THE ACTION PLAN FOR GOOS/GCOS AND SUSTAINED OBSERVATIONS FOR CLIVAR

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ABSTRACT *-The design and implementation of an ocean observing system for climate has been actively considered by various international bodies over the last decade. This paper describes these efforts and, in particular, the observing system design, and its basis, as provided by the OOSDP and subsequently by the OOPC. The latest specifications for the observing system as detailed in the GOOS/GCOS Action Plan for Global Physical Ocean Observations are given in the Annexes. These form the basis for the considerations of OCEANOBS99 and whatever elaborations or changes that may be recommended.*

1- INTRODUCTION AND BACKGROUND MATERIAL

Scientific understanding of the climate system has been advanced by the programs of the World Climate Research Program (WCRP), including the Tropical Ocean and Global Atmosphere Programme (TOGA), the World Ocean Circulation Experiment (WOCE), and the Global Energy and Water Cycle Experiment (GEWEX). These programs were planned and implemented in the mid-to-late 1980s to address fundamental questions concerning climate variability and change. Although these experiments have greatly increased our observational base (and will continue to do so) of various aspects of the climate system, being time-limited research programs they were not primarily designed to provide an ongoing set of observations. However, more recently another WCRP program, the Climate Variability and Predictability Experiment (CLIVAR), is being planned and implemented with, as is discussed below, a longer-term focus. As predictions of climate variability become feasible and evidence of anthropogenic climate change increases, policy makers require increased observations of global climate change and variability to make use of increased understanding of the climate system and on which to base decisions on matters related to climate.

The First Assessment Report of the Intergovernmental Panel on Climate Change (IPCC) was released in 1990 (IPCC, 1990). This report assessed the state of scientific information that existed at that time on climate change. It identified the oceans, clouds, greenhouse gases and polar ice sheets as the key areas requiring further examination and research in order to reduce uncertainties in predictions of climate change. Regarding the oceans, the IPCC stated that "the oceans play a central role in shaping the climate through three distinct mechanisms: the absorption and exchange of carbon dioxide with the atmosphere; the exchange of momentum, heat and fresh water with the atmosphere; and the storage of heat absorbed at the surface in the depths of the ocean". The exchange of energy between the ocean and the atmosphere and between the upper and deeper layers of the ocean, and the transport of energy within the ocean were identified as processes that control the rate of global change and the patterns of regional change. The IPCC also pointed out that the ocean has not been well observed and that therefore "there is less confidence in the capability of models to simulate the controlling processes".

The IPCC also stated that "systematic long-term **observations** of the system are of vital importance for understanding the natural variability of the Earth's climate system, detecting whether man's activities are changing it, parameterizing key processes for models, and verifying models simulations. Increased accuracy and coverage in many observations are required. Associated with expanded observations is the need to develop appropriate comprehensive global information bases for the rapid and efficient dissemination and utilization of data. The main observational requirements are.

The IPCC First Assessment Report was the principal document submitted to the Second World Climate Conference in November, 1990. The conference attendees agreed that the scientific conclusions set out in the IPCC report reflected the international consensus on scientific understanding of climate change and on the need to reduce the uncertainties in climate prediction by a program of research and systematic observations. In particular, the conference recommended that a system of observations of the various components of the climate system, including a global ocean observing system, should be developed to monitor climate variably and change more effectively.

In order to meet these needs GCOS was established in 1992 by four international organizations: the World Meteorological Organization (WMO), the International Oceanographic Commission (IOC), the United Nations Environmental Programme (UNEP) and the International Council of Scientific Unions (ICSU). The stated strategy of GCOS is to define and specify an operational climate observing system to be realized next century, to identify key deficiencies and to stimulate a research and development program leading to an enhanced operational program. It was further anticipated that "the benefits of GCOS, in particular that it will lead to the earlier detection and more reliable prediction of climate change, are likely to be much larger than the costs of providing GCOS."

In June 1992, 150 nations signed the United Nations Framework Convention on Climate Change (FCCC) and subsequently conferences of the Parties to the Convention (COP) have been held at Kyoto in late 1997 (COP3) and Buenos Aries in November 1998 (COP4). That GCOS is an essential element of understanding and addressing the problem of global climate change has been accepted and supported at these conferences. As preparation for the Buenos Aries meeting, the Subsidiary Body for Scientific and Technical Advice (SBSTA) was asked for a "Report on the Adequacy of the Global Observing Systems" which includes a number of recommendations concerning the implementation of GCOS. COP4 recommended that Governments put much more effort into monitoring the climate system and man's effect on it, and included a recommendation to collect more ocean measurements, especially from data sparse areas like the Southern Ocean. In addition, more capacity building was called for to enable developing countries to contribute to and benefit from global climate observations.

As GCOS was taking shape, other observing systems were being set up; in particular, the Global Ocean Observing System (GOOS) and the Global Terrestrial Observing System (GTOS). GCOS has worked closely with these programs and has incorporated the components that deal with climate. Thus, the global climate module of GOOS is identical to the ocean component of GCOS and the Ocean Observation Panel for Climate (OOPC), which is responsible for the design and implementation of an ocean climate observing system, is a common subsidiary body of both GOOS and GCOS.

Lastly, it is useful to recognize the different nature and state of the climate observing systems required for the atmosphere, the ocean and the land. In particular, the required GCOS atmospheric station network is for many nations a subset (meeting uniform standards) of existing stations, many of which were established to support weather prediction and are part of the World Weather Watch (WWW). However, globally there is the need to enhance the existing network in a number of countries, primarily in the Third World. The same is true of much of the required terrestrial climate network. For the ocean however, especially subsurface, essentially no operational observing system exists and most observations have been obtained from research programs, including the large-scale WCRP programs WOCE and TOGA.. Thus, as was recognized by the IPCC in 1990 and as is stated above, there is primarily a need to “maintain, enhance and improve” the atmospheric and terrestrial observing systems while there is a need to “establish” one for the ocean. A recent example of change in this situation is the establishment of much of the tropical Pacific ocean observing system that is required for ENSO prediction as an operational system through the efforts of the US and several other countries. Other differences between the systems required for the land, atmosphere and ocean arise from the different spatial and temporal scales of both the climate signal to be observed and the natural variability that can hide it.

2 - THE DESIGN OF THE OCEAN OBSERVING SYSTEM FOR CLIMATE

The original design of an ocean climate observing system for climate was completed by the Ocean Observing System Development Panel (OOSDP) in late 1994, published in early 1995 (OOSDP,1995) and endorsed by both GCOS and GOOS soon afterwards. The OOSDP was able to provide this design so soon after the formation of GCOS and GOOS because the OOSDP predated the establishment of both programs. In the late 1980s, as WOCE and TOGA were completing their planning phases and entering a period of field programs and analysis, it seemed that there was the possibility of obtaining international and national support for substantial operational ocean observing systems. WOCE, with the support of TOGA, recommended to the then existing SCOR/IOC Committee on Climate Change and the Ocean (CCCO) that a panel be formed outside of WOCE to address broad ocean observing requirements. With the cooperation of the Joint Scientific Committee (JSC) of the WCRP, the OOSDP was constituted and met for the first time in September, 1990. Initially the OOSDP served as a sub-committee of the CCCO and the JSC but with the formation of GCOS and GOOS it was also supported by those bodies. The OOSDP was disbanded with the publication of its report and its responsibilities were assumed by the Joint GCOS/GOOS/WCRP Ocean Observations Panel for Climate, the OOPC, upon its formation in 1996.

