, both because of the extreme conditions and because of its vast area remote from many of the countries with the resources to work in the region. Thus international coordination and collaboration is needed.

The users of a SOOS would not be limited to the research community, but would include resource managers, policy makers, local planners (relationship to e.g. sea-level rise), the tourist industry, shipping operations, weather and climate forecasters as well as the education community.

4. Relationship to other relevant bodies:

Keith Alverson introduced the *Global Ocean Observing System* (GOOS) and discussed how this might be related to the SOOS. He made the following points:

- There already exist a certain number of “SOOS” observations. Are these optimal?
- Governmental support will be needed for sustaining any observing system.
- The SOOS will need to bridge the gap between research and operations.
- Outreach, particularly to the general public, has to be a part of SOOS.
- Intergovernmental Oceanographic Commission (IOC) nations with particular interests in the Southern Ocean should consider forming a GOOS regional alliance for the Southern Ocean, like the one for the Indian Ocean, for instance.

Albert Fischer gave a presentation on behalf of the *Ocean Observing Panel for Climate* (OOPC). The OOPC is co-sponsored by and reports to GOOS, the Global Climate Observing System (GCOS) and the World Climate Research Programme (WCRP) and advises the Joint World Meteorological Organisation (WMO)-IOC Technical Commission on Oceanography and Marine Meteorology (JCOMM). Albert suggested that SOOS will need to:

- Include sustained observations needed to answer pressing scientific questions.
- Select components which are technologically feasible and complement a global system.
- Be of interest of funding agencies.
- Build on the consensus of the community to move forward.

Werner Stambach from the *International Associated of Antarctic Tour Operators* (IAATO) commented that the tour operators have more than 30 ships available that could contribute e.g. by fitting with FerryBox type equipment in order to improve SOOS coverage. Other bodies, such as ship operators should also be approached for similar reasons.

Saad el Nagaar gave a short presentation on behalf of the *Council of Managers of National Antarctic Programmes* (COMNAP), which is very supportive of a SOOS. Saad took note of several questions from the meeting attendees e.g. in terms of underway measurements – should additional requests or recommendations go through COMNAP or through national organizations? Should recommendations such as putting Improved METeorological (IMET) on ships be made through COMNAP?

The above represents a selection of the groups and projects that will be involved with the SOOS. The scientific community is interested in gathering data to address specific scientific questions such as what is the role of the Southern Ocean in the climate system? Tour operators are interested in forecasting ice and ocean conditions on short and longer time scales. Organisations whose remit includes living resources such as the Commission for the Conservation of Antarctic Marine Living Resources (CCAMLR) need to understand how changes in the ocean may affect ecosystems. Government agencies of neighbouring states are likely to be interested for reasons such as weather and climate forecasting; search and rescue; and the stability of fisheries. As the plan progresses input of these bodies into the SOOS development process is needed.

5. Pre-meeting questionnaire:

Before the meeting a questionnaire was sent out to the meeting attendees asking each research/observing group to detail:

i) What observations of interest to them are currently made in the Southern Ocean?

(ii) What observing systems of interest to them are currently in place?

(iii) What are the gaps (a) technological, (b) process understanding, (c) geographic, (d) temporal and historical, (e) modelling, in areas of interest to them?

(iv) How can research activities contribute to a sustained observing system?

(v) What priorities can they suggest (a) for the short term; (b) for the long term?

(vi) Other comments that may be relevant for our purposes?

Seventeen completed sets of questionnaires were received, see: (http://www.clivar.org/organization/southern/expertgroup/SOOS_workshop.htm#question). The results were summarised by Mike Sparrow (SCAR Secretariat), and further considered in the individual working groups (see Section 7). Two things that did come up consistently were (a) the importance of open (as far as possible) data access and management and (b) the importance of Outreach and Education, which was further emphasised in a presentation by David Carlson.

Mike also gave examples of parts of the observing system that are already, at least partly, in place, e.g. Argo, repeat hydrography, the tide gauge network and time series sites.

6. The structure of the SOOS:

Steve Rintoul and Eberhard Fahrbach led the discussion on the structure and design of the SOOS.

(i) Guiding principles

It was suggested that the SOOS should have the following guiding principles:

- Sustained observations are needed to address key societal and scientific needs in the Southern Ocean.
- Process studies have a key role to play in providing the understanding required to design a sustained observing system and in transition from research to operations.
- Integrating across disciplines is needed because key science challenges cross disciplines, as well as being a more efficient way to proceed.
- Data management, quality control and data access must be thought of as integral parts of SOOS.
- SOOS should start by building on what already exists (observations, data management).
- SOOS must be well-integrated with global efforts.

(ii) The scope of the SOOS

The following was suggested for the scope of the SOOS:

Domain:
- Circumpolar
- Subtropical Front to coast / ice sheet grounding line
- Sea surface to sea floor (including bathymetry)
- Ocean and sea ice
- Includes lower atmosphere in order to obtain air-sea flux, but not upper atmosphere which should be covered by another component of PAnTOS.
- Includes sub-ice shelf cavity and iceberg calving, but not glacial ice itself.

Time:
- Days to decades (longer-term proxies from ice and sediment cores are critical to understanding but are not sustained observations).

Feasibility/readiness:
- Consider what is “ready now” and a “10-year vision”.
- Consider both a “minimal” and an “ideal” SOOS.

