University-National Oceanographic Laboratory System

UNOLS
Fleet Improvement Plan
2009

The UNOLS Academic Research Fleet: Continued Access to the Sea

Prepared by the
UNOLS Fleet Improvement Committee

April 2009

UNOLS Fleet Improvement Plan 2009

A Report Prepared by UNOLS Fleet Improvement Committee

Dave Hebert, University of Rhode Island (Chair)
Jim Bauer, Virginia Institution of Marine Science
Ron Benner, University of South Carolina
David Checkley, Scripps Institution of Oceanography
James Cochran, Lamont-Doherty Earth Observatory
Maureen Conte, Bermuda Institute for Ocean Sciences
Newell Garfield, San Francisco State University
Al Hine, University of South Florida
Clare Reimers, Oregon State University
Niall Slowey, Texas A&M
Al Suchy, Woods Hole Oceanographic Institution
Terry Whitledge, University of Alaska, Fairbanks
Marc Willis, Oregon State University

Other Contributors:

John Bane, University of North Carolina
Annette DeSilva, UNOLS
Marcia McNutt, Monterey Bay Aquarium Research Institute
Robert Pinkel, Scripps Institution of Oceanography
Mike Prince, UNOLS
Peter Wiebe, Woods Hole Oceanographic Institution

Dedication

This 2009 update of the UNOLS Fleet Improvement Plan is dedicated to the memory of Marcus Langseth.

Cover Photos: Center – Net operations from R/V *Thompson* (Image courtesy of University of Washington). Right, top to bottom:– R/V *Revelle* (Photo by Chief Engineer Paul Mauricio, Scripps Institution of Oceanography), R/V *Kilo Moana* (Image courtesy of University of Hawaii Marine Center - School of Ocean and Earth Science and Technology), R/V *Oceanus*, (Photo by Tom Kleindinst, Woods Hole Oceanographic Institution) R/V *Point Sur* (Image courtesy of Moss Landing Marine Laboratories), R/V *Hugh R. Sharp* (Image courtesy of University of Delaware), R/V *Savannah* (Image courtesy of Skidaway Institute of Oceanography).

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(This Plan was appended with Appendix III in Oct 2012)

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Acronyms and Abbreviations

2-D	Two-dimensional
3-D	Three-dimensional
ABE	Autonomous Benthic Explorer
ACOE	Army Corp of Engineers
ADCP	Acoustic Doppler Current Profiler
AICC	Arctic Icebreaker Coordinating Committee
ALPS	Autonomous Lagrangian Platforms and Sensors
ARRV	Alaska Region Research Vessel
AUV	Autonomous Underwater Vehicle
BATS	Bermuda Atlantic Time-series Study
BIOS	Bermuda Institute for Ocean Sciences
BTSM	Bermuda Testbed and Science Mooring
CalCOFI	California Cooperative Oceanic Fisheries Investigations
CSN	Coastal Scale Nodes
CGSN	Coastal and Global Scale Nodes
CIRPAS	Center for Interdisciplinary Remotely Piloted Aircraft Studies
CLIVAR	Climate Variability and Predictability
CODAR	Coastal Ocean Dynamics Applications Radar
CoOP	Coastal Ocean Processes
CPI	Consumer Price Index
CTD	Conductivity-Temperature-Depth
DESSC	Deep Submergence Science Committee
DOE	Department of Energy
DSV	Deep Submergence Vehicle
ENSO	El Niño-Southern Oscillation
EPA	Environmental Protection Agency
FIC	Fleet Improvement Committee
FIP	Fleet Improvement Plan
FLIP	Floating Instrument Platform
FOCUS	Future of Ocean Chemistry in the U.S.
FOFC	Federal Oceanographic Facilities Committee
FOY	Full Optimal Year
GEOSECS	Geochemical Ocean Section Study
GSN	Global Scale Nodes
HABs	Harmful Algal Blooms
HBOI	Harbor Branch Oceanographic Institution
HNLC	High-Nitrate, Low Chlorophyll
HOME	Hawaiian Ocean Mixing Experiment
HOTS	Hawaii Ocean Time-series
HOV	Human Occupied Vehicle
ICCAGRA	Interagency Coordinating Committee for Airborne Geosciences Research and Applications
IDOE	International Decade of Ocean Exploration
IMBER	Integrated Marine Biogeochemistry and Ecosystem Research
IODP	Integrated Ocean Drilling Program
ISS	Integrated Study Sites
IWG-F	Interagency Working Group on Facilities
JGOFS	Joint Global Ocean Flux Study
LDEO	Lamont-Doherty Earth Observatory
LOICZ	Land-Ocean Interactions in the Coastal Zone