The terms of reference of the OOSDP were to provide the "Conceptual design of a long-term, systematic observing system to monitor, describe, and understand the physical and biogeochemical processes that determine ocean circulation and the effects of the ocean on seasonal to decadal climate changes and to provide the observations needed for climate predictions." Such a broad mandate caused the OOSDP to consider a number of generalities and principles that such an observing system must encompass to meet its overall objectives. Many of these are discussed in the paper "An Integrated Sustained Observing System" by Nowlin et al in this volume and will not be discussed further here.

The OOSDP faced the difficulty that it is essentially impossible to separate one climate concern that places demands on the observing system from another. Various variables provide input to a number of fundamental climate signals. Some variables such as SST, which is important in its own right as an indication of global warming, is required in the tropics for the initialisation and verification of ENSO predictions and globally for the estimates of the surface heat flux. Thus, the division of the requirements for the elements of the observing system into a number of non-redundant unique climate problems or signals is not possible. In designing the Initial Observing System (IOS), the OOSDP decided to divide the requirements for a climate observing system into three goals each with a number of subgoals (OOSDP, 1995). The first OOSDP goal addresses the ocean's surface and the subgoals concern the determination of a) SST, b) wind and wind stress, c) the surface fluxes of heat and fresh water, d) the surface flux of CO2, and e) the extent, concentration, volume and motion of sea-ice.

The second OOSDP goal addresses the upper ocean with subgoals addressing a) the global data required for monitoring, analysing and understanding monthly to interannual temperature and salinity variations, b) the upper ocean tropical Pacific data necessary for the initialisation and verification of models for ENSO prediction, and c) the upper ocean data outside the tropical Pacific for understanding and description of ocean variability and for the initialisation and development of models aimed at climate prediction. The OOSDP analysis not only provides priorities among the upper ocean variables but also describes which of the surface variables are required to meet particular upper ocean subgoals.

The third OOSDP goal includes issues of the full-depth ocean and includes as subgoals a) the determination of the oceanic inventories of heat, fresh water and carbon, b) the determination of the changes in the oceanic circulation and its transport of heat, fresh water and carbon on long time scales, and c) the determination of the long-term change in sea level due to climate change.

The OOSDP also included a fourth goal focussing on the need to provide the infrastructure and techniques that will ensure that the information obtained is used in an efficient way. A synthesis will be achieved in a variety of ways including routine monitoring and analysis, improved climatologies and through model data assimilation. Subgoals addressed a) the need for improved climatologies, such as of temperature, salinity and carbon, especially for validating climate predictions and simulations at decadal and longer scales, b) the provision of data management and communication facilities for routine monitoring, analysis and prediction, and c) development of the facilities for processing assembled data sets and providing timely analyses, model interpretations and model forecasts. These integrated application and interpretation aspects of the observing system provide the mechanisms for ensuring that the benefits of the observations are realised to the greatest extent possible. They cannot be forgotten in the process of implementing the observing system.

The OOSDP recognised that observations of different physical fields will have different impact on meeting a particular subgoal. To illustrate this they made use of feasibility-impact diagrams to describe the feasibility of observing a particular physical field and the priority of various observed variables in meeting the subgoal's objectives. In some cases the observations appropriate for various regions of the global ocean are different (e.g., SST from drifters where VOS are not present).

The OOSDP set priorities for the elements of the observing systemobservations the basis of their contribution to addressing the subgoals. First priority was given to observations needed for the determination of the global sea surface temperature (SST)and the global surface wind and wind stress, the observations needed for the initialization of ENSO prediction models and verification of their results, and to those needed for the determination of the global change in sea-level. The reader is referred to the OOSDP report for a description of the priorities given other observational requirements. The OOSDP report also illustrates how the observations required to address high priority subgoals can contribute to meeting the requirements of lower priority lower priority, often leading to minimal additional observations to address the latter.

3 - CLIVAR SUSTAINED OBSERVATIONS

Much of the planning of the design of CLIVAR has been subsequent to the work of the OOSDP and, although it is ongoing, the initial design is to be found in CLIVAR Implementation Plan (WCRP, 1998). Unlike WOCE and TOGA, which had time-limited field programs of 5-10 years and which were designed to end after their analysis phase, CLIVAR is essentially an open ended research program that includes programs to examine decadal climate variability and the detection of climate change. As such they require systematic observations that essentially meet the criteria set by the OOSDP for an operational system.

Thus, CLIVAR has recognized the need for **sustained observations** to be carried out for the indefinite future. These have been elaborated in the CLIVAR Implementation Plan (WCRP, 1998) and were at that time were essentially identical to the those specified by the OOSDP as subsequently modified and/or made more precise. though the work of the OOPC. That CLIVAR and GOOS/GCOS have a strong common interest in the maintenance of an ocean observing system for climate is illustrated by their joint organization of this meeting.

There may however remain differences, at least in approach, between the sustained observations of CLIVAR and the ocean climate observation system of GOOS/GCOS. One is that as a research program CLIVAR might give rather different priority to some observations in comparison to others than would GOOS/GCOS, which in principle must give priority to observations that are required to meet defined operational needs such those observations required to initialize ENSO prediction models or to verify the rate of global warming from increasing greenhouse gases. A second difference exists in the way GOOS/GCOS and CLIVAR may be funded in many countries. CLIVAR may be primarily funded through the proposals of scientists to scientific funding agencies to carry out a program of research over a limited time frame. GOOS/GCOS as an 'operational' system requires the long-term commitments of nations to a system of observations that meet their unified global requirements and support their ability to set national and international policies such as under the FCCC.

4 - **THE GOOS/GCOS ACTION PLAN FOR GLOBAL PHYSICAL OCEAN OBSERVATIONS**

The design of the ocean observing system for climate will clearly evolve with time for a variety of reasons, including increased understanding of the climate signal and changing technology. Since its formation, the OOPC has followed a program of increased specification of the details of the required observation system from that specified by the OOSDP as well as pursuing ways to ensure its implementation. An initiative of the OOPC that has already influenced the development of the ocean observing system is the development of the Global Ocean Data Assimilation Experiment (GODAE). It has the general objective "to provide a practical demonstration of real-time global ocean data assimilation in order to provide regular, complete depiction of the ocean circulation, at high temporal and spatial resolution, and consistent with a suite of space and direct measurements and appropriate dynamical and physical constraints" and is described in detail elsewhere in these papers. Profiling floats are seen as essential to GODAE with a sampling density of about 3 times that recommended by the OOSDP.

