Annual Report
on the
Ocean Observing System for Climate
FY 2006

Program Plan For Building a Sustained Ocean Observing System for Climate

Office of Climate Observation, Climate Program Office

National Oceanic and Atmospheric Administration

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Program Plan
For
Building a Sustained Ocean Observing System for Climate
Office of Climate Observation
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Overall Summary

The mission of the Office of Climate Observation is to build and sustain a global climate observing system that will respond to the long term observational requirements of the operational forecast centers, international research programs, and major scientific assessments. Although the U.S. Climate Change Science Program (CCSP) has identified the critical need for the federal government to deliver regular reports documenting the state of Earth's climate, an observing system does not presently exist that is capable of accurately documenting climate variability and change. Through this program plan NOAA will develop the infrastructure necessary to build, with national and international partners, the ocean component of a global climate observing system and to deliver regular reports on the adequacy of the system in documenting the ocean's contribution to climate.

1.0 Base Program

1.1 Key activities currently carried out by NOAA for this strategy area: Over the past decade NOAA has worked with national and international partners to begin building a sustained global ocean system for climate, focusing first on the tropical Pacific, and expanding to the Atlantic and the Indian Oceans. It is now well understood that documenting and forecasting climate will require continuous measurements from space along with the instrumenting of the entire global ocean. The present international effort is about 57% of what will ultimately be needed for the global system. NOAA presently maintains approximately 50% of the *in situ* networks and 30% of the space components and is committed to the goal of providing at least 50% of the composite system over the long term.

The existing foundation is comprised of twelve complementary *in situ*, space based, data and assimilation subsystems: 1) Global Tide Gauge Network; 2) Global Surface Drifting Buoy Array; 3) Global Ships of Opportunity Network; 4) Tropical Moored Buoy Network; 5) Argo Profiling Float Array; 6) Ocean Reference Stations; 7) Ocean Carbon Monitoring Network; 8) International Arctic Ocean Observing System; 9) Dedicated Ship Operations; 10) Satellites for Sea Surface Temperature, Sea Surface Height, Surface Vector Winds, Sea Ice, and Ocean Color; 11) Data and Assimilation Subsystems, and 12) System Management and Product Delivery. The system design is illustrated in Figure 1. This is an international effort. The system illustrated in Figure 1 represents the common goals and objectives of the international Global Climate Observing System (GCOS), the Global Ocean Observing System (GOOS), the Joint WMO/IOC Technical Commission for Oceanography and Marine Meteorology (JCOMM), the Global Earth Observation System of Systems (GEOSS), the U.S. Integrated Ocean Observing System Global Component (IOOS), and well as NOAA.

The plan is being advanced by NOAA via matrix management within the Climate Goal. Implementation of the in situ networks is through distributed centers of expertise at the NOAA Research laboratories, the National Ocean Service Center for Operational Oceanographic Products and Services, the National Data Buoy Center, and the university laboratories that have developed the instruments and techniques. The space and data components are centered in the NOAA Environmental Satellite, Data and Information Service. The space components are being advanced via other NOAA program planning; they are described here because of their central role in global observation but they are not detailed in this plan. The focal point for developing global ocean data assimilation capabilities is the Geophysical Fluid Dynamics Laboratory in partnership with the National Centers for Environmental Prediction and university-based applied research centers. The system management functions are focused in the Office of Climate Observation.

1.2 Budget and funding history for each of the major activities ($K)

Network	**FY02**	**FY03**	**FY04**	**FY05**	**FY06**	**FY07**
Tide Gauge Stations	670	710	970	1196	1177	1196
Drifting Buoys	1699	2077	2769	3130	3427	3130
Tropical Moored Buoys	3175	3175	3625	4360	3094	3329
Ships of Opportunity	1960	1903	2487	2907	2776	2804
Argo Profiling Floats and Gliders	7149	9881	9984	9640	9530	8714
Ocean Reference Stations	1712	2082	2998	2995	3958	5148
Ocean Carbon Networks	1478	2204	2875	3521	3482	3326
International Arctic Ocean Observing System	1937	4659	3988	5325	5237	4031
Dedicated Ship Time	0	626	523	92	542	570
Data & Assimilation Subsystems	1286	1323	1487	1418	1331	1036
Service Argos Data Processing	813	480	1525	1408	823	1143
Product Delivery, Analysis/Reanalysis	578	638	896	1982	2048	2448
Institutional Infrastructure	726	753	1369	1456	811	1739
Lab support infrastructure (AOML, PMEL)	13100	13100	13100	13100	13100	13325
NDBC TAO/PIRATA operations	0	0	0	0	3200	3200
Global Systems Total	**36283**	**43611**	**48596**	**52530**	**54536**	**55139**

2.0 Statement of Need

The *Second Report on the Adequacy of the Global Observing System for Climate in Support of the UNFCCC* (2003) concludes "there has been progress and improvement in the implementation of global climate observing systems since the first report, especially in the use of satellite information and in the provision of some ocean observations. At the same time, the Report notes that the global terrestrial networks remain to be fully implemented; the ocean networks lack global coverage and commitment to sustained operations; and the atmospheric networks are not operating with the required global coverage and quality. The Report concludes, in agreement with the IPCC, that there remain serious deficiencies in the ability of the current global observing systems for climate to meet the observational needs of the UNFCCC. …Without urgent action to address these findings, the Parties will lack the information necessary to effectively plan for and manage their response to climate change."

The Report goes on to note "new technology developed and proven by the ocean climate programs of the 1990s has allowed the ocean community to design and commence implementation of an initial ocean climate observing system that is well focused on the UNFCCC needs. The first priority is the full implementation of this system together with its associated data, analysis and product capabilities."

In response to the Adequacy Report, the international community published the GCOS *Implementation Plan for the Global Observing System for Climate in support of the UNFCCC* (GCOS-92) in October 2004. This implementation plan details the actions needed to achieve global coverage by the ocean networks. The system put in place for climate will also support global weather prediction, global and coastal ocean prediction, marine hazard warning, marine environmental monitoring, and many other non-climate users.

This program plan is founded on the international design noted in GCOS-92; it is illustrated in Figure 1. Other requirement drivers include the CCSP Strategic Plan expressing need for "complete global coverage of the oceans with moored, drifting, and ship-based networks," the Ocean Research Priorities Plan requirement to deploy "a robust ocean observing system that can describe the actual state of the ocean", and the US National Oceanographic Partnership Program's *First U.S. Integrated Ocean Observing System (IOOS) Development Plan* which lists as a primary objective: "Continue implementing the global ocean-climate component of the IOOS (important for addressing the goals of climate change, maritime operations, and natural hazards)." NOAA's contribution to global implementation is represented in the program budget and the progress to date is illustrated in Figure 2. Implementation of this program plan will demonstrate to the world community that the United States is intent on taking immediate action to address the Second Adequacy Report findings, is willing to play a leadership role in achieving global coverage of the ocean networks, and is committed to sustained operations.

2.1 Program organization within NOAA: The NOAA Climate Goal is organized into five Programs: 1) Climate Observations and Analysis; 2) Climate Predictions and Projections; 3) Climate Forcing; 4) Climate and Ecosystems; and 5) Regional Decision Support. This plan describes the "ocean sub-capability" of the Climate Observations and Analysis Program.

2.2 Input from NOAA leadership related to this strategy: This program plan addresses NOAA's Strategic Plan, Climate Strategies, and the Annual Guidance Memorandum. In particular:

- Strategic Plan: Describe and understand the state of the climate system through integrated observations, analysis, and data stewardship.
- Climate Strategies: Improve the quality and quantity of climate observations, analysis, interpretation, and archiving by maintaining a consistent climate record and by improving our ability to determine why changes are taking place.
- Annual Guidance Memorandum: The Integrated Ocean Observing System (IOOS) must be developed as a major component of the U.S. contribution to the Global Earth Observation System of Systems (GEOSS).

2.3 External constituent input related to the strategy: In 2001 the U.S. GOOS Steering Committee conducted a formal review of the 2001 version of this program plan. The review panel included international representatives of the IOC, IGOS, CLIVAR, WOCE, OOPC, GODAE, and JCOMM as well as partner agencies within the United States – NASA and NAVOCEANO. The panel demonstrated strong overall support for the plan. U.S. GOOS urged NOAA to implement the plan with the following additional recommendations:

1. The need for a management plan – An effort of the proposed magnitude must be integrated, organized, and managed as a system in order to be effective. The management plan should define an orderly decision making process with management accountability that is understood by other agencies and by customers. A single NOAA point of responsibility and authority is very desirable. (Sections 7.0–7.8 achieve this recommendation.)
2. The need for a data and information management budget. (Section 6.12 achieves this recommendation.)
3. The need for improved ocean products – evaluation and delivery. (Sections 7.0-7.8 achieve this recommendation.)
4. The need for transition to operations of precision altimetry. (Section 6.11 achieves this recommendation.)
5. The need for ocean carbon monitoring to be better defined. (Section 6.8 achieves this recommendation.)
6. The need to deal with dedicated ship time issues. (Section 6.10 achieves this recommendation.)

2.4 Relevant Congressional input or guidance related to the strategy area: The FY03 Senate Committee on Appropriations Report "reaffirms its support for the establishment of an integrated, interagency ocean and coastal observing system … and requests the submission of a plan to implement such a system." The National Oceanographic Partnership Program's Ocean.US office responded to this Congressional request on behalf of the contributing agencies by publishing in 2005 the *First U.S. Integrated Ocean Observing System (IOOS) Development Plan*. The observation system detailed in this program plan forms the nucleus of the Global Component of the U.S. Integrated Ocean Observing System.