LTER	Long-Term Ecological Research
LUMCON	Louisiana Universities Marine Consortium
MATE	Marine Advanced Technology Education
MCS	Multi-Channel Seismic
MG&G	Marine Geology and Geophysics
MLML	Moss Landing Marine Laboratories
MLSOC	Marcus Langseth Science Oversight Committee
MMS	Mineral Management Service
MREFC	Major Research and Equipment Facilities Construction
MSF	Mid-Shelf Front
NAO	North Atlantic Oscillation
NASA	National Aeronautics and Space Administration
NAVO	Naval Oceanographic Center
NCAR	National Center for Atmospheric Research
NDSF	National Deep Submergence Facility
NOAA	National Oceanic and Atmospheric Administration
NOAF	National Oceanographic Aircraft Facility
NOPP	National Oceanographic Partnership Program
NORLC	National Ocean Research Leadership Council
NOSF	National Oceanographic Seismic Facility
NRC	National Research Council
NRL	Naval Research Lab
NSF	National Science Foundation
O&M	Operations and Maintenance
OBS	Ocean Bottom Seismometer
OCCC	Ocean Carbon and Climate Change
ODP	Ocean Drilling Program
OFP	Oceanic Flux Program
ONR	Office of Naval Research
OOI	Ocean Observatories Initiative
OSU	Oregon State University
PI	Principal Investigator
PolarTREC	Polar Teachers and Researchers Exploring and Collaborating
R/V	Research Vessel
REVEL	Research and Education: Volcanoes, Exploration and Life
RiOMaR	River-dominated to Ocean Margins
ROV	Remotely Operated Vehicle
RSL	Rupturing Continental Lithosphere
RSN	Regional Scale Nodes
RVOC	Research Vessel Operators' Committee
RVTEC	Research Vessel Technical Enhancement Committee
S2S	Source to Sink
SCOAR	Scientific Committee for Oceanographic Aircraft Research
SEIZE	Seismogrenic Zone Experiment
SIO	Scripps Institution of Oceanography
SLEP	Service Life Extension Program
SMRs	Science Mission Requirements
SOFex	Southern Ocean Iron Enrichment Experiments
SOLAS	Surface Ocean Lower Atmosphere Study
SSC	Ship Scheduling Committee
SST	Sea Surface Temperature

STR	Ship Time Request
STRI	Smithsonian Tropical Research Institute
STRS	Ship Time Request and Scheduling System
SWATH	Small Waterplane Area Twin Hull
TTO	Transient Tracers in the Oceans
UNOLS	University-National Oceanographic Laboratory System
UAF	University of Alaska Fairbanks
URI	University of Rhode Island
USAP	U.S. Antarctic Program
USCG	United States Coast Guard
USCGC	U.S. Coast Guard Cutter
USGS	U.S. Geological Survey
VOS	Volunteer Observing Ships
WHOI	Woods Hole Oceanographic Institution
WOCE	World Ocean Circulation Experiment

Executive Summary

The world's oceans are vast and vital to the health, safety, and economic stability of our global society. The oceans drive our weather and climate by storing and distributing heat and carbon. They are a source of clouds that provide water to our fields and aquifers. Ocean organisms provide much of the life-supporting oxygen humans and animals rely on. Pharmaceuticals derived from marine plants and organisms offer health benefits by prevention and treatment of diseases. The oceans offer a bounty of natural resources that marine industries in fisheries, tourism, recreation, shipping, and energy exploration and exploitation have relied upon. The geological features of the sea floor along with the unique ecological communities that exist in the extremes of the deep ocean may help shed light on the origins of our planet Earth and its inhabitants.

