TOWARDS AN INTEGRATED OBSERVING SYSTEM: IN-SITU OBSERVATIONS

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ABSTRACT

(to be completed after review)

1. OBJECTIVE

The goal of the OceanObs'09 Conference and of the follow-up process is to build a community consensus for the path forward in building a *global integrated ocean observing system* that is ready to meet the scientific and societal needs and challenges of the future. Many critical aspects and components of such a system are presented in individual plenary papers from the conference. The objective here now is, by building on the other papers, to analyze the required steps which might most effectively lead to the required future ocean observing system.

The important words describing the desired system are "global" and "integrated", and these terms will provide the thread and glue of the subsequent considerations and analyses. At the conference there seemed to be overwhelming agreement that "global" implies the need for a permanent presence in all ocean regimes/provinces and the ability to provide access to them via platforms or vehicles. This presence is required for obtaining the information to understand and predict the ocean's role in the global climate and ecosystem, to conduct experiments, to detect changes, and to build a record that allows us to go back 50 years from now to look for events, processes, changes that we could not anticipate at present. We cannot afford to restrict ocean observations entirely to locations or regions that are deemed important according to our current knowledge, and thus risk missing and understanding/predicting new or unexpected interactions or responses in the system. The prudent approach for science, society, and policy makers would be a balanced observing system with a broad distributed global background coverage plus intense and focused observing capability in hot-spots or representative regions (according to current knowledge, which has to be allowed to evolve).

The "integration" aspect of the global in-situ observing system is more multi-faceted and ambiguous. The word itself means to *combine pieces or elements to form a whole*. Many of the possible and desirable elements of the future observing system are presented in individual plenary paper from the conference. There is no unique way to integrate these into a whole. For clarity of language, the terms "element" or "component" of the observing system will be used to refer to observing infrastructure components like floats, fixed timeseries, underway observations, or gliders. The term "ingredient" will be used to refer to other aspects of the observing system which may need combining or integration, such as observed variables, data management efforts, or the organizational aspects of programs. The approach pursued here is to first consider enhancing or completing components of the observing system, then to address separately the integration of various elements and ingredients, and finally to merge these considerations with aspects of practicality and efficiency, exploiting synergies where possible and joining forces across disciplines.

2. CONSENSUS STATEMENTS GUIDING THE INTEGRATION

Probably the single most repeated statement in many conference presentations is the need to focus on applications that society cares about. Many examples for those are addressed throughout the contributions, including

- sea level and storms
- climate change prediction (IPCC model initialization, testing, validation)
- changes in carbon uptake (including the biological pump), fate of anthropogenic carbon
- acidification (ecosystem damage, coral reefs, planktonic carbon sink impact)
- management of Living Marine Resources, attribution of climate impact
- health of ecosystems, Harmful Algal Blooms, hypoxia
- changes in the Arctic
- pollution and pollutant transports

The quintessential conclusion from these applications is that they span the three major disciplines, and thus it is inevitable that the future observing system *must* comprise physics, biogeochemistry, and ecosystems.

Another consensus statement to guide integration is the need for more global coverage and the inclusion of more key variables. In particular the gaps in the global sampling locations/depths and the undersampling in space and time are frequently drawn attention to. Even a basic quantity like global heat content has an unexplained imbalance due to undersampling, and this is far worse for surface fluxes, CO_2 fluxes and inventories, and other quantities. The inclusion of new variables needs new sensors/techniques, as well as platforms to carry them.

The community also appears to agree on the need for long timeseries observations with high temporal resolution. These are essential for detecting events, for documenting and quantifying changes in circulation, fluxes, and multi-disciplinary processes, for observing regime shifts, *changes* in biogeochemistry conditions, and more. It is recognized that the collection of sustained timeseries is “not sexy” but nonetheless critical, and that funding for such efforts needs to be protected since repeated routine observations over long times are difficult to justify by pure short-term research arguments.