Discipline:
- Physics (ocean circulation and marine cryosphere)
- Biology and Ecology (microbes to whales)
- Biogeochemistry
- Bathymetry
- Surface meteorology

Models: Emphasis is on sustained observations, but modelling, in particular dataassimilative modelling, plays a key role in system design and on the development generation of products (especially forecasts)

- interpolation and interpretation of sparse observations
- demonstrating utility of SOOS (e.g. initialisation of climate models)
- Provision of data in a mode that can be input to a wide range of models

Many documents on observing systems have been published already. Therefore the document planned for SOOS has to go beyond general statements such as "we need to resolve important scales of variability in the ocean" or "we need sustained observations of important biological variables". However, the design process has to be ongoing and will not be finished in one step. Aiming to produce a 'strawman' outlining what will be measured, where, how often, and how, will likely spark the debate that is needed to design and implement the SOOS. The transition from what is desired in a particular field to what is feasible for sustained long-term measurement that is of use to a large part of the community is likely to require difficult decisions, compromises and restrictions. Any SOOS should also aim to identify a subset of priorities for the shorter term, for example putting underway systems on a few ships that go to key locations or concentrating on key regions.

(iii) Document outline

Based on the Arctic Observing Network model, the following draft outline for the SOOS document, was adopted noting that it would be modified as contributions are received:

Ch.	*Title*	*Approx. Pages*
	Executive Summary	4
1	Introduction	4
2	Scientific background	10
3	Key Variables to Monitor in the Long Term	10
4	Antarctic Observations: Existing Activities and Gaps	38
5	Data Management	10
6	Education and Outreach	2
7	Implementation	10
8	Overarching Recommendations	2
	References	5
	Appendix A Contributors List	2
	Appendix B Acronyms and Abbreviations	3
	Total	100

(iv) What sort of measurements would be involved in a SOOS?

Any SOOS will need to involve a diverse array of measurements, the exact mix being defined by the sort of science questions that need to be answered (see Section 7) and what is available and feasible. For example:

- Repeat hydrography and tracers

- Autonomously floating sensors (e.g. Argo, drifters)
- Moorings in key locations and gateways
- Remote sensing (sea surface height and temperature sea ice extent, ocean colour etc.)
- Volunteer Observing Ship (VOS) underway sampling (e.g. temperature, carbon, phyto- and zooplankton)
- Animal-borne sensors (e.g. Southern Elephant Seals as Oceanographic Samplers, SEaOS)
- Surface meteorology measurements
- Ice-tethered platforms
- Autonomous Underwater Vehicles (AUVs) and gliders
- Observatories/time series/reference sites
- Monitoring properties of flow in, out and under ice shelf cavities

Pierre-Philippe Mathieu gave a presentation and answered questions on remote sensing, expanding on the range of products available in the Southern Ocean region. In particular he emphasised that we should look into ways of increasing coordination between groups and individuals involved with *in situ* and satellite measurements. SOOS could also consider "supersites" for satellite validation. Satellite derived products such as Polarview (http://www.polarview.org/) should also be included in any SOOS.

7. Working groups

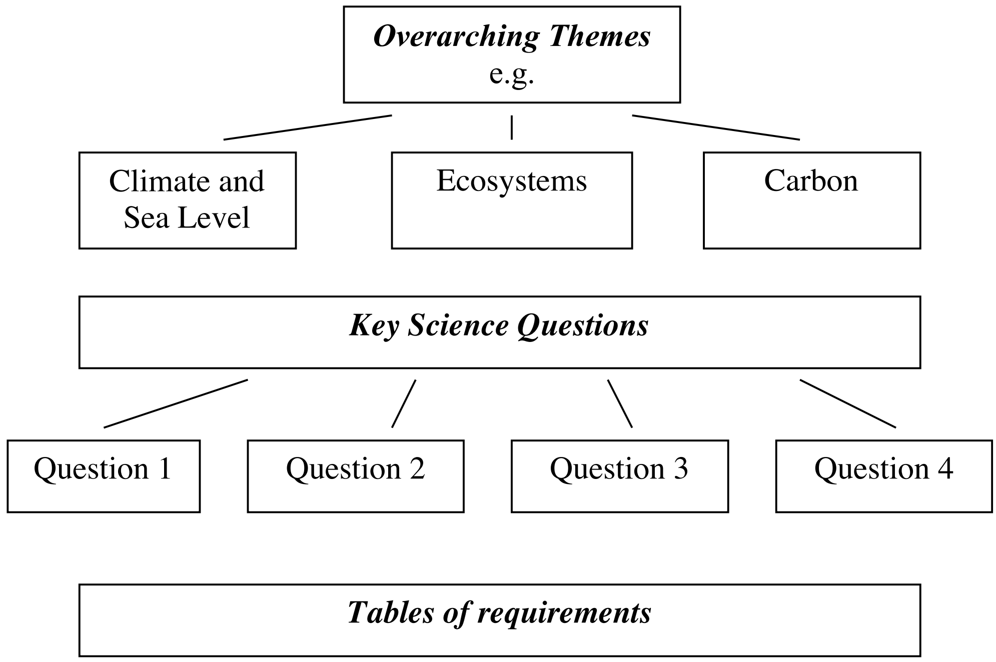
The meeting attendees split into groups to tackle different (though interconnected) aspects of the SOOS, that focused on (i) marine physics and surface meteorology (ii) ecosystems/biology, (iii) biogeochemisty/Carbon and (iv) the marine cryosphere.

As a guideline the following questions were addressed:

- Why are sustained observations needed?
- What key variables need to be measured? Why?
- Examine 'core' variables (e.g. temperature) against 'indicator' variables (e.g. phenology)
- For the key variables, what is being done now? What are the major gaps?
- What mix of broad-scale measurements, repeat surveys/transects, intensive time series at key sites, and remote sensing is needed?
- If insufficient information exists to identify what needs to be measured (variables, sampling), how can we make progress (e.g. pilot experiments, model studies, analogy to better-measured regions)?