3.0 Program Initiative

3.1 Overall strategy for addressing deficiencies outlined in the Statement of Need Section. The strategic approach underlying this program plan is as follows:

- Build the long-term ocean component of the observing system in the context of a comprehensive, multi-year, climate program. Improved marine and coastal forecast services will be immediate byproducts.
- Set an initial 2000-2010 timeline for phased implementation (the time line has now been extended to 2014 because of budget realities).
- Establish accountability by defining specific objectives and performance measures.
- Define an "initial observing system design" that will accomplish the objectives and performance measures. Identify annual milestones to complete the initial system over the time line. Emphasize that the initial design is our best guess at this time – it must be evolutionary as knowledge and technology advance.
- State the obvious – a global observing system cannot be built with existing budgets. Estimate the annual funding needed to achieve the identified milestones. Estimate that NOAA will implement about 50% of the global system.
- Work with national and international partners to achieve 100% completion.

Although NOAA's marine and coastal services and the mission services of the other agencies and nations will benefit from this plan, and are considered throughout, accomplishing NOAA's climate mission is the fundamental driver. The scientific foundations come from the Climate Variability and Predictability program and the Global Carbon Cycle program. The programmatic drivers come from the Climate Observations and Analysis Program, the Climate Predictions and Projections Program, the Climate Forcing Program, and the Climate & Ecosystems Program. It is not the intent of the plan to provide all of the observations needed by these programs but to provide a baseline observing system, to be sustained over the long term, that can be built upon where needed to answer specific questions. This baseline system looks for efficiencies to be gained by utilizing common platforms/sites/data infrastructure for several objectives in parallel, and seeks to foster a system approach to effective international organization of complementary in situ, satellite, data, and modeling components of climate observation.

Priorities for implementation are now in place based on the concept of extending the building blocks that have already been put in place, and on the international GCOS Implementation Plan (GCOS-92) which has been specified as the ocean baseline for GEOSS. NOAA will work to implement the specific actions called for in GCOS-92, particularly those actions assigned to the Joint WMO/IOC Technical Commission for Oceanography and Marine Meteorology (JCOMM). JCOMM is NOAA's principal intergovernmental linkage to international implementation.

3.1.1 NOAA context*:* This plan supports NOAA's strategic goal to monitor and observe: "NOAA will invest in needed climate quality observations and encourage other national and international investments to provide a comprehensive observing system in support of climate assessments and forecasts." The plan details how NOAA will achieve one element of that strategic goal – implementation of the sustained *in situ* ocean component of the global climate observing system – and this plan details how NOAA will implement the Global Component of the Integrated Ocean Observing System (IOOS).

3.1.2 Interagency context: The observational objectives of NOAA's climate program and those of the CCSP are essentially identical and the ocean observing system architecture detailed below will be implemented by NOAA within the framework of, and as an element of, the CCSP. At the same time the observing system must be advanced in support of climate services, it must also be advanced in response to a national demand for the ocean agencies to coordinate implementation of a U.S. contribution to the Global Ocean Observing System. It is recognized that an effective global ocean observing system can be achieved only through continuing interaction among all national (and international) partners. In this context, NOAA will provide a significant contribution to the Global Component of the Integrated Ocean Observing System (IOOS). Implementation will be coordinated with the National Oceanographic Partnership Program agencies.

3.1.3 International context: The observational component of climate services has by far the greatest opportunity and necessity for international collaboration. A global observing system by definition crosses international boundaries and the potential exists for both benefits and responsibilities to be shared by many nations. The system described below is based on the international design of, and is an U.S. contribution to GCOS-92. The observing system projects that make up the climate component have been developed, and will continued to be evolved, organized and managed, in cooperation with the international implementation panels of the Joint IOC/WMO Technical Commission for Oceanography and Marine Meteorology (JCOMM), and with scientific guidance from the GCOS/GOOS/WCRP Ocean Observations Panel for Climate (OOPC).

3.2 Cost and schedule for each investment

3.2.1 Cost Methodology

Cost estimates are derived by observing platform (buoy, float, shipboard system, tide gauge station, etc.) times the number of platforms maintained per year based on the cost of procuring hardware and software, calibrating sensors, deploying/installing sensors, providing satellite transmission of real time data, quality control and archival of processed data. Due to the harsh environment, most ocean platforms are considered expendables, not capital equipment. Continual purchase of replacement sensors, rebuilding, and reseeding of the arrays are required such that annual maintenance costs in the out years are estimated to be the same as the initial cost of establishing a new platform/system in the first year. For analysis work, the annual costs are intellectual (people) and computer resources.

The implementation of the global ocean observing system is based on partnerships. On average, NOAA provides about half of the global requirement, with partner agencies in the U.S., primarily NSF, and partner countries (presently 64 other countries) providing the other half. For some systems, e.g., drifting buoys, NOAA provides more than half, and for some systems, e.g., tide gauge stations, NOAA provides less than half. This is based on historical partnerships over the past 10 years. A report of contributions by countries is maintained at www.jcommops.org/network_status.

Accounting within the ocean program is by "project." Each project files an annual report documenting progress of the previous fiscal year and outlining the work plan for the coming fiscal year. A budget sheet(s) is part of each project report and details the costs required to sustain the project – personnel, supplies, travel, contracts, etc. Cost estimates are based on these documented expenditures. The project reports are compiled each year into an *Annual State of the Climate* report (a special edition of the *Bulletin of the American Meteorological Society)* and an annual *State of the Ocean Observing System for Climate* report. Together these two annual reports document the changing state of the ocean and the observing system. Copies of the annual reports are available from climate.observation@noaa.gov. An electronic file is available at www.oco.noaa.gov.

3.2.2 Schedule: The summary below is based on the 100% requirement documented in the Climate Observations and Analysis Program Operating Plan (POP). Detailed cost estimates are updated annually in the spring as part of the mini-POP focusing on the oceans sub-capability.

The ocean observing system needs to be completed as soon as possible in order to provide the fundamental measurements needed to deliver credible climate forecasts and assessments. The executable gap is limited, however, by NOAA's ability to implement new system expansions with available management and infrastructure capabilities. The maximum budget increase per year that can be accommodated is estimated to be $16.8 million. A steady ramp of $16.8 million increase per year therefore describes the optimum multi-year plan to reach 100% capability. The 100% capability budget is estimated using this optimum multi-year ramp. This summary is based on actual budgets through FY07 (see section 1.2 for historical budgets), the President's budget for FY08, and the executable ramp of $16.8 million per year through FY14. Summary:

($M)	FY05	FY06	FY07	FY08	FY09	FY10	FY11	FY12	FY13
System annual operating cost	51.2	53.2	55.1	57.8	63.3	80.0	96.9	112.5	128.3

4.0 Program Goal and Objectives

4.1 Goal: The goal of this plan is to build and sustain the ocean component of a global climate observing system that will respond to the long-term observational requirements of the operational forecast centers, international research programs, and major scientific assessments.

4.2 Objectives: The ocean is the memory of the climate system and is second only to the sun in effecting variability in the seasons and long-term climate change. It is estimated that the ocean stores 1000 times more heat than the atmosphere, and 50 times more carbon. Eighty-seven percent of the rain and snow that water our Earth comes directly from the ocean. Changing sea level is one of the most immediate impacts of climate change. Additionally, the key to possible abrupt climate change may lie in deep ocean circulation.

Accordingly, the objectives of the sustained ocean observing system for climate are to:

1) Document long-term trends in sea level change;
2) Document ocean carbon sources and sinks;
3) Document the ocean's storage and global transport of heat and fresh water; and
4) Document the ocean-atmosphere exchange of heat and fresh water.

This implementation plan will provide a composite global ocean observing system of complementary networks that includes: 1) deployment and maintenance of observational platforms and sensors; 2) data delivery and management; and 3) routine delivery of ocean analyses. This end-to-end ocean system will provide the critical "up-front" information needed for climate forecasting, research, and assessments – continuous, long term, climate quality, global data sets and a suite of routinely delivered ocean analyses. At the same time, the system will provide real-time data to serve the needs of NOAA's marine and coastal forecast and warning missions and the needs of the other agencies in accomplishing their missions.

5.0 Performance Measures

In order to achieve the four objectives, the system must accurately measure: 1) sea level to identify changes resulting from climate variability and change; 2) ocean carbon content every ten years and the air-sea exchange seasonally; 3) sea surface temperature and surface circulation to identify significant patterns of climate variability; 4) sea surface pressure and air-sea exchanges of heat, momentum, and fresh water to identify changes in forcing functions driving ocean conditions and atmospheric conditions; 5) ocean heat and fresh water content and transport to identify where anomalies enter the ocean, how they move and are transformed, and where they re-emerge and interact with the atmosphere; and identify the essential aspects of thermohaline circulation as well as the subsurface expressions of the patterns of climate variability; and 6) sea ice thickness and concentrations. These parameters represent the specific "outcomes" of the global ocean observing system for climate.

The sampling requirements for these parameters have been documented by international GOOS and GCOS. Table 1 lists the requirements as presented at the international OCEANOBS 99 Conference in Saint-Raphael, France. It represents the best estimates of the international community at this time.