An integration need which has been articulated widely by the biogeochemical and ecosystem communities is the collection of co-located observations of many variables, in order to provide a context for the interpretation and understanding of specific processes. This requires sampling many linked variables in physics, climate, geochemistry, ecology.

While integration of the many aspects and elements into an observing system will make it vastly more powerful, compelling, and effective, nothing would be gained without equal efforts to make the data and the *information* publicly available and to share them freely. It is probably fair to say that every single member of the community and of the agencies endorses this statement. The main reason is that the data can yield benefits only when they are *used*. In order to facilitate this useage, data and information exchange also needs to be enhanced (or even enabled) between different research communities and countries, or between diverse types of data bases.

Finally, many plenary presentations have emphasized also the human resource dimension in building, integrating, and sustaining a global ocean observing system. It will be crucial to train a new generation of ocean observers, and include countries around the world via capacity building, for making the ambitious OceanObs09 vision a reality.

Guided by the various above consensus statements the required steps for combining the elements and ingredients into an integrated system will be analyzed in the following sections.

3. ENHANCEMENT OR COMPLETION OF ELEMENTS OF THE SYSTEM

3.1 More and Better Sensors

Regardless of the platforms or the geographic distribution of the in-situ observing system, there is an acute need for the implementation and deployment of additional sensors, in order to meet the scientific and societal challenges ahead. Much of the present sustained ocean observing system provides only physical observations, while it is clear now that the future system must cover a wide range of biogeochemical and ecosystem observations as well.

There is a need for more and better sensors that are capable of the long-term and autonomous measurements which have to become part of an integrated in-situ system. Examples from the Community White Papers are improved wave sensors (Swail et al CWP), more accurate and reliable nutrient sensors (Adornato et al CWP), sensors for measuring components of the carbon system like pCO2, pH, alkalinity (Byrne et al CWP), autonomous optical plankton imaging sensors (Sieracki et al CWP), and improved technology and analysis techniques for acoustic zooplankton/fish sonars (Handegard et al CWP). Developments in terms of endurance, stability, accuracy, fouling protection, and size/power consumption will lay an important foundation for the integrated in-situ system.

3.2 Improved Platforms

The future in-situ observing system should take advantage of new technological developments for carrying the sensors and relaying the data to shore. This will increase coverage, efficiency, and impact of the observations. For example underwater gliders have large potential for becoming an element of the system, but would benefit enormously from increased endurance and range. Outfitting them with an acoustic navigation capability would allow them operate under ice or dive under strong current systems, while adding acoustic modems can turn gliders into data shuttles between subsurface instruments and shore. Some of these developments are already under way (Testor et al CWP).

Advanced mooring technology will also improve the range of applications (and thus benefits) of sensors deployed in timeseries mode. Platforms are now being designed which can survive being moored at the surface in high-latitide wave conditions, and others allow vertical profiling with sizeable sensor packages through different parts of the water column (Brasseur et al CWP). Similarly, a range of technology has recently been brought to bear to enable installation and maintenance of sensors under the ice (Lee et al CWP), and this will be crucial for extending the observing system to polar oceans. Biologging is another technology whose usage is expanding, and using animals to carry small sensor packages may have merits in specific aspects of the future in-situ observations.

3.3 Enhancing Existing Elements and Systems

Before integrating efforts across elements and combining pieces and ingredients, it is worth to explore options for enhancing the existing programs. In some cases these are low-hanging fruits since expanding scope or capability within a program may be more feasible or quickly implementable than coordination and merging efforts, data, logistics, resources across very diverse efforts (which would be the longer term goal). Opportunities that are worth pursuing in this category (drawn from plenary presentations) include the frequently cited addition of sensors to profiling floats in the ARGO system, in particular for oxygen observations. With appropriate additional funding a subset or all of the existing ARGO floats could be upgraded without jeopardizing the sampling coverage of the network.

A different example is OceanSITES, where with modest additional effort/funding a subset of core or backbone global sites could be upgraded to collect a wide range of truly identical observations serving the interests and needs of a variety of disciplines at once. A strawman for existing sites that would easily lend themselves to this enhancement is shown in figure 1.