Following on from examples given by Steve Rintoul, the groups were asked to draft key science questions relevant to the area/variables being considered. The science questions then provided the basis for the measurements and platforms required to answer each of these. Science questions and tables of measurements will be integrated as far as possible in the final SOOS planning document under a few overarching headings, such as "Climate and Sea Level", "Ecosystems" and "Carbon", resulting in an overall programme structure as shown below:

The Southern Ocean Observing System



The discussion summaries given below reflect the different nature of the groups and are best regarded as works in progress that will form the basis of the final document after further refinement.

(i) Marine physics and surface meteorology

The draft *science questions* identified by the group were the:

1. *role of the Southern Ocean in global freshwater balance*
2. *stability of Southern Ocean overturning*
3. *stability of Antarctic ice sheet and future contribution to sea-level rise*
4. *future of Southern Ocean carbon uptake*
5. *future of Antarctic sea ice*
6. *impacts of climate change on Antarctic ecosystems*
7. *ecosystem response to acidification*

Topics 5, 6 and 7 are within the focus of other groups and so this group elected to concentrate on the first four.

Gaps and Implementation

a. Physical oceanography

Compared to e.g. the biological observation system the sustained physical ocean observing system existing in parts in the Southern Ocean region is relatively well developed, although in order to reduce seasonal bias and to include unresolved modes of variability, for example, there are several important extensions that need to be considered:

1. Improvement of underway systems on ships, particularly with regards to salinity measurements and the inclusion of additional properties referring to biogeochemical processes.
2. Under-ice extension to existing systems (e.g. ice-capable, acoustically tracked floats, sensors on marine mammals)
3. Antarctic-base-oriented hydrographic sections to extend these sections to the Antarctic continent
4. Multiple fixed sites (3+?) with moorings including near bottom instruments (e.g. active shelves, polynyas, topographic gaps as Princess Elizabeth Trough)
5. Increase the number of Argo floats taking measurements below 2000 m in particular in the Antarctic Circumpolar Current
6. Extend monitoring to ice cavities and the harsh environment in front of ice shelves
7. Transport array/sites at Weddell Sea and Ross Sea "outflow" regions – so called "supersites"

Upcoming improvements in sensors and platform technology have to be considered in order to optimize the system, for example ice-tethered buoys on multi-year ice are able to provide real-time data in winter, increase range gliders will, the addition of biogeochemical sensors to Argo and drifting buoys (e.g. O_2, Fl/Cl, nutrients, light, acoustics) will allow to monitor non physical processes.

The following key questions serve as a scale for which measurements are required: The fresh water balance, ocean carbon, the overturning circulation, ice sheet stability, and sea-level rise. Steve Rintoul and Kevin Speer were suggested as the coordinators of the Marine Physics group, with possible lead authors being identified for each key question. The idea is that these authors would identify people to write particular sections of the final document. A first draft table showing the science questions, measurements required and draft author list can be seen in Appendix 4.

b. Surface meteorology

1. Antarctic reanalysis should help identify gaps in meteorology
2. Surface flux improvements are needed (e.g. Orion flux site at 55°S)
3. More IMET on research and re-supply ships needed

c. Bathymetry

Need to try to ensure important gaps in the bathymetric record are filled, e.g. by slightly altering ships' repeat tracks, especially on ships equipped with swath bathymetry systems.

Requirements on modelling and data management:

1. Beyond the combination of observations and model efforts to provide useful products for potential users with satisfy a wide range of time and spatial coverage, work is needed to detect correlations within forward models to identify key monitoring sites in the Southern Ocean.

2. In order to fulfil user requirements data from a SOOS has to be available in a timely fashion with easy access. The International Polar Year synthesis will help to adjust priorities.

(ii) Ecosystems and biology

During the initial discussions of the ecosystems and biology group the following points were made:

- There is the need to differentiate between what we can do operationally versus research mode.
- There are already many programs underway that provide measurements of many components of the marine food web.
- Coordination and integration of existing programs provides a starting point for SOOS.
- Measurements that need to be sustained to detect long-term trends need to be identified to allow planning of possible prevention and identification of adaptation .
- Data must be collected and provided to allow different uses.
- There is need for long-term sustained funding, providing evidence for the value of long time series to understand change.
- Technological developments make it possible to deploy autonomous observing systems.
- Ship-board autonomous systems (research vessels supply vessels, ferries, commercial vessels, etc.) can be equipped with underway pCO_2, measurements, flow cytometry, phytoplankton pigments, continuous plankton recorder, etc. (FerryBox-type systems can provide data of e.g., temperature, salinity, Photosynthetically Active Radiation, pCO_2, major nutrients). The access to ships can be facilitated through COMNAP, CCAMLR (fishing vessels), IAATO, POGO, Coast Guards etc.
- Much can be accomplished by bringing together existing data, for example biology data through SCAR MarBIN. This is a possible portal for SOOS data.
- There is the need to integrate physical data with biological data. Metadata needs to be improved.
- There is the need of getting access to proprietary data, such as fisheries data.

The draft *science questions*, including suggested lead authors, identified by the group are:

1. *What are the global change impacts on Southern Ocean ecosystems (organisms, populations, food web structures and fisheries)?* Likely impacts include changes in pH, temperature, salinity, mixed layer depth, wind field, sea ice timing and extent, and iron supply. Changes should be considered within the context of natural cycles or other anthropogenic impacts. – (Eileen Hofmann to draft)

Goal: to document and predict changes in marine resources and biodiversity, and to understand ecosystem resilience, trophic pathways, feedbacks between foodwebs and biogeochemistry.

Approach: what is needed to measure change and what is needed to predict change (models). Need to consider research, pilot projects, sustained system.