The Proceedings of OCEANOBS 99 and the final report from the conference, *Observing the Ocean in the 21st Century*, outline implementation strategies for achieving these sampling requirements. Additionally, for documenting sea level variability and change, the implementation strategy is further defined in the *International Sea Level Workshop Report*, 1998; and for documenting ocean carbon sources and sinks the implementation strategy is defined in the *Large Scale CO_2 Observing Plan: In Situ Oceans and Atmosphere (LSCOP)*, 2002. The latter plan is for the United States only, but is a vital component of the Global Ocean Observing System (GOOS) as outlined by the Integrated Global Carbon Observing system Implementation Plan (Appendix A). The scientific objectives are also important for international research programs such as the Surface Ocean and Lower Atmosphere Study (SOLAS) and Integrated Marine Biogeochemistry and Ecosystem Research (IMBER) program (refs) and is coordinated with other ocean carbon studies through the International Ocean Carbon Coordination Project. These programs will be implemented in the United States as components of the U.S. SOLAS and the Ocean Carbon and Climate Change (OCCC) programs.

Based on the requirements in Table 1 and the implementation strategies defined in the foundation documents listed in Appendix A, the system's effectiveness in meeting the objectives will be gauged by the performance measures listed below. The goal is to reduce measurement errors to limits acceptable for documenting climate scale changes in the ocean. The reduction of measurement error depends directly on achieving complete global coverage by the *in situ* networks, in conjunction with continuous satellite missions. The present number of data buoys, floats, ships, and tide gauge stations is not adequate. Global coverage can be achieved only by deploying additional platforms to fill the gaps.

The "outcome" performance measures detailed below will quantitatively demonstrate why 100% global coverage is necessary to adequately document climate variability and change in the ocean. These performance measures, including the percentage of global coverage, will provide a quantitative way to evaluate the effectiveness of the ocean observing system for delivering climate outcomes.

Performance Measures:

5.1 Increase percentage of in-situ global integrated ocean observing system (IOOS) implemented. (CPM)

- PM short title: *Global Ocean Observing System - IOOS Implemented*
- Indicator: *% Implemented against international plan*
- Unit of Measure: *Cumulative total % completed.* (Based on combined units deployed for all eight (8) observing system networks)
- Type: *Outcome*
- Baseline FY/Target: FY 03/45%
- Targets FY 07-14: Refer to Tables above.
- 100% FY/Target: FY 14/100%
- Reporting Frequency: Quarterly
- Source of data: Office of Climate Observation (OCO)
- Person Reporting Progress on the Target: Krisa Arzayus, OCO
- Approving Individual: Mike Johnson, OCO
- State of Development: Well Developed.
- Explanation: This measure documents NOAA's progress in deploying an internationally agreed upon ocean observing system for climate. Original international and U.S./NOAA 100% target completion was FY 10. 100% Target completion is now FY 14. Delays due to funding profiles, executable gap: $16.8M/yr. Execution is limited by ability to augment implementation work with existing infrastructure.

- Verification: The data is verified by the NOAA OCO working in partnership with the GOOS Project Office at UNESCO in Paris.
- Baseline/Target Metadata: This measure is calculated by tracking observing system network deployments (most networks are tracked online) and comparing progress against the planned deployments for each network.

5.2 Reduce the error in global measurement of sea surface temperature. (GPRA and CPM)

- PM short title: *Sea Surface Temperature*
- Indicator: *Reduce Error* (Potential satellite bias error.)
- Unit of Measure: *Degrees Celsius (*ºC*)*
- Type: *Outcome* {Global sea surface temperature analysis (maps)}
- Baseline FY/Target: FY 03/0.7ºC
- Targets FY 07-14: Refer to Tables above.
- 100% FY/Target: FY 10/0.3ºC
- Reporting Frequency: Quarterly
- Source of Data: Office of Climate Observation (OCO)
- Person Reporting Progress on the Target: Richard W. Reynolds, NCDC
- Approving Individual: Mike Johnson, OCO
- State of Development: "Well Developed"
- Explanation: 100% Target can be reached by the end of FY 10 with the Current Budget profile.

Sea surface temperature is the <u>single most important ocean variable</u> for determining the heat and water cycles. It is also a critical variable for determining global ocean carbon fluxes. Achieving an acceptable error target of 0.3 ºC (within the acceptable range specified by GCOS) is the <u>number one priority of the ocean program</u>.

- Verification: The data are verified by the NOAA National Climatic Data Center.
- Baseline/Target Metadata: The difference between satellite measurements and surface measurements is calculated for all 1000 kilometer square regions of the global ocean surface. The differences for all regions are then averaged. The average difference produces a single indicator number for the global ocean. That indicator is calculated monthly and graphed in a time series.

5.3 Number of ocean climate state variables reported. (CPM)

- PM short title: *Ocean State Variables Reported*
- Indicator: *Essential Ocean Variables Reported* (15 essential climate variables listed in the international GCOS Adequacy Report: a) surface: sea surface temperature, sea surface salinity, sea level, sea state, sea ice, currents, ocean color, carbon dioxide partial pressure; b) sub-surface: temperature, salinity, currents, nutrients, carbon, ocean tracers, phytoplankton)
- Unit of Measure: *Cumulative Total Number reported.*
- Type: *Output* (Scientific information derived from observation of the global ocean.)
- Baseline FY/Target: FY 03/2
- Targets FY 07-14: Refer to Tables above.
- 100% FY/Target: FY 14/15
- Reporting Frequency: Annual

- Source of data: Office of Climate Observation (OCO)
- Person Reporting Progress on the Target: Krisa Arzayus/Joel Levy, OCO
- Approving Individual: Mike Johnson, OCO
- State of Development: "Well Developed"
- Explanation: 100% Target is FY 14 for regularly reporting the 15 essential ocean variables.

All climate variables need to be analyzed routinely, with error bars, even before the observing system is completed, to reduce the measurement errors to acceptable limits. Consequently this PM contributes to "a predictive understanding of the global climate system on time scales of weeks to decades with quantified uncertainties sufficient for making informed and reasonable decisions." The essential climate variables describe the ocean's contribution to Earth's climate. The State of the Climate Report quantify uncertainties in our present understanding of the climate, and thus help quantify how well the global ocean observing system is doing its job and how the system needs to evolve in order to reduce the uncertainties.

- Verification: Peer review prior to publication. Analyses that are not scientifically sound will not be published.
- Baseline/Target Metadata: N/A

5.4 Reduce the error in global measurement of sea level change.

- PM short title: *Sea Level*
- Indicator: *Reduce Error* (Difference between tide gauge measurements and satellite altimeter measurements of sea level trend.)
- Unit of Measure: *mm/yr*
- Type: *Outcome*
- Baseline FY/Target: FY 06/5.1 mm/yr
- Targets FY 07-14: Refer to Tables above.
- 100% FY/Target: FY 10/2 mm/yr
- Reporting Frequency: Quarterly
- Source of Data: Office of Climate Observation (OCO)
- Person Reporting Progress on the Target: Mark Merrifield, UHI
- Approving Individual: Mike Johnson, OCO
- State of Development: Developed/Experimental
- Explanation: This new outcome-based performance measure provides a quantifiable metric for evaluating the effectiveness of the tide gauge network.
- Verification: Data are verified by the University of Hawaii.
- Baseline/Target Metadata: N/A

5.5 Reduce the error in global measurement of ocean heat content.

- PM short title: *Ocean Heat*
- Indicator: *Reduce Error* (difference between in situ upper ocean heat and altimetry-derived heat)
- Unit of Measure: $Joules/m^2x10^9$
- Type: *Outcome*
- Baseline FY/Target: FY 02/2.8 $Joules/m^2x10^9$
- Targets FY 07-14: Refer to Tables above.

- 100% FY/Target: FY 14/0.5 *Joules/m^2x10^9*
- Reporting Frequency: Quarterly
- Source of Data: Office of Climate Observation (OCO)
- Person Reporting Progress on the Target: Claudia Schmid, AOML
- Approving Individual: Mike Johnson, OCO
- State of Development: Being Developed- Experimental – routine quarterly reporting underway
- Explanation: This new outcome-based performance measure will provide a quantifiable metric for evaluating the observing system's ability to deliver fundamental climate information.
- Verification: Data are verified and quality controlled by AOML.
- Baseline/Target Metadata: N/A

5.6 Reduce the error in global measurement of ocean carbon sources and sinks.
- PM short title: *Ocean Carbon*
- Indicator: Uncertainty in seasonal CO_2 flux maps
- Unit of Measure: *Petagrams of carbon per year* (Pg C yr^{-1})
- Type: *Outcome*
- Baseline FY/Target: FY07/TBD (baseline will be revised FY07 Takahashi carbon climatology)
- 100% FY/Target: TBD
- Reporting Frequency: Quarterly
- Source of Data: Office of Climate Observation (OCO)
- Person Reporting Progress on the Target: Chris Sabine, PMEL
- Approving Individual: Mike Johnson, OCO
- State of Development: Being developed. The first global flux maps were developed in 2006. Efforts are currently underway to make robust assessments of unbiased uncertainty.
- Explanation: This measure directly evaluates NOAA's progress in reducing the uncertainty in estimates of ocean carbon uptake, and is the first step toward achieving an accurate evaluation of the sources and sinks of carbon in the world's ocean. The stated goals for reducing uncertainty will only be achieved with an enhanced in situ ocean carbon network.
- Verification: Data will be verified by PMEL and AOML.
- Baseline/Target Metadata: N/A

5.7 Summary: 100% Budget Profile Performance Measures:

Performance Measure & Unit of Measure	FY06	FY07	FY08	FY09	FY10	FY11	FY12	FY13	FY14
Reduce the error in global measurement of sea surface temperature (degrees Celsius)	**0.52**	**0.50**	**0.40**	**0.30**	**0.30**	**0.30**	**0.30**	**0.30**	**0.30**
Reduce the error in global measurement of sea level change (mm/yr)	**5.1**	**4.3**	**3.5**	**2.7**	**2.0**	**2.0**	**2.0**	**2.0**	**2.0**