Also many underway observations in the VOS system can be supplemented relatively easily to collect measurements pCO2 concentration or other chemicals.

3.4 Closing Gaps in the Present System

Much discussion is centered around identifying and closing spatial gaps in the current in-situ observing system. A variety of CWP's and plenary presentations are drawing attention to needed regional or vertical additions. At a basin level, the Arctic Ocean (Calder et al, Lee at al, Sagen et al), the Southern Ocean (Rintoul et al), and the Indian Ocean (Masumoto et al) all require completion of their sampling coverage, in order to build a truly global ocean observing system. A present phenomenological gap is the routine and sustained sampling of boundary currents (Send et al) and inter-basin exchanges (Gordon et al). And also the abyssal ocean is virtually unsampled by most of the existing observing infrastructure (Garzoli et al). Options have been proposed in the various papers for closing these gaps before attempting the actual integration steps into a more unified and powerful global in-situ system.

4. COMBINING MANY OBSERVATIONS AT ONE PLACE

One aspect of integration across the elements, disciplines, platforms, and programs, is to assure sufficient supporting or background information for specific questions or challenges. Often the physical and chemical measurements needed to link ecosystem variability to environmental variability do not exist (Gruber et al CWP). Truly integrating observations (as the basis for addressing the societal challenges) need more collaborative efforts between investigator, programs and disciplines, and increased sharing of platforms, of funding, and of expertise. This is currently hampered not only by traditional mindsets of researchers (focussing on justifying, funding, publishing their specific projects/objectives) but also of funding agencies which still have difficulty jointly supporting efforts or projects from several disciplines, or even multi-agency or multi-nation funding. The largest mutual benefit results if platforms and logistics are shared, development efforts and measurements are coordinated, and observations are placed into a mutual context with other information or programs.

As an example a novel effort is under way in the southern California Current. It is a mooring addition to ongoing observations with quarterly ship surveys (for mainly fisheries applications, CalCOFI), with intensive ship board process studies (CCE-LTER), and with regular glider transects across the inshore part of the boundary current. The mooring closes the temporal gap in the sampling and allows continuous deployment of a large variety of state-of-the-art sensors, some of which (acoustic zooplankton/fish sonars) are designed to be identical to the ones used on the ship surveys for obtaining ground-truthing from the net hauls. The mooring (figure 2) is a highly collaborative effort (seven PI's at SIO, NOAA SWFSC, NOAA PMEL) merging funding from several sources (institutional, Navy, NOAA climate, NOAA fisheries). Everybody contributes and everybody gains from it, and this is a promising model for future parts of a truly integrated in-situ observing system.

5. COMBINING EFFORTS ACROSS PROGRAMS

At present, each component of the present observing system (ARGO, SOT, OceanSITES, Global Drifter Program, waves) and each community (CLIVAR, carbon, IMBER, SOLAS) is fully occupied to make its own part work. While those inward efforts have paid off and are essential to get started, the integration into a multidisciplinary system that serves the future societal needs now requires joining forces across the communities.

Since the existing global components are mainly climate/physical systems, but have much of the programmatic and logistic (and data) structure in place, it appears beneficial and efficient if these (especially ARGO, SOT, OceanSITES) start to work more closely with the biogeochemical and ecosystem communities, to

- plan/design the future network together
- share the funding/proposal writing
- share the implementation
- merge disciplinary expertises
- build a joint data system

- interact on analyses.

6. COMBINING THE DATA

6.1 Data from Different Components of the System

Combining the data from very diverse in-situ systems is still a significant challenge. Usually this is done via state estimation (using adjoint or Kalman filter data assimilation). For broadly distributed data (like ARGO) of a simple quantity like T or S, the techniques are well established and successful. Problems arise when the sampling scales or accuracies are not well matched, or more indirect or bulk observations are collected.