Key Variables: primary production (ocean colour, fluorometry, rates), abundance, composition, and distribution, functional groups, key species (e.g., E. huxleyii), diet of top predators, pH, temperature changes, salinity, mixed layer depth, wind field, trophic relationships.

Existing Variables Measured Regularly:

- CCAMLR Ecosystem Monitoring Programme (CEMP) Indices– population demographics, foraging trip information. Comprehensive stations on the Antarctic Peninsula and South Georgia, less comprehensive elsewhere. Chinstrap, Adélie, and Gentoo penguins; fur and crabeater seals CEMP sites where there are interactions between fisheries and predators.
- British Antarctic Survey; Antarctic Marine Living Resources; and The Palmer Long-Term Ecological Research (LTER) measure krill populations along the western Antarctic Peninsula. Also Acoustic Doppler Current Profiler (ADCP) measurements of krill at South Georgia, off Bird Island
- SEaOS (Southern Elephant Seals as Oceanographic Samplers). Long data series from South Georgia and Macquarie Island, Weddell seal data set. Leopard seal counts at Bird Island and Macquarie Island.
- South African and Chilean seal data
- French emperor penguin data sets and seabird data sets. Heard Island time series.
- Whale data – New acoustic monitoring by Australia – still in research phase.
- Fur seals and elephants seals are most important to monitor, and Chinstrap, Adélie, and Gentoo penguins.
- Buoys that will signal when a particular species has been detected (barcoding). Used for detecting when a phytoplankton species change has occurred.
- Continuous Plankton Recording – phytoplankton and zooplankton biomass and species composition
- Ocean colour from satellites
- Phytoplankton time series – l´Astrolabe – Hobart to Dumont d'Urville. Transect from Rio de Janeiro to King George Island. Japanese Antarctic Research Expeditions – chlorophyll and zooplankton
- Admiralty Bay time series, CAML is funding conversion of these data to digital form. There are about 25 years of data.
- Hull-mounted acoustic measurements
- LTER annual cruise – 15 years
- Antarctic Meridional Transect
- Highly fragmented datasets, geographically. Need finer spatial and temporal resolution.

2. *What are the feedbacks from the Southern Ocean ecosystem back to climate?* Potential feedbacks include DMS (Dimethylsulphide) production, affects of algae on albedo and surface layer warming; krill affect iron cycling in Southern Ocean. – (Eugene Murphy to draft); export of dissolved nutrient signal through Antarctic Intermediate Water to mid-latitude coastal upwelling systems (e.g. Benguela)

Goal: to identify and determine magnitude of the feedbacks (are these feedbacks as important as in tropics?)

Approach: to measure variables that allow direction and magnitude of feedback to be determined

Measurements: similar to question 1

3. How will global change alter the key role of the Southern Ocean in the global carbon cycle?

Goal: to refine the magnitude of the Southern Ocean role in the global carbon budget; to predict the trajectory of uptake/release of CO_2 and refine global models; to understand the impacts of wind changes and stratification and to understand carbon cycle affects on pH changes and consequences for carbon inventory and air-sea fluxes of carbon. (suggest Maria Hood and others to draft)

Approach: to measure components of carbon budget that control/influence carbon cycling, CO_2 uptake, air-sea exchanges

Measurements: pH, temperature changes (leading to salinity and pH changes), salinity changes. mixed layer depth changes, wind field changes, alkalinity

A draft table identifying the measurements required etc. to answer the first of the science questions is shown in Appendix 5.

(iii) Biogeochemistry and carbon

The following draft science questions were identified by the biogeochemistry and Carbon group:

1. *What are the global change impacts on Southern Ocean ecosystems (organisms, populations, food web structures and fisheries.)?* Likely impacts include pH, temperature, salinity, mixed layer depth, wind field, sea ice timing and extent, and iron supply. Changes should be considered within the context of natural cycles or other anthropogenic impacts.

2. *What are the feedbacks from Southern Ocean ecosystem back to climate?* Potential feedbacks include DMS production, affects of algae on albedo and surface layer warming, krill affect iron cycling in the Southern Ocean.

3. *How will global change alter the key role of the Southern Ocean to the global carbon cycle?*
To maintain an observing system over many years if not decades requires that it has to be very selective in the number of variables one is committed to survey. Moreover the choice of variables tends to be not only on the basis of scientific rationale, but is also very much tool-driven with obvious preference for autonomous methodology.

Underway Surface Sampling

The suite of underway surface sampling parameters should be designed in conjunction with the requirements of the phytoplankton community. The listed (see Appendix 6) biogeochemical variables in surface waters are selected to be able to assess various aspects of phytoplankton productivity, versus actual feasibility in terms of state-of-the-art methodology. Moreover the values of pCO_2 will be directly useful in the basin-wide and global mapping of pCO_2 gradients between air and water so as to be able to assess net fluxes (the Takahashi approach and maps).

Ideally the suite of combined parameters (biological, chemical, physical) will be collected at the same time by the same ship whilst in transit. The obvious ships to install and operate such multi-parameter data collection are the research/supply vessels now operating in the Southern Ocean, e.g. Marion Dufresne, James Clark Ross, Polarstern, Aurora Australis, Oden. Ideally this would be adopted by the respective expert scientists in their own nations, e.g. Australia, Britain, Germany, France, or group of nations (e.g. European Union) when submitting research proposals to their respective funding agencies towards acquisition, installation and long term operation of their Antarctic research vessels. In this manner the very costly operation of these ships already taking place and financed, will yield a much greater scientific output.