Regarding the implementation of the ocean observing system for climate, the OOPC and its parent bodies, GOOS and GCOS, have been instrumental in the creation of a new international body for this purpose. All GOOS/GCOS planning documents (e.g. the GOOS Strategic Plan) have recognized the need to build such implementation as much as possible on existing systems and mechanisms, without being explicit as to how this is to be done or on the overall coordination mechanism that is obviously required. Serious consideration of the various options has led the WMO Congress and the IOC Assembly in the spring of 1999 to approve the formation of a new body, the Joint WMO/IOC Technical Commission for Oceanography and Marine Meteorology (JCOMM) to oversee the implementation of the physical observations required by GOOS/GCOS (and CLIVAR). It has been established through the merger of the Commission on Marine Meteorology (CMM) and the Integrated Global Ocean Services System (IGOSS), and is the reporting and coordinating mechanism for all other existing bodies of WMO and IOC concerned with ocean observations and data management. JCOMM will report primarily to the Executive Councils of the WMO and IOC but will also interact directly with the GOOS Steering Committee, the GCOS Steering Committee and the Intergovernmental Committee for GOOS.

Of importance for OCEANOBS99 is not only that concrete steps are being taken to promote and initiate an ocean observing system for climate but also that in preparation for this process an

Action Plan for Global Physical Ocean Observations has been prepared and that this Action Plan includes the latest detailed specification of the observing system for climate. It is this description of the observing system that serves as the basis for the deliberations of OCEANOBS99. It is based on the work of the OOSDP as modified and elaborated by the OOPC.

The Action Plan recognizes that while the scientific rationale for the observing is organized behind the goals and subgoals the OOSDP used in the design of the ocean observing system for climate (OOSC) and listed above, it is the recognized applications that ultimately drive the 'shape' of the requirements While there is some degree of arbitrariness about the way the goals are selected and arranged, the applications are directly linked to recognized societal needs. The applications are:

Atmospheric Prediction. The OOSC is a provider of information to, and a customer for, numerical weather prediction (NWP) products.
Ocean and Climate Prediction. Seasonal-to-interannual climate forecast systems, principally for the El Ni¤o Southern Oscillation (ENSO) phenomenon, exist in both experimental and operational forms. Ocean analysis and coastal ocean forecast systems are also major applications under this theme.
Climate Assessment. The large heat capacity and slow but relentless circulation of the ocean means that the, sometimes confounding, high-frequency noise attached to climate signals of the atmosphere is filtered to some extent by the ocean thus making the signals somewhat easier to detect.
Model Validation. It is important that models faithfully represent, as far as is practical, the actual physical, dynamical and geochemical processes of the ocean. Ocean data are used to check that that is the case.

In view of the broad approach being taken in the Action Plan, two further applications are mentioned explicitly:

Short-range Ocean Prediction. There are many applications related to the prediction of the open ocean, mainly currents and temperature in the upper ocean, on time scales from days to several weeks.
Marine and Sea-state Prediction. Ocean waves (mainly surface), sea-ice monitoring and prediction and high-seas marine forecasts are relatively mature activities in many agencies.

The priorities that are attached to the different requirements are determined in part by a judgement of how relevant that data are for the above applications, and in part by their perceived contribution toward the scientific goals. For each requirement, there may be one or more candidate measurement methods, and the ranking attached to alternative approaches must be determined by how well they address the requirement (some approaches may address several requirements) and by the cost, feasibility and effectiveness of the method.

The Action Plan recognizes that it is important that to understand the connection between the scientific drivers on the one hand, and the desirable characteristics of the data network on the other. The priorities among the different applications, and among the different scientific goals, do evolve, as does the technology used to collect the observations. In some cases, sampling requirements for a particular field may be extremely sensitive to such evolution, in other cases, not.

The Action Plan notes that discussions of applications usually refer to products and outputs. These may be fields in some cases, but often are in a tailored form that is more useful to those exploiting the product. For the scientific goals one is almost always referring to fields (e.g., a SST analysis, or an estimate of global sea level rise); these in fact represent the signals that we want our observing network to yield. In most cases, there are likely to be several useful signals associated with a particular field (e.g., tides, equatorial Pacific dynamic height and climate change sea level rise are all important sea level signals), each with its own characteristic variability.

The real ocean not only contains these signals but also many other variations, sometimes with small amplitude, but not always. We refer to these as noise, though it should be remembered that the division between signal and noise is just an artifact of our particular interests and characterization. Our ideal observing network aims to minimize the errors in our estimate of the signal, or minimize the influence of the noise. The normal strategy is to exceed the sampling rate suggested by the characteristic space and time scales of the signal, and use our knowledge of the noise to assist the signal processing.

Since ocean models and assimilation are usually the preferred signal processing technique, it should also be noted here that the grid resolution of the model is not directly involved in the sampling rate decisions. There may be some indirect influence since, for example, the capabilities of particular models may restrict the signals that can be processed. The more relevant parameters are those used to characterize the statistics and coherences in the assimilation method. Ocean model assimilation systems are, in general, relatively simple compared with our meteorological equivalents. SST analyses, for example, are mostly performed without the aid of any dynamical or physical models. This can be compared with re-analysis estimates of surface wind stress and heat flux where very complex estimation systems are used.

It is also important to appreciate that the sampling requirements are usually met through a mix of data from different platforms (e.g., Advanced Very High Resolution Radiometer (AVHRR), VOS and TAO for SST), and sometimes also from indirect methods. For example, previous analyses may be used to forecast the present state, or other fields may be used (with models) to infer the field of interest (e.g., altimetry for currents). Usually, no one method will provide the desired accuracy for the product. To avoid a method-by-method account of useful accuracies, the concept of a "benchmark accuracy has been introduced.

While the sampling rate is an effective strategy for reducing the (geophysical) noise, the sampling strategy must also address bias and other sources of noise. Data quality is a prime consideration for reducing measurement bias. Quality in turn will depend on the instrument characteristics and any algorithms used to convert the instrument measurement into a geophysical parameter. In some cases instrumental bias may be removed after the fact, so long as the bias has scales that are resolved by an independent data source (e.g., AVHRR corrected by buoys and VOS; ALT sea level trends corrected by in situ gauges). This is sometimes referred to as calibration, but to oceanographers (and meteorologists) calibration usually means checking the signal from an instrument against a "standard" (e.g., a Conductivity Temperature Depth (CTD) sensor and standard seawater for salinity; or a radiometer against a blackbody with known properties). The assumption is then made that this calibration will hold true for the deployment period of the instrument and/or is reliable for other locations.

Bias can also be introduced through aliasing; that is, the sampling rate permits signals of one frequency/wave number to manifest as another signal. Aliasing can distort the amplitude and shape of the signal spectrum, including a shift in the mean.