Reduce the error in global measurement of ocean carbon sources and sinks (PgC/yr)	**TBD**	**TBD**	**TBD**	**TBD**	**TBD**	**TBD**	**TBD**	**TBD**	**TBD**
Reduce the error in global measurement of ocean heat storage (Joules/m^2x10^9)	**2.1**	**1.7**	**1.7**	**1.4**	**1.1**	**0.9**	**0.8**	**0.7**	**0.5**
Deployed global observing systems (percent complete)	**57**	**59**	**59**	**62**	**72**	**81**	**89**	**98**	**100**
Number of ocean climate state variables reported	**6**	**8**	**8**	**9**	**11**	**12**	**13**	**14**	**15**

5.8 Performance Measure linkages to the Outcomes:

	Outcomes					
Performance Measures	**Sea level**	**Ocean carbon**	**SST, surface currents**	**Air-sea exchange**	**Ocean heat & transport**	**Sea ice**
Reduce the error in global measurement of sea surface temperature		**X**	**X**	**X**	**X**	**X**
Reduce the error in global measurement of sea level change	**X**				**X**	
Reduce the error in global measurement of ocean carbon sources and sinks		**X**				
Reduce the error in global measurement of ocean heat storage	**X**				**X**	**X**
Deployed global observing systems (percent complete)	**X**	**X**	**X**	**X**	**X**	**X**
Number of ocean climate state variables reported	**X**	**X**	**X**	**X**	**X**	**X**

5.9 System linkages to the Performance Measures: The following sections indicate network improvements that work toward building the observing system as a whole. The ocean observing system is a composite of complementary networks, each one contributing its unique strengths; most serve multiple purposes. One of the primary goals of NOAA's Office of Climate Observation is to look for efficiencies to be gained by utilizing common platforms/sites/data infrastructure for several objectives in parallel. For these reasons it is difficult to assign the network components specifically to product lines on a one-to-one basis. In general, however, the network tasks described below will contribute to the deliverables as follows:

				Performance Measures		
OUTPUT Capacity	**SST**	**Sea Level**	**Ocean Carbon**	**Ocean Heat**	**System Percent**	**Variables Reported**
Tide Gauge Stations		**X**			**X**	
Drifting Buoy Array	**X**	**X**	**E**	**X**	**X**	
Tropical Moored Buoy Network	**X**	**X**	**X**	**X**	**X**	
Ships of Opportunity	**X**	**X**	**X**	**X**	**X**	
Argo Profiling Float Array		**X**	**E**	**X**	**X**	
Ocean Reference Stations	**X**	**X**	**X**	**X**	**X**	
Ocean Carbon Networks			**X**	**X**	**X**	
Arctic Observing System	**X**	**X**	**E**	**X**	**X**	
Data and Assimilation	**X**	**X**	**E**	**X**	**X**	
Analysis and Product Delivery	**X**	**X**	**X**	**X**	**X**	**X**

E: exploratory phase- its utility is currently investigated in research projects.

<u>6.0 Milestones</u>

In order to achieve the Performance Measures, the integrated ocean observing system will be completed according to the following schedule. The schedule is based on the initial design and projections of adequate funding. The milestones will be updated annually to reflect evolution of the design as knowledge and technology advance, and to reflect the realities of funding availability.

	FY07	FY08	FY09	FY10	FY11	FY12	FY13	FY14
System % complete	59	59	62	72	81	89	98	100

Although individual network priorities are described below, they must all go forward together as a system. For example, the global Argo array of profiling floats is a primary tool for documenting ocean heat content; yet deployment of the floats in the far corners of the ocean cannot be achieved without the ships-of-opportunity and dedicated ship time elements; and the Argo array cannot do its work without global over-flight by continued precision altimeter space missions; the Argo measurements must be continually calibrated by deep ocean measurements from the dedicated ships conducting the global ocean carbon inventory surveys; while the measurements taken by all networks will be rendered effective only through the data and assimilation subsystems.

Priorities and milestones for the individual networks follow. For each network the several priority tasks are listed in tabular form. The bottom lines of the tables give the representative milestones that are shown graphically in Figure 2; representative milestones are used to simplify the graphic depiction of the phased implementation plan illustrated by Figure 2. Relative emphases in completing the several components of the observing system will depend on the relative priorities assigned to the network tasks in the context of the overall requirements of climate services.

6.1 Tide Gauge Network: Tide gauges are necessary for accurately measuring long-term trends in sea level change and for calibration and validation of the measurements from satellite altimeters, which are assimilated into global climate models for predicting climate variability. Many tide stations need to be upgraded with modern technology. Permanent GPS receivers will be installed at a selected subset of stations, leading to a geocentrically located subset expansion from the present 43 GPS sites to 180 sites globally by 2010. These 180 climate reference stations will also be upgraded for real-time reporting, not only for climate monitoring, but also to support marine hazard warning (e.g., tsunami warning). In cooperation with international partners NOAA will maintain a global climate network of 290 tide gauges stations as the Global Sea Level Observing System (GLOSS) core network, including the subset noted above, for validation of satellite retrievals, validation of climate model results, documentation of seasonal to centennial variability in the El Nino Southern Oscillation, Indian Ocean and Asian-Australian monsoons, tropical Atlantic variability, North Atlantic Oscillation, North Pacific variability, high latitude circulation, western boundary currents, and circulation through narrow straits and chokepoints, and in support of navigation and other marine services. This task will contribute to climate services by providing the long term records needed to 1) document sea level change: 2) document heat uptake, transport, and release by the ocean (sea surface height contributes to the measurement of ocean heat content); and 3) document the ocean's overturning circulation (gradients of sea surface height across straights and choke-points are used to calculate large-scale ocean currents).

NOAA Contributions	FY06	FY07	FY08	FY09	FY10	FY11	FY12	FY13	**Intl Goal**
Operational GLOSS stations	40	51	62	72	82	92	96	96	**290**
GPS installation	14	15	16	26	46	66	84	84	**180**
Real-time reporting (GCOS)	34	45	56	66	76	84	84	84	**180**
GPS data processing	X	X	X	X	X	X	X	X	**X**
Technology development					X	X	X	X	**X**
International real-time reporting	**102**	**127**	**152**	**162**	**172**	**180**	**180**	**180**	**180**

6.2 Drifting Buoy Array: Data sparse regions of the global ocean are a major source of uncertainty in the seasonal forecasts and are also a major uncertainty in the detection of long-term trends in global sea surface temperature, which in turn is an indicator of global change. Data gaps must be filled by surface drifting buoys to reduce these sources of error to acceptable limits. Standard global SST analyses are derived from satellite retrievals, but the satellite measurements must be continuously tuned using surface *in situ* measurements. The scientific design for the global drifting buoy array calls for 1250 buoys to be maintained world wide, spaced approximately 500 km apart in order to adequately tune the satellites measurements. The drifter array also provides the primary source of global ocean surface circulation measurements which are necessary to validate climate and ocean forecast models, and specially equipped "hurricane drifters" are now routinely air-dropped in the path of hurricanes approaching the U.S. coast in order to improved hurricane intensity and landfall predictions. NOAA, together with international partners, will extend the global SST/velocity drifting buoy array to data sparse regions while adding wind, pressure, salinity, and temperature profile measurement capabilities to serve short term forecasting as well as climate research, seasonal forecasting, and assessment of long term trends. This task will support climate services by providing measurements needed to 1) document heat uptake, transport, and release by the ocean; 2) document ocean carbon sources and sinks (sea surface temperature affects the rate of transfer of CO_2 between the ocean and atmosphere; 3) document the air-sea exchange of water and the ocean's overturning circulation, and 4) document sea level change by providing the sea surface atmospheric pressure measurements that are essential for calculating sea surface height from satellite altimeter measurements.

NOAA Contributions	FY06	FY07	FY08	FY09	FY10	FY11	FY12	FY13	**Intl Goal**
Operational buoys	1000	1000	1000	1000	1000	1000	1000	1000	**1250**
Hurricane drifters	62**	40	40	50	50	50	50	50	**50**
Add barometers	240	270	270	30	350	350	350	350	**700**
Add salinity sensors	12	5	55	105	200	300	300	300	**300**
Technology development					X	X	X	X	**X**
International array size*	**1294**	**1250**	**1250**	**1250**	**1250**	**1250**	**1250**	**1250**	**1250**

*Actual number of operational buoys in 06 is larger than "required" uniform spatial distribution of 1250 buoys to compensate for the complex ocean surface circulation and many drifters go ashore in remote locations and continue to transmit.
**Because no hurricanes approached the US coast in 2006, the hurricane drifters stand ready for deployment in 2007.

6.3 Tropical Moored Buoy Network: Most of the heat from the sun enters the ocean in the tropical/sub-tropical belt. The advanced understanding of the role of the tropics in forcing mid-latitude weather and climate was learned primarily through the observations of the tropical moored buoy array (TAO/TRITON) in the Pacific. A similar pilot array in the Atlantic basin (PIRATA) now offers the potential of even better understanding, improved forecasts, and improved ability to discern the causes of longer-term changes in the Oceans. In addition to monitoring the air-sea exchange of heat, the moored buoys provide platforms for supporting instrumentation to measure carbon dioxide and rainfall in the tropics. The global tropical moored buoy network will be expanded from 82 to 119 stations by 2010 and will ultimately span all three oceans - Pacific, Atlantic, and Indian Ocean. This task will support climate services by providing both ocean and atmospheric observations to 1) document heat uptake, transport, and release by the ocean; 2) document carbon sources and sinks; and 3) document the air-sea exchange of fresh water.