The critical resources of the oceans have become threatened by the degradation of the health and physical state of our waters. The impact of global climate change has resulted in warming waters, intensified hurricanes, ocean acidification, alteration of ocean currents, and rising sea levels. Pressures from increased development in coastal zones have impacted water quality and pollution levels. Coral reef degradation has accelerated. Harmful algal bloom events, such as red tides, have been on the rise resulting in wildlife mortalities. The lowest levels of the marine food chain are threatened by the increased pollution and acidification of ocean waters.

The need to enhance our understanding of the ocean's physical, chemical, biological, and geological processes is urgent. Increased knowledge of the seas will better enable our nation to anticipate the ocean's role in climate change and assist in efforts to develop management programs that will preserve the oceans' natural resources and sustain the economic benefits they offer. Reports from both the Pew Oceans Commission and the U.S. Commission on Ocean Policy have documented the importance of understanding the processes acting in the ocean and have called for a coordinated, national ocean policy based on unbiased, credible, and up-to-date scientific information [Pews Ocean Commission][U.S. Commission on Ocean Policy].

Access to the Sea

Oceanographic research depends on the ability to take measurements and collect data directly from the sea. Access to a modern fleet of research vessels has been and will continue to be essential. The United States Academic research fleet, coordinated through the University-National

The World's Oceans – A Vital Resource

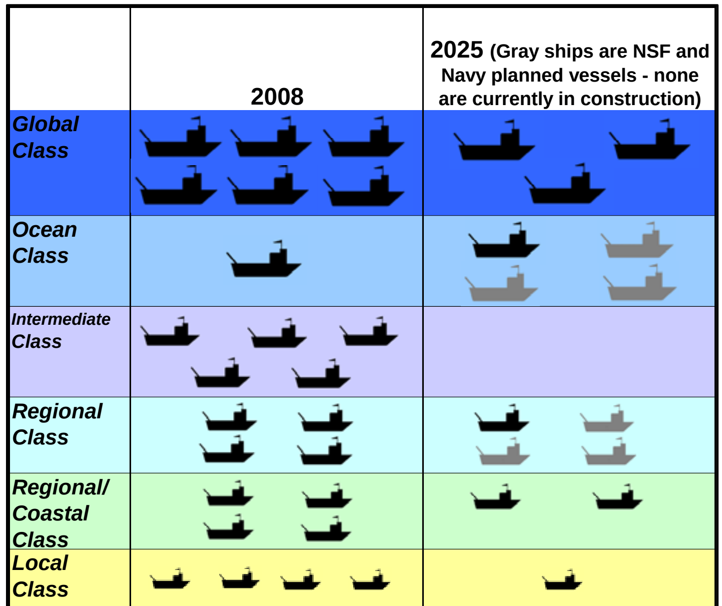
- The world's oceans cover 71 percent of the Earth's surface and contain 97 percent of the planet's water.
- The oceans control our weather and climate through the global transfer of heat and water; water that is essential for agriculture and drinking supplies.
- Much of the oxygen we need to survive is generated by the organisms that live within the ocean.
- The ocean holds the sedimentary library of past planetary change.
- The U.S. has more than 90,000 miles of shoreline with more than 50 percent of the U.S. population living in coastal communities.
- The ocean is an economic resource that supports a $60 billion annual seafood industry, a $20 billion recreational fishery industry and contains approximately $8 trillion in oil and gas reserves. 33 percent of the U.S. Gross National Product is produced in coastal areas.
- The majority of the Nation's commerce travels through U.S. ports.
- The oceans support the life of 25-50 percent of all species on Earth; 80 percent of these life forms are found only in the ocean.