All these issues make the specification of a sampling requirement difficult, rendered even more so by the fact that our knowledge of the real ocean (which we use to characterize signals and noise) is extremely limited. In the present case a balance must be drawn between the need to stay faithful to the science and what we really understand, and the need to specify requirements which are feasible and meaningful from the point of view of those charged with implementation. OOSDP (1995) focussed on requirements for each sub-goal (the so-called Feasibility- Impact diagrams) and attempted to present a rationale for prioritizing different candidate elements of the observing system.

The Action Plan focuses on requirements for particular fields since, to a large extent, the available implementation mechanisms are arranged that way (TAO for ENSO is a notable exception). It should be noted that OOSDP preferred to leave sampling requirements open-ended if it believed insufficient knowledge existed to make such a recommendation. In some cases that remains so, particularly with respect to global inventories and the deep ocean circulation. In the following we give guides where we think it is reasonable to do so.

The requirements as specified in the Action Plan are given in Annex I. As mentioned previously, these form the last definition of the ocean observing system for climate prior to OCEANOBS99. Summary tables of both space-borne and *in situ* observations are given in Annex II

5 - REFERENCES

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ANNEX I

THE REQUIRED OBSERVING SYSTEM AS SPECIFIED IN THE ACTION PLAN.

These are derived for the most part from the OOSDP (1995) report and several subsequent publications (Smith et al. 1995; Nowlin et al. 1996), but consideration has also been given to re-evaluations by the Ocean Observations Panel for Climate meeting reports (OOPC, 1996, 1997, 1998) and associated activities.

As noted above, we will present the requirements by field, first noting the desired characteristics of the processed signal (output) for different applications. The sampling is presented in terms of a strategy and a set of "benchmark" accuracies (P. Taylor, pers. comm.). The benchmark accuracy is a standard against which measurement accuracies can be compared. Measurements which fall well below the benchmark may not be useful at all, or may require improved technique and/or quality management. On the other hand, measurements with accuracy far greater than the benchmark may have reduced cost-effectiveness. Where appropriate we note specific implications of remote sensing. We also comment on alternative sources of information and perceived trends in the requirements.

The sampling requirements are summarized in Table A, Annex II. Table B, Annex II shows space-based requirements alone, with particular reference to GODAE. GODAE is likely, in general, to be more demanding in terms of spatial and temporal resolution, but with decreased emphasis on the deep ocean and perhaps slightly weaker accuracy requirements

Sea Surface Temperature

Characteristics of the processed signal

- For NWP which supplies stress, heat flux estimates: 0.2-0.5°C on 100 km squares with 3 day resolution. (Note that regional systems and severe weather prediction seek 10-20 km resolution daily (Annex III), and that these are becoming increasingly important for coastal applications (e.g., hurricane forecasts) and some climate applications).
- For ENSO prediction and verification: 0.2-0.3°C at 200 km x 30-100 km scales every 5 days in the tropics. The bias requirement is more severe in the convective regions, less severe in the central to eastern Pacific. Meridional resolution has a high premium attached to it.
- For climate change detection: 0.1 °C on 2-500 km squares monthly.
- Mesoscale and coastal oceanography/GODAE: 0.2°C (relative) 10 km scales daily. Quality and bias is less of an issue, but gradients and features are more important.

The diurnal cycle is a potential source of error for most of these signals.

Sampling strategy and benchmark accuracies

- Use geostationary and polar orbiting satellite data for spatial resolution and to reduce geophysical noise in climate signals (Annex II Table B).
- Use in situ data for calibration and to produce blended products with optimized bias reduction.
- The requirement for remotely sensed SST is 10 km resolution and 3-6 hour sampling, the latter to reduce aliasing error, with 0.1-0.3°C relative error. The temporal sampling implies increased utilization of geostationary platforms. The NWP and mesoscale applications are the dominant determinants of resolution; climate for the error.
- The sampling for *in situ* observations is controlled by the need to remove bias from the satellite product, mainly for climate change applications, but also in the event of unexpected aerosol interference. The best estimate remains at 0.1°C on 500 km squares on weekly time scales and O(25) samples with accuracy }0.5°C. ENSO requires an adjustment in the tropics as suggested by the scales mentioned above.

Indirect sources of information

Virtually none. None of the operational analysis systems use model predictions or assimilation to great effect. It remains a field that is far easier to observe than model. It should be remembered that remotely measured SST is indirectly inferred from radiative measure. There is also no unique definition of SST.

Trends

CLIVAR and GEWEX may require resolution of the diurnal cycle and improved accuracy of products in the tropics (0.1°C). There remain some issues concerning the use of bulk, near-surface and skin temperatures in climate applications. This is likely best addressed through greater use of mixed layer models. Applications requiring accurate high-latitude SSTs might also become more important; satellite sampling is poor in some regions and so in situ programs become more important. (See also the final report of the OOPC/AOPC Workshop on Global Sea Surface Temperature Data Sets, IRI, LDEO, Columbia University, USA, 2-4 November 1998.)

Surface salinity

Characteristics desired of the processed signal

While sea surface salinity (SSS) products remain largely in the research community, the OOSDP expressed a strong desire for improved monitoring of SSS.

Sampling strategy and benchmark accuracies

- One sample per 200 km square every 10 days with an accuracy of 0.1 is the benchmark [the signal to noise ratio is typically not favorable]. The tropical western Pacific and Indian Oceans, and high latitudes are the highest priorities.

Indirect sources of information

Precipitation estimates provide some useful indirect estimates of SSS. In theory, a combination of altimetry and ocean temperature should also be useful for inferring SSS, but this has yet to be demonstrated in practice.

Trends

Retrievals using passive microwave L-band with an accuracy of 0.1-0.2 over 200 km are sought. ESA's SMOS mission is aimed at such accuracy.

There remains the possibility of remotely-sensed SSS, at the threshold level listed in Annex II, Table B. The need for improved salinity networks has been a theme in CLIVAR and in the OOPC, principally because of the significant interest in the tropics and the interest in decadal-to-centennial variations at high latitudes.

Surface wind vectors

Characteristics desired of the processed signal

Estimates come from NWP, from direct analyses of wind data (e.g., the Florida State University (FSU) product) and from products generated directly from remote sensing. Re-analysis products are also popular in the research community.

- For ENSO applications: 5% in direction and 0.5 m/s in speed estimates are required at 5° longitude and 2° latitude horizontal scales monthly. For longer periods the accuracy requirements are slightly weaker, but a global resolution of 2° x 2° is desirable (such products are not used directly for detecting climate change but for driving models studying climate change).
- Many mesoscale, coastal, and some climate applications seek much finer temporal and spatial resolution. Research applications also have demanding requirements.

Sampling strategy and benchmark accuracies

The OOSDP did not give a specific sampling rate, citing the many different applications as one of the mitigating circumstances. The following is a guide:

- 2° x 2° resolution at an accuracy of 0.5-1.0 m/s in the components every 1-2 days is the benchmark for climate applications;
- Daily 50 km resolution at an accuracy of 1-2 m/s daily is the benchmark for mesoscale/GODAE and coastal applications.