NOAA Contributions	FY06	FY07	FY08	FY09	FY10	FY11	FY12	FY13	**Intl Goal**
TAO/Triton array	55	55	55	55	55	55	55	55	**71**
PIRATA	16	18	18	18	18	18	18	18	**18**
Indian Ocean	6	9	11	13	15	18	22	27	**43**
Add salinity sensors*	33	55	55	55	55	55	55	55	**55**
Add flux capability	7	9	10	11	12	13	13	13	**15**
Technology development	X	X	X	X	X	X	X	X	**X**
International network size	**91**	**97**	**103**	**112**	**115**	**117**	**118**	**119**	**132**

*Salinity sensors needed to be added to TAO only; they are standard on all other tropical moorings.

6.4 Ships of Opportunity: The global atmospheric and oceanic data from Ships of Opportunity (SOOP) have been the foundation for understanding long-term changes in marine climate and are essential input to climate and weather forecast models. Improved instrument accuracy, automated reporting, and improved information about how the observations were taken will greatly enhance the quality of these data, reducing both systematic and random errors. NOAA will improve meteorological measurement capabilities on the global SOOP fleet for improved marine weather and climate forecasting in general, and will concentrate on a specific subset of high accuracy SOOP lines to be frequently repeated and sampled at high resolution for systematic upper ocean and atmospheric measurement. This climate-specific subset will build to a designed global network of 51 lines by 2010 and will provide measurements of the upper ocean thermal structure, sea surface temperature and chemistry, and surface meteorology of high accuracy. Additionally, the SOOP fleet is the primary vehicle for deployment of the drifting arrays. This task will support climate services by providing ocean and atmosphere measurements needed to 1) document heat uptake, transport, and release by the ocean; and 2) document ocean carbon sources and sinks (carbon sampling instrumentation is detailed under a separate task below); and 3) document the air-sea exchange of water and the ocean's overturning circulation.

NOAA Contributions	FY06	FY07	FY08	FY09	FY10	FY11	FY12	FY13	**Intl Goal**
Total XBTs dropped	12544	15823	16000	18000	20000	20000	20000	20000	**24000**
High resolution lines	12	12	15	17	21	21	21	21	**26**
Frequently	7	7	7	7	8	8	8	8	**25**

repeated lines									
Add flux/salinity HRX	4	5	7	10	15	15	15	15	**26**
Auto-met package, VOSClim	12	12	20	50	50	50	50	50	**250**
Technology development					X	X	X	X	**X**
International lines	**41**	**41**	**44**	**46**	**51**	**51**	**51**	**51**	**51**

6.5 Argo array of profiling floats: The heat content of the upper 2000 meters of the world's oceans, and the transfer of that heat to and from the atmosphere, are variables central to the climate system. Global sea level change is directly related to the ocean's heat content – as the ocean's temperature rises the water expands and thus sea level rises. The Argo array of profiling floats is designed to provide essential broad-scale, basin-wide monitoring of the upper ocean heat content. Three thousand floats will be deployed worldwide by 2007. The U.S. contribution is approximately one-half of this international project. Glider technology will replace standard drifting Argo floats in the boundary currents and targeted deep circulation regions. This task will support climate services by providing measurements needed to 1) document heat uptake, transport, and release by the ocean; 2) document global sea level change, and 3) document the air-sea exchange of heat and water and the ocean's overturning circulation.

NOAA Contributions	FY06	FY07	FY08	FY09	FY10	FY11	FY12	FY13	**Intl Goal**
Operational Argo floats	1263	1500	1500	1500	1500	1400	1400	1400	**2800**
Operational gliders	0	0	0	0	0	50	100	100	**200**
Research gliders	2	3	5	10	20	50	0	0	**0**
Technology development	X	X	X	X	X	X	X	X	**X**
International Argo array size	**2557**	**3000**	**3000**	**3000**	**3000**	**3000**	**3000**	**3000**	**3000**

6.6 Ocean Reference Stations:

6.6.1 Subtask 1: NOAA, together with international partners, will implement a global network of ocean reference station moorings, expanding from the present six pilot stations to a permanent network of 21 (plus 12 within the tropical moored buoy network) by 2012. NSF's Ocean Observatories Initiative will provide a major piece of the infrastructure needed for this network, establishing high-capability re-locatable moored buoys in remote ocean locations. NOAA will maintain climate instrumentation aboard the NSF-supplied platforms.

6.6.2 Subtask 2: Monitoring the transport within the ocean is a central element of documenting the overturning circulation of fresh water and heat and carbon uptake and release; heat and carbon generally are released to the atmosphere in regions of the ocean far distant from where they enter. Long-term monitoring of key choke points, such as the Indonesian through-flow, and of boundary currents along the continents, such as the Gulf Stream, must be established to measure the primary routes of ocean heat, carbon, and fresh water transport. Additionally, major boundary currents such as the California Current have a major impact on marine ecosystems; changing climate regimes in the ocean basins are reflected in changing boundary currents which in turn transfer the ocean climate's influence to fisheries and ecosystems.

6.6.3 Subtask 3: Monitoring thermohaline circulation is a central element of documenting the ocean's overturning circulation and a critical need for helping scientists understand the role of the ocean in abrupt climate change. It is essential that the ocean observing system maintain watch at a few control points at critical locations. Key monitoring sites have been identified by an international team of scientists for deployment of long-term subsurface moored arrays and repeated temperature, salinity, and chemical tracer surveys from research vessels. NOAA will focus with Canadian partners on monitoring the Labrador Sea and upstream locations in Davis Strait and the Canadian Arctic Archipelago, while European partners will focus on the eastern north Atlantic. Additionally, to estimate the effect of Antarctic zone water on the global thermohaline circulation, NOAA will maintain time series moorings and repeat sections in the northwestern Weddell Sea, and will establish time series measurements in the Ross Sea. These locations are important to examine the variability of water mass transformation processes as they relate to climate variability in the Southern Ocean.

6.6.4 Summary: These three subtasks will support climate services by providing ocean and atmosphere measurements needed to 1) document heat uptake, transport, and release by the ocean; 2) document ocean carbon sources and sinks (carbon sampling instrumentation is detailed under a separate task below; and 3) document the air-sea exchange of water and the ocean's overturning circulation.

NOAA Contributions	FY06	FY07	FY08	FY09	FY10	FY11	FY12	FY13	**Intl Goal**
Flux moorings*	4	4	5	5	7	7	7	7	**21**
Full depth stations	5	5	5	5	7	7	7	7	**44**
Transport sections	1	3	3	4	5	5	5	5	**10**
Tropical flux stations	7	8	8	9	12	12	12	12	**12**
Technology development					X	X	X	X	**X**
***International reference stations**	**43**	**46**	**47**	**49**	**57**	**58**	**58**	**58**	**87**

*These do not include the flux stations in the tropical moored arrays.

6.7 Coastal Moorings: Improved near shore measurements from moored buoys are critical to coastal forecasting as well as to linking the deep ocean to regional impacts of climate variability. The boundary currents along continental coastlines are major movers of the ocean's heat and fresh water (e.g., the Gulf Stream). Furthermore, the coastal regions are critical to the study of the role of the ocean in the intensification of storms, which are key to the global atmospheric transport of heat, momentum and water, and are a significant impact of climate on society. Coastal arrays are maintained by many nations making this a "global" network of "coastal" stations. A climate subset of NOAA's existing network will be improved by augmenting and upgrading the instrument suite to provide measurements of the upper ocean as well as the sea surface and surface meteorology. Ten of these moorings will serve as platforms-of-opportunity for the addition of carbon sampling instrumentation. This task will support climate services by providing ocean and atmosphere measurements needed to 1) document heat uptake, transport, and release by the ocean; 2) document ocean carbon sources and sinks (carbon sampling instrumentation is detailed under a separate task below); and 3) document the air-sea exchange of water.

NOAA Contributions	FY06	FY07	FY08	FY09	FY10	FY11	FY12	FY13	**Intl Goal**
Upgrade w/ climate sensors	1	5	10	25	45	65	65	65	**105**
Technology development					X	X	X	X	**X**
International coastal network	1	5	10	25	45	65	65	65	**105**

6.8 Ocean Carbon: Understanding the global carbon cycle and the accurate measurement of the regional sources and sinks of carbon are of critical importance to international policy decision making as well as to forecasting long-term trends in climate. The ocean controls global cycling of carbon because it contains 50 times more carbon than the atmosphere, its surface waters exchange carbon with the atmosphere on yearly timescales, and most importantly it absorbs and stores approximately one third of the carbon dioxide released to the atmosphere annually from human activities. Two independent approaches are used by NOAA and its national and international partners to document changes in the ocean carbon system. Short-term (daily to inter-annual) changes in ocean carbon uptake are examined with sea-air CO_2 flux estimates from instruments deployed on ships and moorings. Carbon instruments are generally co-located on other components of the observing system network (e.g. Tropical Moored Buoy Network, Ocean Reference Stations, Ships of Opportunity). Long-term (decadal) changes in ocean carbon inventory are examined by repeating measurements that are made along specific cruise tracks (repeat hydrography) at intervals of 5-15 years. Within the U.S. this is accomplished with the CLIVAR/CO_2 Repeat Hydrography Program, which has the goals of quantifying global changes in the storage and transport of heat, fresh water, carbon, chlorofluorocarbon tracers and related bio-geochemical parameters.