[Consortium for Ocean Leadership]

Oceanographic Laboratory System (UNOLS), consists of 22 vessels[1] and is geographically distributed among academic institutions located along the Country's coastal regions, the Great Lakes, and Bermuda. The fleet consists of six classes of ships ranging in size from 20 meters (66 feet) to 85 meters (279 feet) (see Figure below) More than half of the ships in the fleet will reach the end of their useful service life by the year 2015. Notwithstanding the increasing importance of drifting and moored instrumentation, remote sensing, and coastal observatories, a healthy U.S. academic fleet remains a critical part of the essential infrastructure in support of oceanographic research. We must maintain research vessel capability if the U.S. is to retain leadership in ocean affairs.

The vessels in the UNOLS fleet need to be wisely designed to conduct wide-ranging, cutting-edge research efficiently and safely at sea. The fleet should consist of vessels that can operate in the local, coastal waters of the U.S., as well as vessels that can operate virtually anywhere in world's oceans, including ice-covered regions. The fleet's Global and Ocean Class ships must be able to carry large numbers of scientists, technicians, students, and equipment to sea in order to collect samples, conduct experiments and surveys, and observe ocean processes. The design of the ships must provide flexibility in the use of exterior and interior spaces to accommodate the deployment of a vast assortment of oceanographic equipment and to accommodate specialized atmospheric samplers. The ships' labs must be able to be easily reconfigured to meet diverse, multidisciplinary science needs on a leg-by-leg basis. Technologically advanced and specialized equipment and operations increasingly require large amounts of clean power and high data bandwidths. There is also an increasing need for 24/7 high bandwidth two-way communications to the shore.

New and emerging technologies, such as autonomous underwater vehicles, gliders, and ocean observatories, will not eliminate the need for ocean-going research vessels, but will change the nature of the research expedition and ship support requirements. Whereas in the past the ship itself was the primary platform for data collection, these newer technologies will greatly increase the spatial and temporal footprint of information gathering far beyond what was previously achievable with a ship alone. The role of the ship will be to deploy and service these more mobile or enduring assets, and act as a nexus for the information aggregation. Ships will complement the simpler robots by executing the more complex tasks and experiments. Thus the ship of the future will require the utmost in maneuverability, high-bandwidth communications, and the ability to deploy heavy payloads over the side safely.



	2008	2025
Total Ships	23	14
Total Berths	492	331
Available Ship Days	5085	3270

Figure i: Comparison of the 2008 UNOLS Fleet with the projected Fleet of 2025.

Fleet Renewal: Issues and Challenges

Renewal of the Academic fleet faces two major issues today. On the short-term time scale, there is a mismatch of fleet funding, ship time demand (due to decreased research funding), and capacity (ship days available on the current fleet). The fleet is facing severe budget constraints and escalating costs. Federal budgets have either been flat or increasing below the inflation rate. Fuel and manning costs have been rising faster than

[1] At the start of 2008 the UNOLS fleet consisted of 23 vessels. R/V *Urraca* was removed from service mid-year, leaving 22 ships in the fleet at year's end.

general inflation. Additionally, there are added costs associated with new security requirements and new regulations.

On the longer-term time scale, the current fleet is aging and many of the fleet's ships will soon reach the end of their projected service life. As the ships age, there are higher maintenance costs and difficulties in maintaining worn, inefficient systems.

There is a need for acquisition of vessels in all size classes. Planning and acquisition of new ships generally takes about ten years or more; thus, care must be exercised on making short-term decisions that could have effects over a longer time.

The Federal agencies are dedicated to fleet renewal efforts. The National Science Foundation is moving forward with acquisition plans for an Alaska Region Research Vessel (ARRV) and up to three Regional Class ships. The Navy has plans to acquire two new Ocean Class ships.

While these renewal efforts are implemented, many of the existing ships will reach the end of their projected service life. By 2017, all of the Intermediate size ships and all but three of the Regional/Coastal and Local Class ships will reach the end of their projected service life. There are no formal plans currently in place for replacement of the Coastal and Local Class ships.