Indirect sources of information

Clearly NWP and forecasts based upon previous data are an important source of indirect information, as are the other contemporary atmospheric and ocean surface data (e.g., cloud drift winds; mean sea level pressure (MSLP)). Atmospheric assimilation systems continue to have problems ingesting surface wind data, so direct estimates are essential, particularly in the tropics (e.g., TAO).

Trends

ADEOS/NSCAT showed that estimates of around 2 m/s accuracy every 2 days could be obtained, at resolution of around 50 km. If such an instrument is flying operationally, then the role of in situ data would be more like that of in situ SST data for SST estimates. That is, providing ground truth for bias correction. The reanalysis projects have yielded improved products, which are popular, but which have short-comings with respect to quality and resolution. The demand for higher resolution, particular for cyclones and hurricanes, is growing. There is consensus that at least one operational double swath scatterometer is justified, and an emerging case for two to eliminate aliasing of these high-frequency variations into climate signals.

Surface flux of heat, water

*Characteristics desired of the processed signa*l

- For surface heat flux: 10 W/m2 accuracy over 2° latitude by 5° longitude by monthly bins.
- For precipitation: 5 cm/month over 2° latitude by 5° longitude by monthly bins.

Sampling strategy and benchmark accuracies

- Use flux estimates from NWP/reanalysis projects and adopt the sampling requirements of WWW.
- Use direct calculations based on surface marine data, both satellite and ocean based (e.g. FSU, SOC) with O(50) observations of the main parameters (wind, air temperature, humidity, MSLP, SST) per bin. Specific high priority actions include:
- Improved SST, air temperature, humidity, MSLP, precipitation and absolute wind velocity on selected VOS; •Shortwave and longwave radiometers on selected VOS;
- Satellite-based estimates of radiation and precipitation; and •A number of flux buoys to provide high-quality verification.

Indirect sources of information

There are no direct methods for measuring the net heat and water surface fluxes, though there are methods for measuring some components. NWP takes advantage of many indirect (non-ocean) sources of information. Ocean budget techniques (e.g. TOGA COARE) have proved quite effective for estimating net heat flux; a similar technique can be employed for net water flux based on salinity (water) budgets. Ocean models with assimilated ocean temperature data can also be used to infer surface fluxes.

Trends

As noted above, there is increasing emphasis on the oceanic water budget, so at-sea measurements of precipitation (e.g., from TAO, VOS) are becoming increasingly important. Several methods are available based on satellite data (e.g. TRMM), and high-quality in situ data are needed for algorithm development and calibration. NWP prediction estimates are still plagued by large uncertainties and systematic bias, particularly in those components influenced by cloud cover. Ocean models are extremely sensitive to bias errors, so the sampling strategy must endeavor to provide as much ground truth as possible. This strategy then places a high premium on data quality, and hence on improving the quality of in situ data streams.

Sea Level

The OOSDP report discussed long-term trends and ocean variability needs, but was not specific with respect to the in situ gauges or altimetry. The OOPC, CLIVAR and NOAA, convened a workshop to refine these requirements, in conjunction with GLOSS and its Implementation Plan (1997).

Characteristics desired of the processed signal

- For climate change: annual global sea-level change on large space scales (~ 500 km), with accuracy of around 1-2 mm a year. For estimates of sea surface topography anomalies (for ENSO and ocean variability studies): for 10-30 day periods an accuracy of 2-5 cm and a spatial resolution of:
- •500 km zonal x 100 km meridional in the tropics; •2° x 2° elsewhere.
- For estimates of mesoscale variability: on a 25-100 km square with an accuracy of 2-10 cm every 5 days (see also Table B, Annex II).
- For ocean circulation (estimates of absolute sea level): on a 200 km scale and 2-5cm accuracy (dependent on a gravity mission).

Sampling strategy and benchmark accuracies

- Long-term trends require a dual strategy.

- The *preferred observing strategy* comprises:

- altimetry for global sampling, at approximately 10 day intervals;
- approximately 30 in situ gauges for removing temporal altimeter drift;
- additional gauges at the margins of the altimeter (e.g., continental coasts and high latitudes); and
- a program of geodetic positioning.

- An alternative observing system, proposed due to the lack of guaranteed availability of altimetric data and due to the lack of experience and confidence in the application of altimetry to measuring long-term trends, would comprise

- a globally distributed network of in situ measurements, with similar effect to the GLOSS Long Term Trends (LTT) set of tide gauges; and
- a program of geodetic positioning.

- For large-scale variability, sites for in situ measurements are limited. The TOGA network should be maintained (at higher priority than assigned in OOSDP, 1995), with increased focus on the tropical western Pacific and Indonesian Throughflow, and in the western boundary current regions. The GLOSS Implementation Plan and OOPC/CLIVAR Sea Level Workshop (GCOS,1998) detail priority stations for monitoring large-scale variability. TOPEX/Poseidon (T/P)-class altimetry with 100-200 km resolution and ~2 cm accuracy is also highly recommended. Altimetry, in general, is now rated far more highly than it was at the time of OOSDP (1995).

- Mesoscale variability is only accessible with multiple altimeters, at least one being T/P class. The optimal sampling is at a 25 km scale and an accuracy of 2-4 cm every 7 days.

Indirect sources of information

For long-term trends there are no viable alternatives, though acoustic thermometry may offer some sort of alternative measure. For ENSO monitoring and prediction, there is redundancy between wind, SST, sea level and subsurface temperature; sea level has the advantage of a history stretching back into the 1970's, and the fact that it measures the joint effect of thermal and haline variations. For large-scale variability in general, thermal data offer similar types of information. However their complementarity would seem a more powerful attribute, with sea level measuring the vertically integrated variability, and temperature profiles measuring vertical structure. There is no alternative for mesoscale variability.

Trends

For ENSO prediction, sea level is enjoying a revival, courtesy of TOPEX/Poseidon and improved methods for assimilating sea level information. There is more confidence in altimetry for long-terms trends (c.f. OOSDP 1995). For the mesoscale, the number and type of altimeters required still remains open (see notes in Table B, Annex II). The gravity missions GRACE and GOCE (OOPC, 1998) will provide an opportunity to exploit absolute measures of sea level.

Sea Ice

Desired characteristics of processed signal and available techniques (for climate)

Although sea-ice is a basic component of the climate system, systems to observe sea-ice properties are limited. The limited OOSDP recommendations reflect this situation.

- Sea ice extent: daily 10-30 km resolution is attainable using passive microwave sensors and meets the requirement for large-scale observations at seasonal to interannual time scales but serious problems remain in their interpretation. Sea ice regions vary greatly in character and there is difficulty in establishing algorithms to describe sea ice extent and concentration in the presence of snow, melt water, thin ice, etc. Synthetic aperture radar (SAR) where feasible provides finer accuracy. In situ techniques are largely insignificant for large-scale monitoring.

- Sea ice concentration: 2-5% in sea ice concentration, measured daily, provides a target for microwave sensors at the same spatial scales as for sea ice extent but the same interpretation problems exist.