NOAA Contributions	FY06	FY07	FY08	FY09	FY10	FY11	FY12	FY13	**Intl Goal**
Inventory cruises, cumulative	4	6	8	10	12	14	16	18	**37**
Time series moorings	8	11	16	22	30	44	60	60	**60**
Coastal flux	2	4	6	10	15	20	25	25	**25**

moorings									
Surface CO2 on SOOP	7	9	10	12	16	20	25	25	**25**
Technology development					X	X	X	X	**X**
Inventory cruises, International total	**17**	**20**	**22**	**26**	**29**	**31**	**34**	**37**	**37**

6.9 Integrated Arctic Observing System: Given the sensitivity of the Arctic environment to climate variability and change, it is in this region that early indications of the future progression of climate change are likely to be first detected. A program of sustained observations of this area is being conducted through dedicated and shared ship-based cruises, permanent oceanographic moorings and gliders, supplemented by acquisition and analysis of historical data sets. The long-term goal is to detect climate-driven physical and ecological change, especially due to changes in sea ice extent and duration, and in ocean density and circulation that together may lead to changes in ocean heat transport, productivity, and food web structure. International collaboration is essential for completing this program, especially with Russia and Canada. Ice-tethered buoys and bottom-mounted moorings are deployed to monitor the drift of Arctic sea ice and to determine its thickness. The long-term goal is to provide an accurate record of changes in sea ice thickness that, together with satellite observations of sea ice extent, can provide an estimate of changes in sea ice volume. This information is critical for improvement of global climate models and development of a regional Arctic climate model. This task will support climate services by providing ocean and ice measurements needed to document heat uptake, transport, and release by the ocean.

NOAA Contributions	FY06	FY07	FY08	FY09	FY10	FY11	FY12	FY13	**Intl Goal**
Ice buoys/ ice-tethered stations	5	10	10	20	25	25	25	25	**40**
Arctic moorings	3	8	8	8	10	10	10	10	**15**
Ship transects	1	1	1	1	3	3	3	3	**12**
Coastal Climate Observatories	2	2	2	2	3	4	4	4	**6**
International total, buoys, stations, transects	**18**	**21**	**21**	**38**	**55**	**55**	**55**	**55**	**73**

6.10 Dedicated Ship Time: Climate Ship time within the UNOLS research fleet for deployment of the moored and drifting arrays, and for deep ocean surveys is an essential component of this initiative. The deep ocean cannot be reached by SOOP and Argo; yet quantification of the carbon and heat content of the entire ocean column is needed to solve the climate equations. In addition to providing the survey and deployment platforms for the autonomous arrays, the research fleet will maintain sensor suites on a small core of vessels as the highest quality calibration points for validation of the other system measurements. This task will support climate services by providing multi-use platforms for the ocean and atmosphere measurements needed to 1) document heat uptake, transport, and release by the ocean; 2) document ocean carbon sources and sinks; and 3) document the air-sea exchange of water and the ocean's overturning circulation.

NOAA Contributions	FY06	FY07	FY08	FY09	FY10	FY11	FY12	FY13
Ka'imimoana	222	240	240	235	240	240	240	240
TAO/TRITON additional	40	40	40	40	40	0	40	0
PIRATA	35	30	30	30	30	30	30	30
Carbon survey	57	0	65	0	69	69	69	69
Coastal flux maps	0	61	0	60	0	60	0	60
Reference stations	54	48	61	54	55	55	55	55
Drifting arrays	0	0	0	30	30	30	30	30
Western Boundary Current	34	50	34	34	54	34	54	34
Weddell Sea moorings	4	3	4	4	4	4	4	4
Arctic hydrographic sections	18	20	18	35	60	60	60	60
NOAA contribution	468	492	492	522	582	582	582	582

6.11 Satellites:

The initial ocean observing system for climate depends on space based global measurements of 1) sea surface temperature, 2) sea surface height, 3) surface vector winds, 4) ocean color, and 5) sea ice. These satellite contributions are detailed in other NOAA program plans.

6.11.1 Sea surface temperature: Satellite measurements of sea surface temperature are included in NOAA's operational satellite program and the NPOESS program. Satellite data provide high-resolution sea surface temperature data. Both infrared and microwave satellite data are important. Microwave sea surface temperature data have a significant coverage advantage over infrared sea surface temperature data, because microwave data can be retrieved in cloud-covered regions while infrared cannot. However, microwave sea surface temperatures are at a much lower spatial resolution than infrared. In addition microwave sea surface temperatures cannot be obtained within roughly 50 km of land. A combination of both infrared and microwave data are needed because they have different coverage and error properties. Drifting buoy and other *in situ* data are critically important in providing calibration and validation in satellite data as well as providing bias correction of these data. Satellite biases can occur from orbit changes, satellite instrument changes and changes in physical assumptions on the physics of the atmosphere (e.g., through the addition of volcanic aerosols). Thus, drifting buoy and other *in situ* data are needed to correct for any of these changes. This task will support climate services by providing measurements needed to 1) document heat uptake, transport, and release by the ocean; and 2) document ocean carbon sources and sinks (sea surface temperature affects the rate of transfer of CO_2 between the ocean and atmosphere.

6.11.2 Sea surface height: The value of spaced-based altimeter measurements of sea surface height has now been clearly demonstrated by the TOPEX/Poseidon and Jason missions. Changes in sea level during major El Nino events can now be discerned at high resolution and provide realistic model initializations for seasonal climate forecasting. The same data, when calibrated with island tide gauge observations, are also able to monitor the rate of global sea level change with an accuracy of 1 mm per year. The planned NPOESS altimeter will be adequate for shorter term forecasting, but the NPOESS altimeter will not fly in the same orbit as TOPEX/Poseidon and Jason; and for monitoring long-term sea level change, continuation of precision altimeter missions in the TOPEX/Poseidon/Jason orbit is necessary. Jason follow-on altimeter missions (Ocean Surface Topography Mission, OSTM) are necessary to continue the long-term sea level record. NASA and CNES have asked NOAA and EUMETSAT to transition the Jason-class altimeter from research to operations beginning with the OSTM. In FY2006, NOAA will assume primary U.S. responsibility for continuing this international effort. This task will contribute to climate services by providing the long term records needed to 1) document sea level change; 2) document heat uptake, transport, and release by the ocean; and 3) document the ocean's overturning circulation (sea surface height contributes to the measurement of ocean heat and fresh water content and their transport).

6.11.3 Surface vector winds, ocean color, and sea ice: The best methods of sustaining satellite measurement of surface vector winds, ocean color, and sea ice are still a research and development question; over the next five years NOAA, NASA, and NPOESS will weigh the alternatives and determine the long term strategy for maintenance of these elements.

6.12 Data and Assimilation Subsystems:

6.12.1 Subtask 1 – Long Term Stewardship: The value of the observations does not end with their initial use in detecting and forecasting climate variability. The data must be retained and made available for retrospective analyses to understand long-term climate change, and for designing observing system operations and improvements. NOAA's long history and unique expertise in environmental data management will be applied to the ocean observing system. NOAA also will include the vast holdings of historical ocean observations within the context of the integrated environmental data access and archive system. Support will also be provided for a World Ocean Database to incorporate modern data into an integrated profile system.

6.12.2 Subtask 2 – Data Management and Communications: A robust and scalable data management infrastructure is essential to the vision of a sustained ocean observing system. NOAA's ocean climate data element will contribute to the Data Management and Communications System (DMAC) of the U.S. Integrated Ocean Observing System (IOOS) that is being implemented by the National Oceanographic Partnership Program agencies. The DMAC plan integrates data transport, quality control, data assembly, limited product generation, metadata management, data archeology, data archival, data discovery, and administration functions. Uniform access to data will be addressed through the concept of "middleware" connectivity – a common set of standards and protocols that connects all data sources to data users. The middleware approach shields end users from many of the traditional barriers that have been associated with climate data access, including file formats, the distributed location of data, and the large size of some data sets. The preliminary design has been developed by the National Virtual Ocean Data System (NVODS) project.

The nature of IOOS requires the DMAC to be very highly distributed, supporting both large and small data providers at Federal, regional, state, municipal and academic levels. Data assembly centers will be built into the design to add fault-tolerance and increase ease of use. The GODAE server presently at Navy's Fleet Numerical Modeling Operations Center (FNMOC) in Monterey will provide robust, operational access to aggregated and quality-controlled real-time data streams and will be a primary assembly center for NOAA's real-time global measurements. Delayed-mode data sources will be distributed across many institutions including the Asia-Pacific Research Data Center (APDRC) (part of the International Pacific Research Center (IPRC) at the University of Hawaii) and the NOAA Data Centers. The APDRC will provide data assembly services for delayed-mode observations in a cooperative partnership with the GODAE Server. Historical data set serving is also an important function of the distributed system.

The GODAE experimental period ends in 2007. The GODAE server system is central to the sustained integrated ocean observing system and the server functions that have been developed during GODAE must be continued. The NOPP agencies must be prepared to continue these functions either at Monterey or some other location. The Navy has not expressed interest in long-term support of the GODAE server and NOAA is presently planning to assume the leadership role in sustaining this critical part of the ocean observing system infrastructure.

The Data Management and Communications component of NOAA's ocean climate observing system must also deliver the information products needed by NOAA scientists and managers for decision support. The products must provide the information needed to monitor the month-by-month effectiveness of the observing system and to diagnose problems. The products should include intelligible scientific graphics and human-readable numeric tables that provide an overview of the integrated system, selectively merging the data from all relevant measurement streams. These information products will be a component of NOAA's contribution to IOOS.