The bottom-up nutrient controls on phytoplankton productivity are deemed pivotal, especially dissolved Fe and secondly major nutrients (N, P, Si). The latter while generally in ample supply south of Polar Front, may occasionally become limiting at the end of an intense bloom within the Southern Ocean. On the other hand major nutrients are, in general, always in low abundance i.e. more or less limiting in the SubAntarctic region (between the Polar Front and Subantarctic Front). Another key bottom-up limitation is the incoming Photosynthetic Active Irradiance (PAR). It would be even more advantageous to be able to obtain vertical profiles of light abundance throughout the euphotic zone, but this currently can only be done on station, i.e. by stopping the ship and doing a lowering of a PAR sensor. In principle a towed undulating instrument (e.g. SEASOAR) can do this while underway, but acquisition and operation of a SEASOAR is expensive.

Secondly the above parameters, notably pCO_2, pH, O_2 provide an indication of the overall state of the plankton ecosystem, i.e. the Net Community Production (NCP), or in other words, the overall autotrophic versus heterotrophic state of the *in situ* community at the given time and place of the surface section. Another important variable here is the Fv/Fm, based on the fast repetition rate fluorometry technique and indicative of the nutrient stress status of the phytoplankton, notably for Fe limited versus Fe repleted conditions.

Repeat Hydrography

The repeat hydrography parameters are in keeping with key parameters of the worldwide Climate Variability and Predictability (CLIVAR)/CO_2 hydrography programme. A major aim is repeated (at circa 10 year time intervals) quantification of the invasion and inventory of anthropogenic CO_2 into the deep waters of the Southern Ocean, integrated with other key anthropogenic transient tracers, notably the

Chlorofluorocarbons (CFCs). Some sections are repeated more often, for example the zero meridian section is repeated once every 2-3 years.

Coordination and data submission.

The CO_2 system parameters are best coordinated with advice from the International Ocean Carbon Coordination Project (director Maria Hood at IOC/ United Nations Educational, Scientific and Cultural Organization (UNESCO)). In practice this would then lead to coordination by CLIVAR and some other international programs like the European Union (EU) CarboOcean. Datasets are best first submitted to these organizations for optimal quality control and compatibility etc. with worldwide datasets. For example US CLIVAR has a data centre at Scripps, similarly the CarboOcean is also assembled by a data centre, moreover the Carbon Dioxide Information Analysis Center (director Alex Kozyc) also plays a key role.

For GEOTRACES the dissolved Fe surveys are focussed on the by far most important and relevant GEOTRACES core parameter within the Southern Ocean and is already quite a challenge to organize, finance, and operate over the long term (say 5-10 years) on several ships in both Underway Surface sampling mode and in Repeat Hydrography mode. We envision an underway continuous sampling of marine aerosols so as to better map their distribution and composition (Fe, Mn, N, P, etc.) and from that, in combination with a particle settling algorithm, arrive at estimates of the aeolian fluxes into the Southern Ocean. Additional dissolution experiments will furthermore provide estimates of the percentage of any given element (notably Fe) that will dissolve in seawater hence will become available, in principle, for uptake by phytoplankton.

The GEOTRACES type parameters best are first submitted to the GEOTRACES data centre so as to ensure optimal formatting and quality control within the expert community.

The SOOS was on the agenda of the GEOTRACES Scientific Steering Committee meeting held in early November 2007 in Barcelona. This will encourage the GEOTRACES community to comment, notably with regards to the desirability to include other GEOTRACES core parameters into SOOS. For example, the addition of 13C was already suggested by the International Ocean Carbon Coordination Project (IOCCP). Next to dissolved Fe, aerosols and 13C, the other GEOTRACES core parameters to be considered are Al, Zn, Mn, Cd, Cu 15N, 230Th, 231Pa, Pb isotopes, Nd isotopes. However a long term commitment for continuous sampling over 5-10 years period of all such variables would be highly unlikely. More realistic would be to pursue a long term observing program focusing solely on (i) aerosols and (ii) dissolved Fe and use this as the basis for occasional sampling of other GEOTRACES variables as required by individual research projects.

(iv) Marine cryosphere

The cryosphere group was rather small and felt that significant input is needed from scientists not participating in the workshop. Additions might be needed beyond the science questions and their requirements in the context of Health of the Ocean, Climate, Services, Living Marine Resources, Coastal areas. The following draft key science questions were identified:

Proposed coordinators: A. Worby and E. Fahrbach from the expert group. However, because of the dominating role of remote sensing, European Space Agency (ESA) and the National Aeronautics and Space Administration (NASA) representatives are needed. Suggested lead authors for each key question are given.

1. *Role of Southern Ocean cryosphere in global ocean freshwater and salt balance, water mass formation and global ocean circulation* (suggest e.g. C. Haas, A. Worby)

- freshwater flux from the continent (ice shelves, icebergs, liquid water),
- sea ice formation and role in salt balance (including polynyas)
- Precipitation/Evaporation (especially precipitation)

2. *Role of Antarctic sea ice in modulating heat exchange between ocean and atmosphere* (suggest e.g. J. Comiso, W. Meier)

- albedo
- fluxes

3. *Contribution of Antarctic Ice Sheet to sea level rise* (suggest, e.g. H.A.Fricker, D. Holland)

- In spite that the Antarctic Ice Sheet is not part of the Southern Ocean the ice shelves can not be regarded without their connections to the ice sheet. Therefore it must be ensured that PAnTOS covers the mass balance components

4. The *role of Southern Ocean sea ice in influencing the composition of the atmosphere* (suggest e.g. E. Wolff, L. Kaleschke)

- focus on carbon uptake, sea ice role in changing atmospheric oxidating capacity

5. *Impact of changing sea ice on the ocean ecosystem* (suggest e.g. C. Fritsen, Hajo Eicken, B. Griffiths)

The *key parameters to measure* will be adapted from documents already written, e.g. the Integrated Global Observing Strategy (IGOS) cryosphere report for sea ice, ice bergs, ice shelves (http://cryos.ssec.wisc.edu/) and documents from the International Global Atmospheric Chemistry (IGAC), Climate and Cryosphere (CliC) and Surface Ocean - Lower Atmosphere (SOLAS) projects for Chemistry, air-ice chemical interactions etc.