- Sea ice drift: Measurement of drift as opportunities arise, using buoys and pattern-tracking from remote sensors (SAR, AVHRR).

- Sea ice thickness: 2-500 km scale mapping of ice thickness on monthly time scales with accuracy O(0.2m), using upward-looking sonars and other devices. Sea ice thickness and volume are an important climate variable but are the most difficult to obtain on the large scale..

Other comments

Operational sea ice systems are more advanced in the Northern Hemisphere than in the Antarctic. Work in the Antarctic is largely driven by climate concerns. In the Arctic operational real-time prediction of sea ice is also a major issue. For decadal-to-centennial variability, sea ice extent, concentration and volume are required. Surface salinity and sea-ice export estimates are complementary. For models to be useful for sea ice prediction (on short time scales), good wind data are essential.

There are extensive services for the provision of real-time sea-ice date in the vicinity of the Arctic. In some cases, observational programs have been going for over 50 years.

At this time, GOOS has not fully considered just how these activities should be dealt with. For JCOMM and the several activities that were being covered by CMM, it is clear sea-ice needs to be considered more fully in future versions of this action plan. In the meantime, the requirements set down by WMO will be used as a guide.

Surface waves

Like real-time sea-ice monitoring and prediction, the requirements for surface wave/sea state analysis and forecasting have not been considered in detail by GOOS - Kamen and Smith (1998) examined some of the issues related to present forecasting systems but did not examine the requirements in detail. Within WMO, wind waves have been the province of CMM and there has been an active sub-group on wave modeling and forecasting. It is the published requirements of this Programme that have been added to Table B of Annex II.

A paper has been solicited for the OceanObs99 conference to develop an agreed set of requirements for wind waves. In broad terms, we can expect wind wave requirements.

i. Significant wave height at 100-250 km and 6-12 hour with accuracy 0.5m.

ii. In situ (wave ride buoy) measurements at several locations, preferably in deep water, to verify remote measurements and operational models. These data should be circulated on R/T.

iii. A wind-wave verification scheme whereby in situ data are assembled and made available to operation agencies.

Surface carbon flux

For the most part, these measurements remain within the research community. But the technology exists to use VOS and drifters to collect pCO2 in situ measurements, and satellite ocean colour provides effective proxy data for pCO2.

Sampling strategy and benchmark accuracies

- Seek pCO2 and total CO2 measurements with an accuracy of ñ2-3 æatm and ñ2 æmol respectively.
- In situ sampling is not expected to reach threshold rates, so simply aim for enhanced VOS, mooring and drifter measurements, piggy-backing wherever possible on existing operational systems. Ancillary SST and atmospheric data are important.
- Aim for continuing global satellite ocean colour measurements, at 25-100 km resolution and daily coverage, with 2-10% accuracy.
- Development and validation of satisfactory remote sensing algorithms is important.
- Time-series stations are playing a key role in research and the Ocean Climate Time-Series Workshop (Baltimore, MD, USA, March 1997) co-sponsored by GOOS, GCOS, WCRP and JGOFS (GOOS Report No. 33, GCOS Report No. 41) saw an important role in the future for such Time- Series.

Comments

Some non-biological applications (e.g. tropical ocean modeling) are using ocean colour to estimate opacity. Independently of any non-physical applications, this suggests that there is a good case for adding ocean colour to the list of needed remote sensing techniques.

Upper ocean temperature

In the past, upper ocean thermal networks have largely been the province of research. Making significant parts of these networks operational is one of the key themes of OOPC and remains a high- priority issue.

Characteristics desired of the processed signal

- General large scale requirement is for 2-500 km scale bimonthly global maps of the heat content and the first few vertical modes of variability; and monthly climatologies on 1° resolution. An accuracy of ~ 0.5°C is useful.
- For ENSO forecasts: 1° latitude and 5° longitude resolution every 10 days and over 500m vertically (mixed layer depth (MLD) and ~5 vertical modes) to an accuracy 0.2-0.5°C.
- For mesoscale applications: 25-50 km resolution every 2 days over 500 m with an accuracy of around 0.5°C
- For climate trend, better than 0.1 C/year accuracy.

Sampling strategy and benchmark accuracies

- Maintain TOGA/WOCE broad-scale VOS sampling (1 XBT per months with 1.5° latitude and 5° longitude resolution). Priority to lines with established records, of good quality, and in regions of scientific significance (e.g., tropics, particularly outside the domain of TAO, and the TRANSPAC region).
- Maintain TOGA Pacific network, in particular TAO (OOSDP did not specify part or all of the present array, but did suggest "close to" 1994 levels). Around 4 samples every 5 days per 2° x 15° bin, with 10-15 m vertical resolution is deemed satisfactory.
- Enhanced coverage in the equatorial regions in the vicinity of sharp gradients (e.g. Kuroshio): O(18) sections per year, with 50-100 km resolution.
- Boost routine sampling of the polar regions (at broadcast mode levels)
- Use of profiling floats to implement a truly global observing system. This is a technology that is developing rapidly and real-time data are now available; sampling strategies have yet to be defined for "operational" use but a float profile per 2-300 km square every 10 days might be a feasible target. Argo, developed under the auspices of GODAE, will become the mechanism for developing a strategy for deploying ~ 3000 floats globally for GODAE in the period 2003-5. As such it will serve as a pilot project for the longer term use of profiling floats in the GOOS/GCOS OOS.

Other sources of information

Clearly altimetry offers complementary data. For the tropics, it is feasible a good model plus SST and wind-forcing may be able to forecast subsurface temperature structure with useful skill. However, at the present time, there is no reason to lessen the requirements outlined above. Several groups are using empirical relationships plus assumptions about the T/S relationship to infer sub-surface structure from altimetry (variously known as synthetic or pseudo XBTs). Acoustic thermometry has good potential, particularly for long-term change and in regional modeling. It seems highly unlikely that an in situ solution will be found for the mesoscale applications. Rather, it is likely a mix of moorings, XBTs and profiling floats may be used to pin-down the global, large-scale thermal structure, and a mix of altimetry, SST and colour used to specify the horizontal structure of the mesoscale field.

Trends

Profiling floats, and in particular the Argo initiative, are arousing a great deal of interest and seem to offer the one real chance for global temperature sampling (VOS are limited in terms of geographic coverage, and moorings are better suited to tropical and boundary regions). A program called PIRATA is testing TAO-like moorings in the tropical Atlantic, and the Japanese TRITON program is testing moorings for mid-latitude climate studies, and for Indian Ocean studies. (See also section on Time Series Stations below.)

Heat and Water Transports and Budgets

The OOSDP recognized that observing changes in the ocean circulation and its inventories of heat, fresh water and carbon would require the use of profiling floats, precision altimetry, knowledge of the surface forcing fields, etc. which are discussed elsewhere in this section. In addition, transocean sections at key latitudes and in regions of watermass formation would be essential. The OOSDP report, which was published at the end of 1994, states that, although repeat hydrography and transocean sections are essential, they lacked some urgency as part of the initial ocean observing system because of the global coverage being provided by WOCE and the expected repeat time of five to ten years. The OOPC has not yet reviewed the question of transocean sections and repeat hydrography given the experience of WOCE.