6.12.3 Subtask 3 – Four dimensional data assimilation including GODAE: For climate forecasting, the combined fields from many different networks are used as initial conditions to begin the forecast. These combined fields, or analyses, are also used to document what the ocean and atmosphere are doing at present and what they did in the past, thus providing a record of the changing climate. By routinely comparing models and data, shortcomings in the observing system can be identified and both the models and forecasts can be improved. To utilize effectively the ocean observations, NOAA will expand ocean analyses to the global domain and will develop and implement improved assimilation subsystems that can more effectively use the new data types that are being collected. The principal vehicle for developing this capability, involving both national and international communities and producing a variety of marine products in addition to the use of these observations in forecast systems, is the Global Ocean Data Assimilation Experiment (GODAE). The global data and ocean product delivery will be operationalized as a contribution to, and continue as a follow-on to, GODAE through the interagency/international server infrastructure being implemented by GODAE; NOAA will provide the primary U.S. support to sustain the server infrastructure over the long term. In addition to improving initializations for seasonal forecasting at NCEP, NOAA will implement sustained ocean data assimilation activities at GFDL to enable experimental decadal forecasts, provide ocean initial conditions for IPCC type scenarios, monitor ocean heat uptake, monitor the thermohaline circulation for abrupt changes, and develop a capability for monitoring changes in oceanic carbon sources and sinks.

6.12.4 Summary: This task will support climate services by providing the integrating data, synthesis, and analysis infrastructure for the ocean and atmosphere measurements, both *in situ* and space based, needed to: 1) document long-term trends in sea level change; 2) document heat uptake, transport, and release by the ocean; 3) document ocean carbon sources and sinks; and 3) document the air-sea exchange of water and the ocean's overturning circulation.

7.0 Management Plan – System organization and product delivery

A global effort of the proposed magnitude must be integrated, organized, and managed as a system in order to be effective. Matrix management is NOAA's corporate business practice and standard protocol. This management plan will follow that protocol by capitalizing on the capabilities that presently exist across the agency while building toward the vision of a single composite system.

Implementation of the individual *in situ* networks will continue to be through distributed centers of expertise at the NOAA Research laboratories, the National Ocean Service Center for Operational Oceanographic Products and Services, the National Data Buoy Center, and the university laboratories that have developed the instruments and techniques. The space components and data management will be centered in the NOAA Environmental Satellite, Data and Information Service. The focal point for developing global ocean data assimilation capabilities will be the Geophysical Fluid Dynamics Laboratory in partnership with the National Centers for Environmental Prediction and university-based applied research centers.

To weld the distributed efforts together into a single vision, NOAA has established the Project Office for Climate Observation (OCO), within the NOAA Climate Program Office. In addition to advancing NOAA's multi-year program plan for *Building a Sustained Ocean Observing System for Climate,* the OCO is working toward an integrated approach for managing both atmospheric and oceanic observations. While there are differences in how ocean and atmospheric observing platforms are coordinated and installed, operated, and maintained, there are basic commonalities that benefit from this synergistic approach to international climate observing support. The OCO is a hybrid combining the functions of a traditional program office with the functions of a center for system monitoring, evaluation, integration, and action. The individual network managers will continue to monitor and evaluate the performance of their individual networks, while the OCO will build the capability to monitor and evaluate the performance of the system as a whole, and take action to evolve the *in situ* networks for overall effectiveness and efficiency in meeting climate observation objectives.

The OCO is the management focus for the distributed ocean network operations and establishes and maintains linkages between the networks and NOAA's other *in situ* and satellite elements and the data and modeling activities that are essential components of climate observation. The office provides a central point of contact within NOAA for coordination with the other agencies and nations involved in observing system implementation. The office receives and acts on feedback from the observing system customers - the operational forecast centers, international research programs, and major scientific assessments.

7.1 Subtask 1 – System Monitoring: The OCO monitors the status of the globally distributed ocean networks to anticipate gaps and overlaps in their combined capabilities. Real-time reports from all platforms are being centralized so that up-to-date status can be displayed at all times. The office reports system statistics and metrics, routinely and on demand. This monitoring activity will ultimately include the atmospheric networks.

7.2 Subtask 2 – Evaluation: A team of expert scientists both internal and external to NOAA is being established to continually evaluate the effectiveness of the networks in meeting the performance measures and the adequacy of the deliverables in meeting the system objectives. The team of experts will evaluate analysis/synthesis products, recommend product improvements, recommend where additional sampling is needed or redundancies are not needed, recommend better utilization of existing and new *in situ* and satellite data, and assess the impacts of proposed changes to the system.

7.3 Subtask 3 – Take action to evolve the *in situ* systems: System monitoring and evaluation will be useless unless there is responsive action taken to build the system, fix problems, and improve sampling strategies. Decisions must be made to implement the best solutions to conflicting requirements (multiple partners and customers have differing missions and will inevitably have differing requirements), to re-deploy existing resources to best improve the system, to select the highest priorities for system extensions and funding of new ideas, and to agree on quid pro quo with interagency and international partners. The OCO is charged with advancing NOAA's multi-year program plan and with evolving the system for maximum effectiveness and efficiency along the way.

7.4 Subtask 4 – Intra-agency, Interagency, and International Coordination: National and international coordination is essential to success in building the global ocean observing system for climate. The OCO is charged with building the infrastructure necessary to organize NOAA's ocean observing efforts along three axes – 1) climate services, 2) the U.S. Integrated Ocean Observing System, and 3) international implementation.

1) For climate services the ocean observations must be available to be combined with data from the atmospheric networks, land surface networks, and cryosphere networks. The requirements from the three user communities – the forecast centers, research

programs, and scientific assessments – must be received and synthesized into common requirements or prioritized if they do not resolve readily.

2) For the U.S. Integrated Ocean Observing System, NOAA's climate system will make a significant contribution to the global component where like data from the various platforms, *in situ* and space-based, must be combined to form complete fields (e.g., sea surface temperature from ships, drifting and moored buoys, and satellites). NOAA's efforts must be combined with the efforts of the other NOPP agencies into a seamless system.

3) For international implementation NOAA must work with the implementation panels of the Joint IOC/WMO Commission for Oceanography and Marine Meteorology (JCOMM) to ensure that consistent standards and formats are used by all participating nations so that data can be easily shared and that consistent quality can be expected from all platforms regardless of their national origin.

In addition to dedicated infrastructure needed for NOAA to operate an office for climate observation, dedicated infrastructure is also needed for operation of the interagency and intergovernmental planning and implementation coordination organizations. These interagency/international organizations rely on funding from the member agencies for their support. NOAA has historically provided a significant portion of the funding needed to maintain the existing international secretariats, science and implementation panels, and capacity building efforts of GOOS, GCOS, and the JCOMM. This funding support has been ad hock and in general from the research programs. As a central component of sustaining the long-term, operational global climate observing system, support for the national/international coordination/implementation infrastructure will be institutionalized via the OCO.

7.5 Subtask 5 – Annual Report on the Ocean's Role in Climate: The organizing framework to bring the multiple elements of the composite ocean observing system together is the routine delivery of Annual Reports on the State of the Ocean and the Ocean Observing System for Climate. The U.S. Climate Change Science Program strategic plan and the U.S. Ocean Research Priorities Plan have identified the critical need for regular reports documenting the present state of the climate system components. NOAA's Office of Climate Observation is leading the national effort to develop this reporting for the ocean component. The theme of the report is the CCSP overarching question for guiding climate observations and monitoring- "What is the current state of the climate, how does it compare with the past, and how can observations be improved to better initialize and validate models for prediction or long term projections?"

The annual reports synthesize satellite and *in situ* observations integrated with models and provide the products to decision makers, the science community, and the public. This reporting framework also establishes a formal mechanism for implementing a "user-driven" observing system and for reporting on the system's performance in meeting the requirements of the operational forecast centers, international research programs, and major scientific assessments. Stakeholders are invited to provide formal recommendations for system improvement and evolution as part of the annual report process.

The annual report contains three chapters as well as front and back material:

The Program Plan for Building a Sustained Ocean Observing System for Climate leads off the Annual Report, with the objective of setting a programmatic context for the technical report that follows.

Chapter One describes The Role of the Ocean in Climate and includes a description of ENSO, SST, sea ice, and sea level, and the various demands on the system incorporating seasonal, interannual, decadal, and climate change time scales. This chapter sets the scientific context for the report and outlines common themes, including the significance of the global ocean observing system and the demands on the system.

Chapter two documents the State of the Observing System. This chapter is comprised of progress reports for each project that contributes either to the observing system networks, or to development of analyzed products. The target audience is NOAA management as well as stakeholders who wish to know what progress has been made in the deployment and maintenance of the sustained ocean observing system for climate. System Progress in meeting milestones is documented by the network managers for their projects and by the OCO for the system in total. Annual statistics and status are given.

Chapter three describes satellite contributions to the ocean observing system for climate, with a view towards explaining the role of remote observations in ocean climate monitoring. The target audience is scientists, generalists, and stakeholders who wish to better understand the relationships between the broad geographic and temporal coverage of remote observations, and the smaller-scale in situ observations that are the foci of the Office of Climate Observations.

The appendix of the report contains a bibliography of recent refereed publications from scientific journals treating the global observation of ocean heat, carbon, fresh water, sea level change, etc., as well as a reiteration of the ten climate monitoring principles that guide all observations made by the program.