Required parameters:

- Sea ice extent/edge,
- Sea ice concentration,
- Leads/polynyas
- Sea ice stage of development

- Sea ice motion
- Sea ice thickness,
- Sea ice ridge height/concentration
- Snow depth
- Melt onset, duration of melt of sea ice
- Surface characteristics of sea ice
- Volume/mass flux of sea ice and ice shelf
- Internal properties of sea ice: structure, temperature, salinity, density, grain size, chlorophyll
- Iceberg volume/mass flux
- Iceberg drift
- Ice shelf melt rates

Gaps:

- Ice and snow thickness from satellites (altimeters, Soil Moisture and Ocean Salinity (SMOS) etc.), need validation data sets (salinity, density, ice and snow thickness, Upward Looking Sonar arrays)
- Chemistry
- Data needs to be freely available
- SAR satellite coordination
- Use IGOS cryosphere report to identify other gaps and existing systems: revisit sea ice, ice shelves, icebergs,

With regards to implementing a SOOS, the cryosphere group noted that we will need to identify the eventual "parents" of the SOOS, e.g. SCAR, SCOR, the Group on Earth Observations (GEO), IOC, WMO, the United Nations Environment Programme (UNEP), the International Council for Science (ICSU) etc. and obtain endorsement from these bodies. A steering group will need to be formed, which will come from a revised membership of the SCAR/SCOR Expert Group on Oceanography. It will be important that existing observing systems are linked together as much as possible.

8. Data management and access

The importance of data management, particularly data access was consistently emphasised in the feedback from the questionnaires (see Section 5). Thus data management should be given a high priority from the beginning and given a separate chapter in the envisioned SOOS document. Taco de Bruin will coordinate this chapter.

Taco de Bruin gave a presentation on the concept of a Southern Ocean Virtual Observatory. This idea, put together with Kim Finney, involves creation of a virtual observatory, i.e. is a single point of access through which Southern Ocean data can be accessed and integrated. This would not replace existing data delivery networks but instead integrate and build on them and their strengths and would focus initially on bringing "biological" and "physical" monitoring data together for exploitation.

A successful Virtual Observatory (VO):

- Consists of one window into all SOOS data and associated metadata
- Maintains the visibility of the VO's constituent contributors
- Uses a comprehensive and flexible search tools that can search within and between data types
- Involves basic and advanced visualisation methods for displaying the results of searches and which allow for deeper interrogation of selected data
- Allows access to data in a range of formats and encodings, deliverable to the desk-top of the user and/or available as services for machine-to-machine consumption
- Includes data hosting facilities for data unable to be hosted elsewhere
- Generates and publicises SOOS aggregation products, in collaboration with a SOOS research team
- Has the resources to assist new monitoring programs to join the VO
- Can only be undertaken as a partnership and needs to build on existing resources (people and existing systems).

To fully produce such a system from scratch would require significant resources (see for example SeaDataNet - http://www.seadatanet.org/). Therefore the idea would be to start in small steps and use already existing systems whilst at the same time trying to get funding to take the concept further forward.

9. Post-meeting plan

The following plan was drafted before the meeting. It was decided that despite the fact that it covers part of the Antarctic field season (and therefore many people will be away on cruises etc.) we should try to stick to it as closely as possible.

- ***29 Feb. 2007*:** Extensive outline of SOOS document
- ***31 May 2008:*** Completion of writing assignments for different parts of the SOOS document
- ***5-11 July 2008**:* Presentation of the draft document, and discussion, at expanded meeting of the SCAR/SCOR Oceanography Expert Group, and as part of the SCAR/IASC Ocean Science Conference (St Petersburg, Russia) to obtain further feedback
- ***30 September 2008**:* Inclusion of feedback to finalise document
- ***31 October 2008:*** Publish the document

SOOS should be presented at meeting such as OceanObs 09 and POGO '09 in order to create enthusiasm for the communities' involvement. There was some discussion as to the most effective way of disseminating the SOOS document. This can be decided upon in the future, but it was felt that initially it should go out the community at large and then perhaps involve targeted reviews. The next SOOS meeting will take part during the SCAR business meetings on the 5-7 July, prior to the SCAR/IASC Open Science Conference in St Petersburg. Please contact Mike Sparrow (mds68@cam.ac.uk) for further details.

Appendix 1: SOOS Agenda

Day 1: Monday October 1

Setting the scene...
10.00-10.20: Introduction - Eberhard Fahrbach, Eileen Hoffman, Mike Sparrow
10.20-11.00: Brief presentations of GOOS recommendations - Keith Alverson and Albert Fischer

Coffee/Tea
11.30-12.00: Who are we: Please state in a few words your interest in SOOS
all of us!
12.00-13.00: Sustained Observations in the SO region (Scientific background) - Steve Rintoul and Kevin Speer

Lunch
14.30-15.30: Discussion of SOOS report structure - Steve Rintoul
What do we expect from the working groups to be provided:
A summary of the contributions each paragraph of the report
15.30-16.00: Summary of input from questionnaires - Mike Sparrow

Coffee/Tea
16.30-18.00: Discussion of SOOS structure – Steve Rintoul
Where are the limits and how are the priorities?