For example, it is unclear what is the best way to use timeseries collected at a small number of isolated points but with high temporal resolution and high accuracy in an eddy resolving model. Expecting or forcing the model to reproduce every detail of the data would lead to huge (and unrealistic) local adjustments of the model. Assigning a large error corresponding to the eddy "noise" throws away the high accuracy of the data set. Forcing only the larger scales with the low-frequency part of the data loses just the high temporal resolution of such data. Maybe it is preferable (and possible) to only assimilate the temporal statistics of the timeseries (they can be temporally and vertically varying). Or possibly the best useage of such data sets would be to withhold them in state estimates or forecasts and use them for validation, skill assessments, performance metrics.

Somewhat related, the estimation of a specific quantity or process may require very high accuracy observations (e.g. calculating or constraining mass transports from T/S or density measurements). However the data error assigned to such inputs in usual cost functions is too large (to account for instrument and eddy noise) for really constraining the process. It is not clear at present, whether in such cases the mass transports should first be calculated directly from the density data and *then* be used as a constraint in the state estimate.

Finding ways to combine and incorporate biogeochemical and ecosystem observations (together with physical data) is another challenge. Many such observations are indirect and represent complicated (often poorly known) responses or properties of an organism (or a compound within an organism). Examples are chlorophyll fluorescence, acoustic backscatter cross-section, total biomass or displacement volume. In many cases even by themselves such observations are difficult to "invert" to yield the quantities really sought (chlorophyll concentration, abundance of species and size classes, etc). It will become increasingly important to find new ways to make use of such derived/indirect data jointly with other observations. With luck, it may turn out that the combination with additional information (via state estimates or other novel means) will make it easier to "invert" the indirect observations for sought quantities.

6.2 Data from In-Situ Observations, Satellites, Models

An integrated observing system will also require improved combination of data from in-situ systems and from remote sensing (possibly also with, or via, models). Remote and in-situ observations depend on each other, and can multiply their stand-alone value by co-using their information. For example, remote sensing requires supplementing with in-situ data for knowledge of the internal structure/distribution of remotely sensed properties, for ground-truthing, and for obtaining critical parameters which cannot be observed from space (but which may be needed for an interpretation/application of the remotely sensed data).

In many cases the data sets are too vast or specialized to make them useful to the other community in original form. The satellite community is holding "truckloads" of data for example, and a practical mutual way forward may be to extract information and products needed by the others. Examples:

- In-situ information needed by the satellite community to use, interpret, and understand satellite data (like vertical structure of chlorophyll, of surface/subsurface currents, nutrients)
- Remote sensing products needed by the in-situ community (like spatial statistics, maps, temporal variability on large scales)
- In-situ products useful to the modelling community (fluxes, timeseries for validation, statistics, integral constraints)
- Model information useful for in-situ data interpretation.

6.3 Data from Climate and Ecosystem Programs

Types of data sets which are being collected and assembled in the respective data bases of the climate and the ecosystem communities are typically so different in nature that there is no direct way to combine them – the climate programs assemble single parameters in 1-D, 2-D, or 3-D fields (timeseries, sections, maps), while biological programs often maintain data bases with millions of samples which identify the occurance and maybe the concentration of organisms found in a location or volume sample.

For successful integration between these programs the ecological databases need to be manipulated to yield information/products to be used jointly in quantitative analyses or models. One approach, which is already being used to some extent, is to extract parameter/index timeseries and spatial distributions for the organism abundance, figure 3. Examples are the timeseries and maps produced by the CPR project (Burkill). Such data can then be merged/compared with climate/biogeochemical data.

As a thought experiment or conceptual suggestion for other approaches, the following ideas might also yield useful results. Denote the concentration of a species "i" in a given sample as c_i. Then look for a set of bulk properties b_k that can be measured autonomously (similar to other climate/biogeochemical parameters) like optical absorption (many wavelengths), optical backscatter (various wavelengths), acoustic backscatter (various frequencies), volume displacement, fluorescence (some wavelengths), and others. Lab experiments can give the relation between the concentration of species "i" and property "k" as a linearized equation $b_k = g_{jk} c_i$. Total backscatter, absorption, and other properties, for the sample then come from summing over the concentrations of all the species, in matrix form

$$\mathbf{b} = \mathbf{G}\,\mathbf{c} + \mathbf{e} \qquad (1)$$

where **b** is the vector with all the b_k, **c** is the vector with all the c_i, **G** is the matrix with all the g_{jk}, and **e** represents uncertainties/errors.