Previously, the OCO *Annual Report* included a chapter entitled "The State of the Ocean." This chapter, written by experts in the field, presented an annually updated climatology of the ocean placed in historical context, including discussions of the uncertainty in our state of knowledge. Prior to 2007, similar information was being prepared for both the *Annual Report* and for the Global Ocean chapter of the "State of the Climate" special edition of the Bulletin of the American Meteorological Society (BAMS), which reports annually on the trends and variability in essential climate variables. Beginning in 2007, in order to eliminate the duplication of effort by the authors, the "State of the Ocean" section of the *Annual Report* was discontinued, and subsumed into the Global Ocean chapter of the BAMS report, which is edited by the Office of Climate Observation, and written largely by scientists who participate in the OCO program. We believe that by integrating the presentation of oceanic and atmospheric essential climate variables into a more widely distributed publication, we better bring to life the value of the ocean observing system.

7.6 Subtask 6 – External Review: The execution of this plan will be subject to normal management review in accordance with NOAA's Requirements-Based Management Process. Additionally, for specific programmatic advice and guidance, the Climate Observing System Council (COSC) has been established to review the program's contribution to the international Global Climate Observing System and to recommend effective ways for the program to respond to the long-term observational needs of the operational forecast centers, international research programs, and major scientific assessments. The Council is comprised of members both internal and external to NOAA who individually offer their expert advice; the Council is not expected to develop consensus opinions. The Council meets at least annually to:

- Advise the OCO on priorities for sustaining and enhancing components of the global climate observing system.
- Review the accomplishments and future plans of specific program activities.
- Recommend realignment of activities, or entirely new activities, within the program as appropriate to satisfy the evolving requirements for climate observation.
- Bring to the OCO a broad view on national and international climate research and operational activities and their implications.
- Provide coordinating linkages with national and international programs requiring and/or contributing to the implementation of the global climate observing system.
- Advise the OCO on the balance of activities within the program in the context of NOAA's overarching climate service requirements, of other national and international requirements, and of other national and international contributions to the global climate observing system.

7.7 Education: The NOAA Office of Climate Observation sponsors two educational initiatives:

1) Teacher at Sea Program – OCO sponsors one or two teachers each year to participate in ocean observing system research and implementation on board NOAA and other research vessels.

2) Adopt a Drifter Program – OCO established this program in 2004 to enable K-16 teachers and their students to adopt a drifting buoy by partnering with an international school. They can follow their buoy's movement across the ocean by using OCO's Adopt a Drifter website (http://www.adoptadrifter.noaa.gov).

Table 1

A summary of the 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.

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 days	1	0.1
D	Climate prediction and variability	Surface wind	2°	-	1-2 days	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	U(surface)	600 km	-	month	1	2 cm/s
T	Climate model valid.	U(z)	a few places	30 m	monthly means	30	2 cm/s

Table 1. From The Action Plan for GOOS/GCOS and Sustained Observation for CLIVAR by Needler et al. – OCEANOBS 99

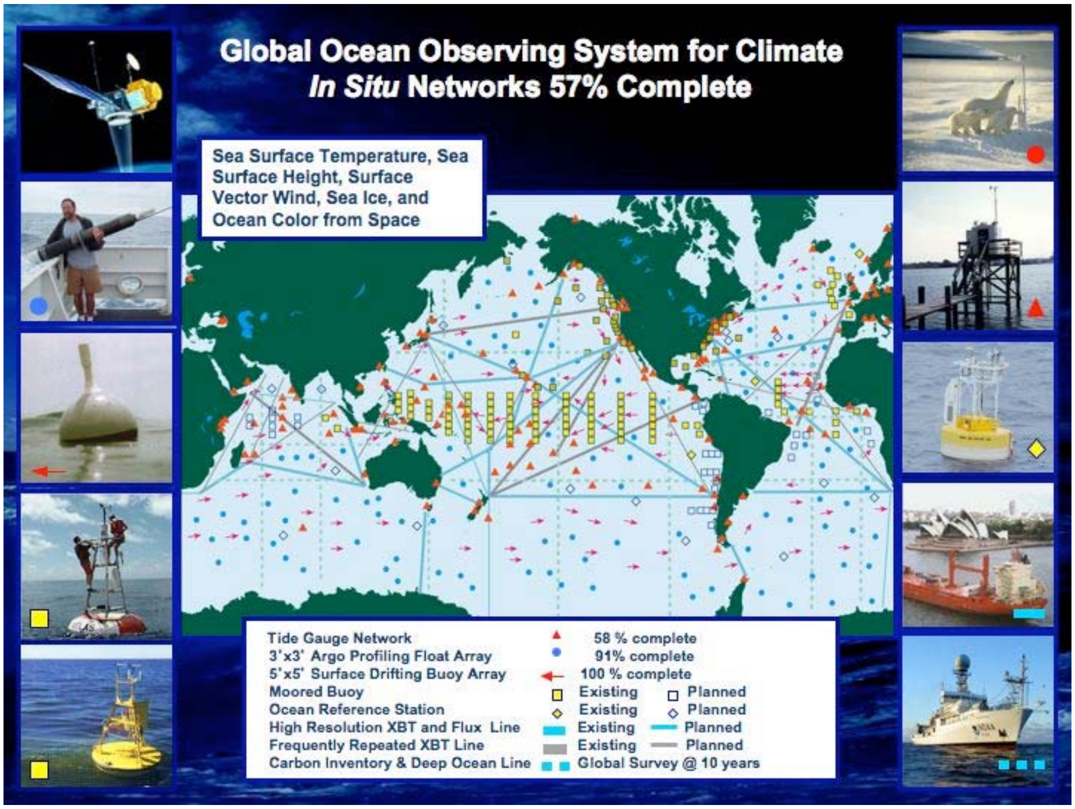

Figure 1

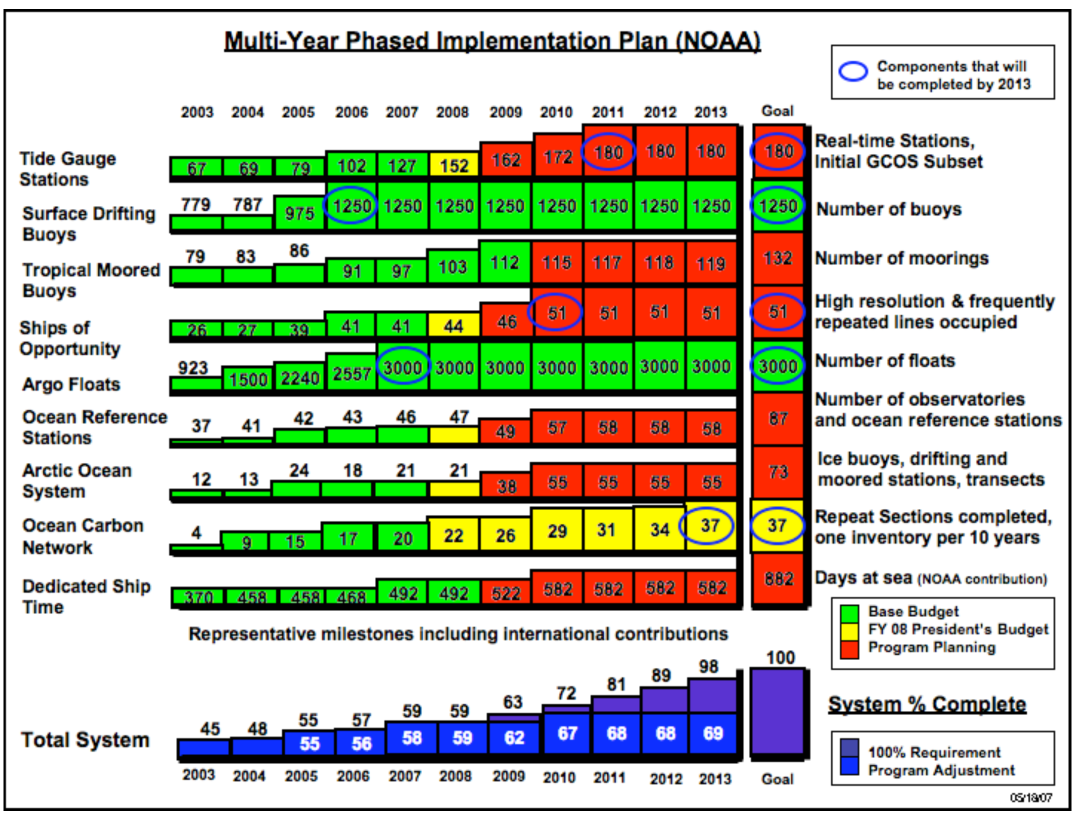

Figure 2

Appendix A

Foundation Documents

Observing the Oceans in the 21st Century, edited by Chester J. Koblinsky and Neville R. Smith, 2001, GODAE Project Office, Bureau of Meteorology, Melbourne, Australia, ISBN 0642 70618 2.

OCEANOBS 99, proceedings of the International Conference on the Ocean Observing System for Climate, GCOS/GOOS/WCRP Ocean Observations Panel for Climate and the CLIVAR Upper Ocean Panel, Saint-Raphael, France, October 1999.

International Sea Level Workshop Report, GCOS/GOOS/WCRP Ocean Observations Panel for Climate and the CLIVAR Upper Ocean Panel, April 1998, GCOS #43, GOOS #55, ICPO #16.

A Large Scale CO_2 Observing Plan: In Situ Oceans and Atmosphere (LSCOP), a contribution to the implementation of the U.S. Carbon Cycle Science Plan by the *In situ* Large-Scale CO_2 Observations Working Group, April 2002.

Implementation Plan for the Global Observing System for Climate in support of the UNFCCC (GCOS-92), the Global Climate Observing System, October 2004, GCOS #92, WMO/TD #1219.