Characteristics desired of the processed signal:

- For the estimates of the variability of meridional heat, fresh water and carbon fluxes, transocean sections are required at key latitudes with station spacing that resolves mesoscale variability, 25-100 km, at specific latitudes and at a repeat time to be determined based on the experience of WOCE.
- For the determination of the changing inventories of heat, fresh water and carbon, additional sections with station spacing appropriate to the sales of variability may be required to supplement the transocean sections for transport estimates.
- For the measurement of water mass formation, sections are at least annually to observed yearly watermass formation and at a station spacing adequate to sample region.

Sampling strategy and benchmark accuracies:

- The sampling strategy, desirable accuracies and operational procedures for deep sea hydrographic observations are fully described in the documentation prepared for WOCE implementation and can be seen in WCRP (1988 a, b) and WOCE (1991), WOCE Hydrographic Programme Office (1994).

Trends

Hydrographic sections remain the fundamental tool for observing changes in watermasses and the climatically important meridional ocean transport of heat, fresh water and carbon. The availability of profiling floats measuring T and S, moored profiling instruments, and precision altimetry combined with the increasing power of ocean dynamical models and techniques for assimilating observations could lead to more comprehensive approaches in the future.

Upper ocean salinity

Upper ocean salinity remains primarily an experimental field in terms of applications. An exception for the OOSC are the upper ocean segments of the hydrographic data to be obtained from transocean and repeat sections as well as time series stations for which the techniques of obtaining accurate salinity data are well established. Expendable CTDs (XCTDs) on selected VOS lines and perhaps also high density lines, and salinity sensors on some TAO moorings, were recommended by OOSDP.

Characteristics desired of the processed signal

Monthly subsurface profiles with an accuracy of 0.1 on 3° squares would serve most large-scale purposes.

Sampling strategy and benchmark accuracies

A profile per month per 3° square at better than 0.02 accuracy is a benchmark.

Trends

There are suggestions that sub-surface salinity is important for ENSO forecasting and CLIVAR Upper Ocean Panel has given high priority to enhanced sampling.

Again, the profiling floats of Argo would seem to offer the best opportunity for increased global coverage, though there remains some questions about the stability of the salinity sensor. Current plans suggest Argo will deliver in excess of 50,000 profiles of 5 to 2.000m. Studies using a combination of altimetry, sea surface salinity and ocean temperature have shown promise for estimating salinity (Reynolds, pers. comm.). CLIVAR is intent on pursuing a better description of the hydrological cycle which implies greater emphasis on subsurface salinity.

Ocean currents

The OOSDP (1995) report was vague with respect to the need for velocity measurements, principally because there were few, if any, operational applications. They recommended a minimal array of current meter moorings and VOS acoustic doppler current profilers (ADCPs) for validation of models as well as gathering surface drift data from buoys.

Sampling strategy and benchmark accuracies

At the surface: a global surface drifter program can yield very good surface current estimates. The benchmark is global coverage of one drifter measurement per 600 km square per month, with current- following accuracy of around 2 cm/s which would give estimates of the mean velocity good to 10% of the eddy variability.

For the subsurface: a minimal array for model verification. Accuracies of the order 5 cm/s for monthly averages would be the benchmark for the tropics.

Trends:

Several groups are experimenting with surface current estimates derived from altimetry and from SST- pattern following techniques. GODAE will place greater premium on surface velocity data since its short-range forecasting goal includes estimates of the surface currents.

There is considerable interest in the prospects from the gravity missions GOCE and GRACE. GOCE to be launched in the period 2001-3 will provide geoid accuracy of ~1.0 cm on scales of 500km and ~0.1 cm on scales of 1000 km. GRACE to be launched after 2003 will provided geoid accuracy of `2.0 cm on 100 km scales and better than 1.0 cm on 1000 km scales. If successful, these missions would allow the calculation of absolute surface geostrophic currents on smaller scales (down to mesoscale at mid- latitudes) and greater accuracy than presently available, and enhance the already substantial impact of satellite altimetry.

Time Series Stations

Time series stations do not fit neatly into the above field-by-field description for the OOSC. They provide long records with temporal resolution that is short compared with the characteristic dominant variability, as well as co-located measurements of several different variables, sometimes including chemical and biological parameters. These attributes make such data sets powerful and complementary to the data mentioned previously, particularly for physical and phenomenological studies. The Ocean Time Series Workshop (IOC, 1997) discussed the merits of time series as a strategy for both GOOS/GCOS and CLIVAR. The CLIVAR Implementation Plan (WCRP-103, 1998) includes a summary of the attributes of 8 existing time-series and attempts to evaluate their relevance to meeting the goals of CLIVAR. The OOPC has yet to attempt this with regard to the OOS. However, it can be noted that the Time Series Workshop presented a strong case for continuing the long time series at Bravo and station "S". The TAO array also contains several important long records (e.g. at 110 W) which should be maintained. Station "Papa" is to be the subject of sustained study within CLIVAR and may be another potential site for consideration for the OOS. Others may be equally relevant.

Ocean modeling

As noted at the beginning of this section and in OOSDP (1995), models are essential for the effective and efficient use of observations. Equally, data from the real ocean are essential if a model is to move beyond theory and concept. Ocean data assimilation, or ocean state estimation in the nomenclature of GODAE, is the preferred methodology for merging theoretical knowledge of the ocean (models) with data. Note the data may be ingested through both boundary conditions and adjustments to the sate variables. The development of models is not the purview of JCOMM. However, the end-to-end chain of observation- processing-service inevitably involves models of varying levels of sophistication and so JCOMM must take into consideration the implementation and routine use of models.

Management and oversight

The OOSDP (1995) stressed the importance of scientific involvement in all parts of the data flow, from measurement through to end product. The OOSDP recommended the establishment of an evaluation process, perhaps built around a distributed network of contact points in operational centres, whose prime objective was to ensure that the data gathering, processing and dissemination was consistent with observing system plan. It was important that this evaluation process provided feedback to the sources of the data in regard to quality, timeliness, percentage consumption (that amount of data that were actually ingested), and so on.

The OOSDP all set out several principles for data management:

- the information management system will be built as far as is possible and appropriate on existing systems;
- the information management system should be "operational" (c.f. experimental) in the sense as that for the observational network; •the information management system should be consistent with the objectives, needs and priorities of the scientific design;
- data should be transmitted from instrument platforms to appropriate data centers and made available for further processing as soon after measurement as is feasible and practical;
- quality assurance of data and products should receive high priority to maximize the benefit drawn from the often difficult and expensive ocean measurements;
- the information management system should be user-oriented to ensure that the needs of users, the ultimate sponsors of the observing system, are served well;
- full and open sharing of data and information among the participants and users of the observing system is essential to its successful implementation and operation;
- observing system participants should contribute data voluntarily and with minimal delay to data archival centers which in turn should be able to provide information to users effectively free of charge;
- the observing system will be most effective if practical international standards are developed for all phases of information management;
- information management will be most effective if it is part of the overall monitoring and evaluation process of the system.