In this form the vast amount of linear inverse theory can be applied to extract, combine, and thus integrate the information between ecosystem and climate data. Example applications, enabled by this formalism, are:

- Synthetic bulk data can be predicted from the ecosystem samples, for qualitative comparisons with field data of the same quantities
- The matrix **G**, determined entirely from lab experiments, allows theoretical studies of which species can be constrained by which bulk measurements or what the optimal combination of bulk measurements (and wavelengths) is in a given ecosystem composition
- Studies of the matrix **G** also allows to look for useful well-constrained linear combinations of species concentrations (a single species or size class may not be well constrained by a set of bulk measurements in a complicated ecosystem, but maybe a sum of several is, in terms of number, weight, volume, total chlorophyll, etc)
- The above approach may also provide a formalism for using bulk data for constraining models which have a few of the species and/or total phytoplankton, zooplankton, etc as variables.

7. OPEN AND SEAMLESS DATA ACCESS

Integration of the observing system elements and programs also means to combine their data systems ultimately. This does not necessitate single joint data bases or even common data formats, since modern technologies exist like distributed systems and Live Access Servers with data dictionaries and data discovery techniques that enable data access across diverse sources. Many programs have their own data system established (ARGO, SOT, OceanSITES, CPR, COML), and a future challenge then is to provide seamless and cross-linked access to all of them.

No standards (ie. formats, QC procedures, best practices) exist currently for many biogeochemical and ecosystem parameters (in profile or timeseries form). OceanSITES has started to try filling that gap and is working to define format and QC/QA procedures.

A possibly controversial recommendation, representing a subset of the community (e.g. the OceanSITES project), is that realtime biogeochemical/ecosystem data (from autonomous systems) be shared in realtime, even without good automated quality control procedures in place (with very clearly stated warnings). The benefits of making even uncertain data widely available and *used* are deemed to outweigh the dangers of uncritical useage or misuse. Also, it may well be possible that other users find problems or draw attention to issues (from comparative analyses for example) which the data owner would be overwhelmed with.

8. POTENTIAL SYNERGIES

One clear and unanimous outcome from the OceanObs09 conference is that the future sustained global ocean observing system must expand to include significant biogeochemical and ecosystem components. This can be achieved by building *additional* and separate projects similar to ARGO, OceanSITES, SOT, or the surface drifter program. But then the new systems would compete for funding and visibility with the established ones and with each other. It is most likely easier and more powerful/compelling to have a small number of expanded, highly capable/versatile programs that address MANY societal needs in an integrated fashion, than many specialized ones.

Also in terms of programmatic effort, it involves a lot of work, time, and funding to set up new projects. It is likely more efficient to add to existing projects, their infrastructure, logistics, and data systems, rather than building separate ones. These considerations lead to the recommendation to look for natural synergies between the existing projects and needed future enhancements, together with the different communities. Some potential synergies are given in the following.

8.1 VOS Synergies

The VOS project, using commercial vessels to observe global surface distributions, currently collects mainly XBT and thermosalinograph data. Independently, separate projects exist that obtain more biogeochemical/ecosystem underway observations

(VOS-Carbon, CPR). Once engine intake water on such vessels is diverted to an analysis system like a thermosalinograph, the shipping line already cooperates, and logistics are in place to collect/deliver the data, it may be relatively easy to add analysis systems for carbon parameters, trace metals and other chemicals, or pollutants. Also an effort could be made to try merging XBT and CPR sampling on some lines. These may be low-hanging fruits that can vastly enhance the power and societal value of a global VOS project.