By 2025, under the current scenario we will have a significantly reduced capacity to support global-ranging programs that require large, general-purpose Global class ships, with only three available ships (R/Vs *Revelle*, *Atlantis*, and *Langseth*), two of which have specialized mission capabilities. Only 3,270 ship days will be available in 2025, as compared with over 4,300 ship days in 2008 (see Figure i on page viii). Thus, the UNOLS fleet will be increasingly unable to meet science user demands, especially during peak periods in spring and summer. Flexibility in fleet scheduling that allows for multi-ship operations and for science expeditions in remote areas will be lost.

Recommendations for UNOLS Fleet Improvement:

The UNOLS Fleet Improvement Plan provides a comprehensive evaluation of today's fleet, future science directions, and fleet capacity projections. The Plan's recommendations do not advocate for a direct replacement of the ships in the current fleet. Instead, they are based on projected future science needs while at the same time recognizing the challenges before us; escalating costs, budgetary constraints, and an aging fleet.

- To realize the U.S. Commission on Ocean Policy recommendation for strong support for ocean research, including ample access to modern research vessels, the UNOLS fleet must increase beyond the current projected levels detailed in the *Federal Oceanographic Fleet Status Report* [Interagency Working Group on Facilities (IWG-F)]. This will not only require increased funding for support of ocean science research and education but also increased funding for facility construction, maintenance, and operation from both public and private sectors.
- We recommend that the Federal agencies implement the fleet renewal activities that are currently underway (the ARRV, the three Regional Class ships, and the two Ocean Class ships), under the timeline shown in the 2007 *Federal Oceanographic Fleet Status Report* [IWG-F].
- Begin the process now for new ships that will be needed in 2017 and beyond. Plans for replacement of the two existing general purpose Global Class vessels (R/V *Knorr* and R/V *Melville*) which will reach the end of their projected service life by 2017, must start now. A minimum of one and preferably two new general-purpose Global Class vessel(s) should be planned for, funded, and constructed by 2018.
- New state-of-the-art ships with technically sophisticated equipment will require more highly-trained and specialized personnel to provide technical support. Personnel strategies must be developed to improve the staffing and retention of experienced technical support personnel and crew.
- We recommend that UNOLS, the federal agencies, and individual operators consider how to make the present and future fleet more environmentally sustainable. New and existing technologies and practices should be used in the construction, operation, and recycling of research vessels and UNOLS should take a leadership role in promoting a green U.S. research fleet, as we move forward in developing the academic fleet.
- Recognizing the delays in the timelines for delivering some of the new planned ships into the fleet, some of the current ships nearing the end of their projected service life should have their service life extended so that they can be

maintained at an adequate operational level to meet near term science requirements until the new ships come on line. However, UNOLS considers the service life extension approach as an option that should only be considered if there is a demonstrated need for ship days and funds for new construction are unavailable or delayed.

- The Ocean Observatory Initiative (OOI) will place new and increased demands on Global, Ocean, and Intermediate vessels of the UNOLS fleet, and on Remotely Operated Vehicles (ROVs) for operations and maintenance. As the observatory systems are installed, the projected service life end dates and geographic locations of these ships should be carefully considered to ensure that OOI ship demands can be met.
- A capable National Deep Submergence Facility (NDSF) that includes a suite of deep submergence vehicles is required for continued support of science on the seafloor and on the mid ocean ridge systems. OOI projects new and increased demands for ROVs for support at their study sites. We recommend that planning and acquisition efforts for new deep submergence assets continue.
- If budget projections remain at the current low level, removal from UNOLS service of the least capable ships near the end of their projected service lives should be considered. Any decisions on ships being removed permanently from UNOLS service versus lay-ups should be made based on multi-year projections of ship time demand rather than single year figures of fleet utilization.
- The smaller ships of the UNOLS fleet serve a crucial role in supporting science in our nation's coastal zone where the human impacts of development and resource use are greatest. To continue to meet current requirements for the entire academic oceanographic community, UNOLS should encourage the timely replacement of Local vessels and Coastal/Regional vessels by institutions, state governments, and regional partnerships.
- Federal agencies that operate their own research vessels are encouraged to examine their respective fleet capacities and capabilities to ensure that the Federal fleet as a whole is optimally utilized. Ship capacity that could be used to support academic research ship demand should be identified. Issues of access, facility scheduling, and financial support of an integrated Federal fleet of vessels should be addressed as a coordinated effort between UNOLS and the Interagency Working Group on Facilities.