ANNEX II - TABLES OF OBSERVATIONAL REQUIREMENTS FOR GOOS/GCOS

Table A

A summary of the *in situ* sampling requirements for the global ocean, based largely on OOSDP (1995), but with revisions as appropriate. These are a statement of the required measurement network characteristics, not the characteristics of the derived field. The field estimates must factor in geophysical noise and unsampled signal. Some projections (largely unverified) have been included for GODAE. More detail is provided in the text (Annex I).

Sampling Requirements for the Global Ocean

Code	Application	Variable	Hor. Res.	Vert. Res.	Time Res.	#samples	Accuracy
A	NWP, climate, mesoscale ocean	Remote SST	10 km	-	6 hours	1	0.1-0.3°C
B	Bias correction, trends	*In situ* SST	500 km	-	1 week	25	0.2-0.5°C
C	Climate variability	Sea surface salinity	200 km	-	10 day	1	0.1
D	Climate prediction and variability	Surface wind	2°	-	1-2 day	1-4	0.5-1 m/s in components
E	Mesoscale, coastal	Surface wind	50 km	-	1 day	1	1-2 m/s
F	Climate	Heat flux	2° x 5°	-	month	50	Net: 10 W/m^2
G	Climate	Precip.	2° x 5°	-	daily	Several	5 cm/month
H	Climate change trends	Sea level	30-50 gauges + GPS with altimetry, or several 100 gauges + GPS	-	monthly means		1 cm, giving 0.1 mm/yr accuracy trends over 1-2 decades
I	Climate variability	Sea level anomalies	100-200 km	-	10-30 days	~ 10	2 cm
J	Mesoscale variability	Sea level anomalies	25-50 km	-	2 days	1	2-4 cm
K	Climate, short-range prediction	sea ice extent, concentration	~ 30 km	-	1 day	1	10-30 km 2-5%
L	Climate, short-range prediction	sea ice velocity	~ 200 km	-	Daily	1	~ cm/s
M	Climate	sea ice volume, thickness	500 km	-	monthly	1	~ 30 cm
N	Climate	surface pCO_2	25-100 km	-	daily	1	0.2-0.3 µatm
O	ENSO prediction	T(z)	1.5° x 15°	15 m over 500 m	5 days	4	0.2°C
P	Climate variability	T(z)	1.5° x 5°	~ 5 vertical modes	1 month	1	0.2°C
Q	Mesoscale ocean	T(z)	50 km	~ 5 modes	10 days	1	0.2°C
R	Climate	S(z)	large-scale	~ 30 m	monthly	1	0.01
S	Climate, short-range prediction	$\underline{U}$(surface)	600 km	-	month	1	2 cm/s
T	Climate model valid.	$\underline{U}$(z)	a few places	30 m	monthly means	30	2 cm/s

Table B

Ocean Remote Sensing Requirements

The requirements include consideration of climate applications as determined by the OOPC and ocean forecasting/estimation as determined by GODAE. The requirements beyond the climate module have not been detailed here

OBSERVATIONS				OPTIMIZED REQUIREMENTS				THRESHOLD REQUIREMENTS			
Code	**Application**	**Variable**	**Type**	**Horizontal scale (km)**	**Cycle**	**Time**	**Accuracy**	**Horizontal scale (km)**	**Cycle**	**Time**	**Accuracy**
ALTIMETRY											
A	Mesoscale Variability	Sea Surface Topography	input	25	7 days	2 days	2 cm	100	30 days	15 days	10 cm
B	Large-scale Variability (seasonal, tides, gyres)	Sea Surface Topography	input	100	10 days	2 days	1 cm	300	10 days	10 days	2 cm
C	Mean Sea Level E Variations	Sea Surface Topography	input	200	decades	10 days	1 mm/year	1000	decades	10 days	5 mm/year
D	Absolute Circulation Heat Transport	Sea Surface Topography	input	100	N/A	N/A	1 cm	500	N/A	N/A	5 - 10 cm
E	Geoid Estimation	Geoid	Base	100	N/A	N/A	2 cm	500	N/A	N/A	~ 1 cm

Footnotes:

A - requires wave height + wind (EM bias correction) measured from altimeter, water vapor content measured from on board radiometer, and ionospheric content / measured from 2 frequency. In addition, A requires adequate sampling: at least 2, and better 3, satellites simultaneously.

B - requires in addition, precise positioning system with an accuracy of 1-2 cm for a spatial resolution of 100 km.; need to address aliasing from solar tides with non-sun-synchronous orbits.

C requires, in addition, precise monitoring of transit time in the radar altimeter

A,B, C require repeat track at ± 1 km to filter out unknowns on geoid as well as long lifetime, continuity, cross calibration.

D requires absolute calibration.

E requires *one-off* missions with both high- and broad-resolution determination

Table B - Ocean Remote Sensing Requirements *(continued)*

OBSERVATIONS				OPTIMIZED REQUIREMENTS				THRESHOLD REQUIREMENTS			
Code	**Application**	**Variable**	**Type**	**Horizontal scale (km)**	**Cycle**	**Time**	**Accuracy**	**Horizontal scale (km)**	**Cycle**	**Time**	**Accuracy**
SURFACE WIND VECTORS											
F	Wind-forced Circulation	Wind field	input	25	1 day	1 day	1-2 m/sec. 20°	100	7 days	7 days	2 m/second 30°
SEA SURFACE RADIATIVE											
G	Ocean/ Atmosphere coupling	Sea Surface Temperature (Radiometer)	input	10	6 hours	6 hours	0.1 K (relative)	300	30 days	30 days	1 K
H	Ocean Forcing	Short wave irradiance	input	200	1 day	1 day	15 W/m^2	500	7 days	7 days	20-30 W/m^2
REMOTE SALINITY											
I	Circulation and Water Transport	Salinity	input	200	10 days	10 days	0.1 PSU	500	10 days	10 days	1 PSU
SEA ICE											
J	Ice-Ocean Coupling	Sea Ice Cover	input	10	1 day	3 hours	2%	100	7 days	1 day	10%
OCEAN COLOUR											
K	Upwelling to Recirculation	Ocean Colour Signal	input	25	1 day	1 day	2%	100	1 day	1 day	10%
SURFACE WAVES											
L	Sea State Prediction	Significant Wave Height	input	100	3 hours	3 hours	0.5 meters	250	7 days	12 hours	1 meter
M	Sea State prediction	Period and Direction	input	10	1 hour	2 hours	½ second 10°	30	6 hours	4 hours	1 second 20°

F Wind field requirements for sea state determination normally exceed sampling requirements for wind forcing altimeter

G requires high resolution sea surface temperature: new geostationary satellite + combination with low satellite.