8.2 ARGO Synergies

The ARGO project uses subsurface floats to observe global subsurface distributions of T and S. It has been demonstrated technologically that such floats can carry other sensors for biogeochemical and ecosystem applications (O_2 and various optical sensors, laser optical plankton counters, etc), and additional sensors are probably close to implementation for floats (such as pH). It would be reasonably straightforward to enhance the ARGO network with several such sensors. The price would be the reduced endurance and higher cost, higher complexity and more failure modes, but this is bound to be more economical and efficient than building separate float programs, especially when taking into account also the deployment logistics.

ARGO-like floats can also operate under the ice now, with ice-detection algorithms and acoustic (RAFOS-like) positioning. This is already being done in some parts of the Southern Ocean, but more wide-spread deployments, especially also in the Arctic Ocean would be desirable. The needed type of acoustic hydrophones and receivers is simple and low-power, and does not need to be powered up frequently for achieving a tracking equivalent to normal ARGO positioning. The main price and effort would be for the sound sources, but those can operate for many years.

A more advanced and demanding synergy offered by ARGO-type floats would be to equip them with broadband acoustic receivers. These could be used for acoustic tomography and animal tracking applications. The technology, especially to make it low-cost, miniaturized, and low-power still needs development, but if it were available the large number of floats would require only a modest number of sound sources. In the polar oceans, these could be the same that provide under-the-ice positioning.

8.3 OceanSITES synergies

The OceanSITES project uses fixed-point measurements, mostly moored, to provide air-sea to bottom timeseries of many variables with high temporal resolution at selected locations around the globe. The sensors are regularly recovered, which allows post-calibration and even recovery of in-situ samples. At present, the sites are very dissimilar and frequently collect data for a single research project theme or discipline. The ability to carry many sensors, nearly regardless of size and power requirement (as long as autonomous) makes these installations ideal for incorporating the needs and the autonomous sensors from many research programs and disciplines. Sharing the sites in such a way would give an unprecedented capability and presence for many societal applications, while sharing the cost, logistics, and disciplinary expertise via collaborations would make their operation efficient and affordable.

The obvious candidate sensors, some of which are already being used on moorings, are biogeochemical and ecosystem instruments, like O_2, pH, pCO_2, radiation or nutrient sensors, and more. These are exactly the types of timeseries that many communities require to unravel process and changes in biogeochemical systems.

The Census of Marine Life (COML) project and many fisheries research or monitoring programs can join efforts with OceanSITES to deploy upward/downward looking fish/zooplankton sonar systems. These can be complemented by imaging techniques, like LOPC’s (Sieracki et al CWP). The acoustic volume sampling combined with optical species identification gives a powerful tool for studying the variability and events/processes in ecosystems.

The OceanSITES infrastructure also offers synergy opportunities for the various observing needs that require deep/abyssal measurements (Garzoli et al, …). The existing moorings can easily be equipped to measure deep T/S changes with better accuracy than other autonomous systems, can contribute to global deep carbon inventory monitoring, and also supplement the circulation, boundary current, and basin-exchange observation effort.

In general, the OceanSITES system can provide surface and subsurface reference information for many programs and disciplines. In that sense, it is fitting that these timeries are sometimes referred to as “ocean reference sites”, somewhat like subsurface equivalents of the atmospheric Keeling curve. The suggested rationale is to choose “hotspots” for certain processes or disciplines (figure 4) or locations representative of ocean provinces, to establish a long-term multi-community presence in the global ocean through OceanSITES.

9. OTHER REQUIRED INGREDIENTS

One impediment to building and sustaining a global in-situ ocean observing system is the present academic review and reward structure. In the current system there is not much merit associated with generating community data, and credit is given only for well-cited research publications. In order to make it attractive to build and sustain the needed observing system, appropriate recognition and credit must be associated with collecting and providing data for the global community and to the benefit of society.

It appears that novel ways are starting to appear to make this possible. J.Helly at the UCSD Supercomputer Center for example has worked out a way for the Crossref organization to accredit and assign a journal-like number (digits before the /) to recognized data centers or atlases, which then can provide citeable DOI numbers to data sets submitted to them. Citations of such data sets then would get counted in the Web of Science, and other quantified citation metrics. Many details have to be worked out if this is intended to be put into practice for the ocean observing system, but at least options for providing credit and recognition are arising now.