19.30 onwards: Meeting Dinner at the Bremer Ratskeller

Day 2: Tuesday October 2
09.00-11.00: Break-out groups (focussing on e.g. physical system, ecosystems, biogeochem etc.) to develop sections of a SOOS plan:
Define content and coauthors of chapter 2: Scientific background

Coffee/Tea
11.30-13.00: Break-out groups (focussing on e.g. physical system, ecosystems, biogeochem etc.) to develop sections of a SOOS plan:
Define content and coauthors of chapter 3: Key Variables to Monitor in the Long Term

Lunch
Plenary added
14.30-16.00: Break-out groups (focussing on e.g. physical system, ecosystems, biogeochem etc.) to develop sections of a SOOS plan:
Define content and coauthors of chapter 4: Antarctic Observations: Existing Activities and Gaps

Coffee/Tea
16.30-18.00: Break-out groups (focussing on e.g. physical system, ecosystems, biogeochem etc.) to develop sections of a SOOS plan
Define content and coauthors of chapter 6: Implementation

Day 3: Wednesday October 3

09.00- 09.30: The SOOS Virtual Observatory including SOOS data management- Taco de Bruin

Addition: SOOS and Outreach added (David Carlson)

09.30-11.00: Review of break-out groups' work. Different groups to report back – Eileen Hoffmann

Coffee/Tea

Addition: COMNAP added (Saad el Naggar)

11.30-13.00: Revision of plans developed on Day 2 (cross membership of working groups)

Lunch

14.00-15.00: Review of revised detailed plan outline (sections and subsections, pages per subsection and identification of post-session Writing Assignments) – Steve Rintoul

15.00-15.45: Next steps to go – Mike Sparrow

15.45-16.00: Final words - Eberhard Fahrbach

End of meeting

Appendix 2: Meeting participants

Project	Representative	Email
IMBER	Julie Hall	j.hall@niwa.co.nz
SOIP/CASO	Steve Rintoul	Steve.Rintoul@csiro.au
GEOTRACES	Hein De Baar	debaar@nioz.nl
IOC	Keith Alverson	k.alverson@unesco.org
iAnZone	Eberhard Fahrbach	efahrbach@awi-bremerhaven.de
CAML	Victoria Wadley	Victoria.Wadley@aad.gov.au
GEBCO/IBCSO	Norbert Ott	Norbert.Ott@awi.de
CLIVAR/Argo	Kevin Speer	kspeer@ocean.fsu.edu
CliC/IGOS/IPAB	Vladimir Ryabinin	VRyabinin@wmo.int
OOPC	Albert Fischer	a.fischer@unesco.org
SCOR	Ed Urban	scor@jhu.edu
GOOS	Detlef Stammer	stammer@ifm.uni-hamburg.de
CPR-AG	Graham Hosie	graham.hosie@aad.gov.au
JCOMM	Etienne Charpentier	ECharpentier@wmo.int
POGO/AGCS	Mike Meredith	mmm@bas.ac.uk
SEaOS	Dan Costa	costa@biology.ucsc.edu
ICED	Eugene Murphy	EJMU@bas.ac.uk
SO GLOBEC	Eileen Hofmann	hofmann@palmer.ccpo.odu.edu
ESA	Pierre-Philippe-Matthieu	Pierre.Philippe.Mathieu@esa.int
COMNAP	Saad el Nagaar	Saad.El.Naggar@awi.de
IPY	Dave Carlson	ipy.djc@gmail.com
CCAMLR	Edith Fanta	e.fanta@terra.com.br
IAATO	Werner Stambach	stambach@t-online.de
NOAA	Steve Piotrowicz	Steve.Piotrowicz@noaa.gov
SCAR	Mike Sparrow	executive.officer@scar.org
GOODHOPE	Isabelle Ansorge	Isabelle.Ansorge@uct.ac.za
AGCS	Shigeru Aoki	shigeru@lowtem.hokudai.ac.jp
CliC	Vicky Lytle	Vicky@npolar.no
Fr/GOODHOPE/SOIP	Sabrina Speich	speich@univ-brest.fr
IOCCP/SOLAS	Mario Hoppema	mhoppema@awi-bremerhaven.de
Cryo	Lars Kaleschke	lars.kaleschke@zmaw.de
Data	Taco de Bruin	bruin@nioz.nl

Please note that many other individuals contributed prior to the meeting.

Appendix 3: Resolution G (2007) of the 30th ATCM

Long-term Scientific Monitoring and Sustained Environmental Observation in Antarctica

The Parties….

1. Urge national Antarctic programmes to maintain and extend long-term scientific monitoring and sustained observations of environmental change in the physical, chemical, geological and biological components of the Antarctic environment;

2. Contribute to a coordinated Antarctic observing system network initiated during the IPY (2007-09) in cooperation with SCAR, CCAMLR, WMO, Group on Earth Observations (GEO) and other appropriate international bodies;

3. Support long-term monitoring and sustained observations of the Antarctic environment and the associated data management as a primary legacy of the IPY, to enable the detection, and underpin the understanding and forecasting of the impacts of environmental and climate change.

Appendix 4 - Marine physics working group draft table

	FW balance	Ocean carbon	OT circulation	Ice sheet stability	Sea-level rise
Suggested lead authors:	Rintoul; Ansorge	Gruber	Speich; Meredith	Speer; Holland; Drinkwater	Church; Holgate; Aoki
Stratification (T(z), S(z))					
- open ocean					
- deep ocean					
- under ice					
- on shelf					
- under ice shelf					
- time series					
Velocity					
- surface					
- subsurface					
Tracers/CO2					
- CFC					
- CO2					
- 18-O					
- helium					
Nutrients					
Oxygen					
Biomass					
- fluorometer					
- Argo fl/trans					
- acoustics					
SO–subtropical exchange					
Air-sea flux					
Wind					
Sea level					
- altimeter					
- tide gauge					
- bottom pres.					
SST / SSS					
Transport					
Sea ice					
- extent					
- thickness					
- drift					
Observatory (super-site)					

Please note that this table is draft and very much work in progress.