Another obstacle for the implementation of a more encompassing, complete, and powerful ocean observing system is the human resource dimension. Many new jobs will need to be created, and a new generation of ocean observers needs to be trained in order to sustain such an undertaking. This also needs a better geographic distribution around the globe, since many efforts will only be sustainable with local participation, if only for political and diplomatic support. This necessitates intensified capacity building and training in countries other than those which may do the initial development and installations.

10. CONCLUSIONS AND RECOMMENDATIONS

The OceanObs09 conference approximately marks the beginning of the 3rd decade of systematic global ocean observations. The first decade was dominated by WOCE (1990 – 2002) whose primary objective was to observe the mean state of the ocean. It was followed by approximately a decade in which CLIVAR (2000 – present) was the main organizer for sustained global ocean observations, with a focus on the *variability* of ocean climate processes. The beginning of that last decade coincided with OceanObs99 through which several of the current observing system elements got support or even initiated. These first two decades were driven nearly exclusively by research needs and by the (physical) ocean climate community.

It is obvious that the international community is at a new branch point now. The coming era of global ocean observation is clearly under the sign of societal applications, rather than pure research needs, and thus must embrace and address the many biogeochemical and ecosystem issues at hand. Probably 10 years from now OceanObs09 will be seen as the start of the decade of truly multidisciplinary sustained global ocean observations.

The sections above attempt to summarize steps that are required to build a future system that is truly integrated in various respects. As a starting point, the community consensus seems to agree on

1. maintaining the existing system
2. closing gaps in the present observations.

As argued above, for the next steps it is likely most efficient, compelling, and cost-effective to <u>at least</u>

3. enhance ARGO, OceanSITES, and VOS to serve and be jointly operated with the biogeochemistry and ecosystem communities.

There may well be additional projects that are initiated and can be added to the list (such as a global repeat hydrography project that is being discussed as a result of OceanObs09), but the main point is that any such projects must collaborate across the disciplines and programs in the future, in order to build an integrated observing system satisfying the societal needs of the future.

Clearly this is an ambitious endeavour, but since it would be jointly funded and implemented by the three communities and corresponding sections within (or across) agencies, such a system should also obtain several time the resources compared to the current observing system. In addition, the urgent societal needs/application may channel more resources into such a system. By following the integrations steps outlined in the above sections, and building an in-situ ocean observing that is ready to address all the scientific and societal needs in a single integrated way, an immensely powerful and compelling capability can be argued for. It would be able to address not only the present-day challenges, but also be ready for the unknown unknowns of the future.

11. REFERENCES

(to be completed)

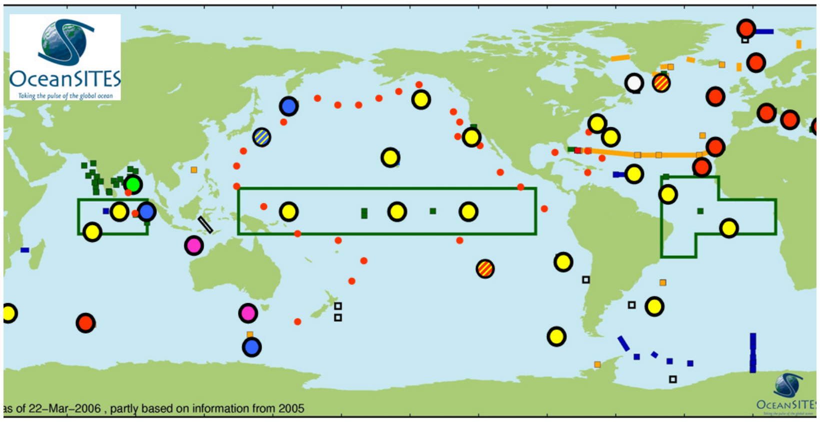

Fig.1: Strawman backbone of OceanSITES locations with identical multi-community measurements.

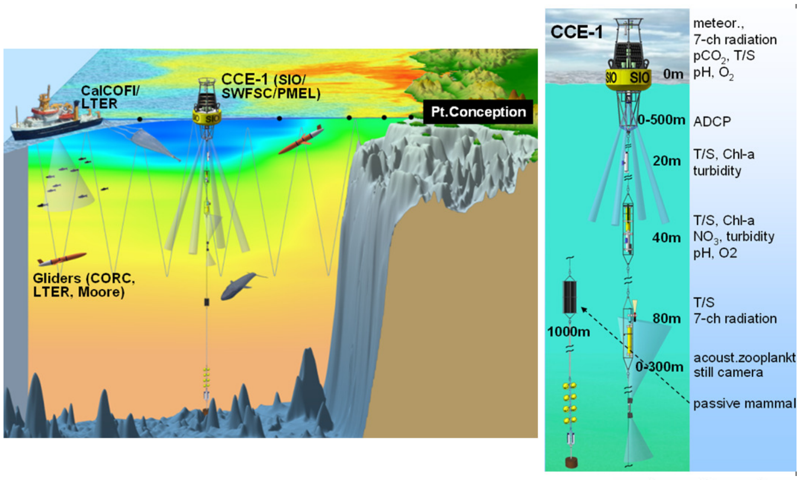

Fig.2: Mooring in the California Current

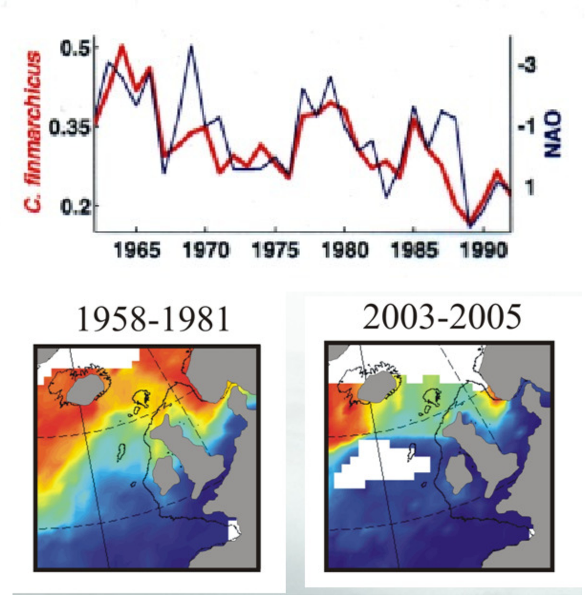

Fig.3: Timeseries and spatial distribution of Calanus species from the CPR program

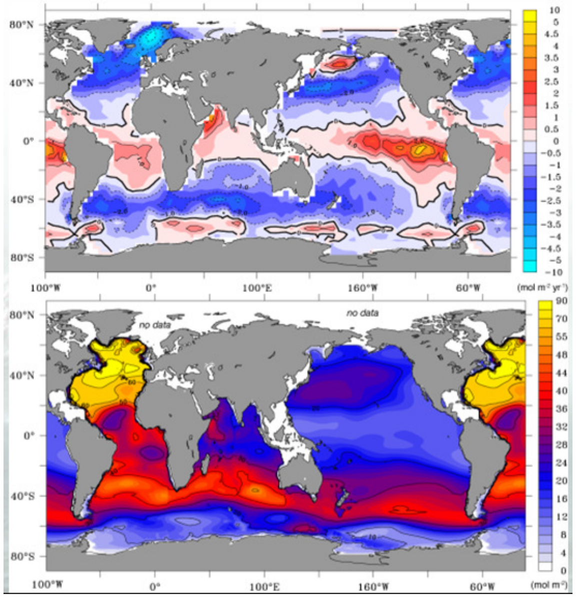

Fig.4: Carbon fluxes and anthropogenic CO2 inventory to identify hotspots where multidisciplinary sustained timeseries wold be especially valuable.