Appendix 5 – Ecosystems and biology working group draft table

Q1-Ecosystem Structure - Presence Abundance Biomass Condition

Key Organisms	*Suggested Person*	*Technique*	*Platform*	*Operational?*	*Space/time coverage*
Phytoplankton	Julie Hall	HPLC Chemtax	VOS	Limited, on L'Astrolabe transect	Seasonal, 1000s km
		CPR	VOS	Yes	Seasonal, interannual 1000s km
		Ocean Color	Satellite	For now	Global, seasonal, interannual
		Autonomous flow cytometer	VOS, supply, research vessel		Seasonal,
		fluorometer	Argo float		
		Size fractionation	Time-series site, ship		
		Underway fluorometry and chlorophyll	JARE, national programs		
Other microbes – viruses, bacteria, protists				No	
Coccoliths				No	
Zooplankton	Graham Hosie	CPR	VOS	Yes	
		Net tows	LTER, JARE, AMLR, BAS, national programs	Yes	
Pteropods				No	
Forams				No	
Krill	Eugene Murphy	Acoustics – biomass and distribution	Ships - LTER, AMLR, BAS, AAD	Yes	CCAMLR region
		Acoustics - biomass and distribution	Moorings – BAS	Yes?	South Georgia
		Net tows – population demographics	AMLR, LTER	Yes	
		Fishery catch	Fishing vessels	Yes	AP

		– biomass and distribution			
		Fishery survey data – population demographics	CCAMLR	Yes	AP
		Predator diets - population demographics	CEMP, LTER, national programs	Yes	CCAMLR region
Fish	Edith Fanta	Fishery catch	Fishing vessels		
		Fishery surveys, stock assessments, fish condition	CCAMLR members, FAO		
		Commercial Exploratory fisheries	Commercial fishing vessels		
		Acoustics – abundance and distribution			
		Tagging	CCAMLR		
Birds	Dan Costa				
Penguins		On colony - Diet analysis, counts, demography, condition	AMLR, BAS, LTER, national programs		
		Tagging - foraging trip durations and tracks and at-sea behavior, environmental (temperature)			
Flying Birds		Underway ships - census	National programs		
		On colony - Diet analysis, counts, demography, condition			
		Tagging - foraging trip durations and tracks and at-sea behavior, environmental (temperature)	BAS and other national programs		

		Longline Fishery bycatch	CCAMLR scientific observers		
Mammals	Dan Costa				
Seals		On colony - Diet analysis, counts, demography, condition	AMLR, BAS, other national programs		
		Tagging - foraging trip durations and tracks and at-sea behavior, environmental (temperature. salinity)	SEAoS, AMLR, BAS		
Cetaceans		Ships - Distribution and abundance	IWC, national programs		
		Acoustics	National programs		
	Benthos		ABBED/CAML	Yes	
	Sea ice			No	
	Mesopelagic			No	

Please note that this table is draft and very much work in progress.

Appendix 6 - Biogeochemistry and Carbon working group draft table

variable	autonomous; semi-auton.; operator	method	platform	operational	time/space
UNDERWAY SURFACE SAMPLING					
Diss O2 surface water	autonomous	optode; or other? type	research vessel	elsewhere	
pCO2 air	autonomous	IR detector	M.Dufresne; Polarstern; JC Ross?	yes	
pCO2 surface water	autonomous	IR detector	see above	yes	
DIC surface	semi-auton;	Coulometry	research vessel	elsewhere	
pH surface	autonomous (stability?)	dual dye spectrophotometry	research vessel	elsewhere	
Alkalinity surface	operator	Vindta	research vessel		
Major nutrients	operator	auto analyzer	research vessel		
nitrate at high levels	autonomous				
indicative chlorophyll	autonomous	fluorometry optics			
particles	autonomous	transmissometer			
POC	operator	filtration			
PIC	operator	filtration			
dissolved Fe	operator	torpedo sampling with in line FI-CL	research vessel	yes on limited cruises	
optional: other biometals	operator	fill bottles from above torpedo	research vessel	yes on limiteds cruises	
aerosol dust	semi-auton.	filters	research vessel	yes on limited cruises	
DMS ????					
isoprene ???					
REPEAT HYDROGRAPHY					
DIC and ALK	operator	Vindta	research vessel	see table X of repeat sections	
pH	operator	dual dye spectro	research vessel		
major nutrients	operator	auto analyzer			
dissolved Fe	operator	clean rosette and			

		FI-CL			
CFC's	operator	regular CTD rosette; optional shipboard detection			
lowered ADCP	autonomous	acoustics			
POC	operator	filtration			
DOC		filtration			
13 C		fill bottles			
BUOYS (EITHER DRIFTING OR ON MOORINGS) AND/OR TIME SERIES SITES					
pCO2 air	autonomous	CARIOCA (Merlivat, Paris)	drift buoy	yes	
pCO2 water	autonomous	CARIOCA	drift buoy	yes	
PULSE time series	2008 -	47°S,142°E	sub-Antarctic mooring	Continuous	B. Tilbrook (CO_2)
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
Marian Cove, King Sejong Station, King George Island	2003-	62°13´S, 58°47´W	Surface measurements	Continuous	Y.C. Kang
Station observed from ship: Zhongshan Station	1984-	69°S, 75°W	Water column including DIC, pH, ^{234}Th, DO, Chl, nutrients, biomass	Annual	L. Chen
Station observed from ship: Changcheng Station	1984-	62°S, 59°W	Water column including DIC, pH, ^{234}Th, DO, Chl, nutrients, biomass	Annual	L. Chen

Please note that this table is draft and very much work in progress.