In conclusion, the U.S. research fleet is an extremely vital component of the national maritime enterprise. The U.S. ocean science research and education programs have benefited by broad access to the best possible mix of modern, capable, efficiently run, and well-operated research vessels, aircraft, submersibles, and other major shared-use facilities. Timely implementation of the recommendations presented in this Fleet Improvement Plan will ensure that the oceanographic community will continue to have access to a capable fleet of vessels to support the open ocean and coastal science initiatives that are important to the nation over the next 20-30 years.

Executive Summary References:

Pews Ocean Commission, 2003. *America's Living Oceans: Charting a Course for Sea Change*, 144pp. [Online] available at <http://www.pewtrusts.org/uploadedFiles/wwwpewtrustsorg/Reports/Protecting_ocean_life/env_pew_oceans_final_report.pdf>.

U.S. Commission on Ocean Policy, 2004. *An Ocean Blueprint for the 21st Century: Final Report of the U.S. Commission on Ocean Policy*, pp 522. [Online] available at <http://oceancommission.gov/documents/full_color_rpt/welcome.html>.

Consortium for Ocean Leadership, http://www.oceanleadership.org/policy/priorities

Interagency Working Group on Facilities, 2007. *Federal Oceanographic Fleet Status Report*, NOPP, 36 pp. [Online] available at <http://www.nopp.org/iDuneDownload.dll?GetFile?AppId=141&FileID=321850&Anchor=&ext=.pdf>.

I. Introduction

Renewal of the academic fleet is critical to maintaining and advancing the capabilities that have allowed the U.S. to excel in oceanographic research. Since its formation in 1972, the University-National Oceanographic Laboratory System (UNOLS) has played an active role in assessing the quality and effectiveness of the academic research fleet. One aspect of this role is to look ahead to future facility needs of the oceanographic community and to compare these needs to the existing fleet and the projected fleet five to 20 years hence. The UNOLS Fleet Improvement Committee (FIC), a standing committee of UNOLS, has the specific mandate to continually assess the number and mix of ships in the UNOLS fleet and to develop plans for additions, replacements or retirements from the fleet. To this end the FIC published a document in May 1990 entitled the *UNOLS Fleet Improvement Plan*" that gave, among other things, specific recommendations with respect to fleet size and composition for the decade of the nineties. The Fleet Improvement Plan (FIP) was updated in 1995 to address new needs, changes in financial circumstances, and evolutions in ocean science. It has been well over ten years since the last FIP update and the need for a fleet plan that accurately represents the changing ocean research requirements is essential.

Since the last publication of the UNOLS FIP in 1995, the fleet has transformed to meet the needs of oceanographic research while at the same time operate within growing budget constraints. The total fleet size has decreased by three ships and the composition of the fleet has changed significantly (Appendix I) [1]. There has been the addition of new, more capable ships (three Global ships, one Ocean Class ship, one Regional ship, two Regional/Coastal ships, and three Local ships). These ships replaced many of the older ships that were in service in 1995. The 2008 fleet includes 13 vessels that will reach the end of their estimated service life by the end of 2015. Table 1 provides a comparison of the UNOLS fleet in 1995 to that of the 2008 fleet.

As the renewal efforts that are currently planned are carried out, FIC will continue to reevaluate the future facility needs. The issues and opportunities that arise as ocean science and the UNOLS fleet evolve are explored in this update of the Fleet Improvement Plan.

Table 1. Comparison of the 1995 UNOLS Fleet with the 2008 UNOLS Fleet

Class of Vessel	**1995**	**2008**
Global/Large	5	6
Ocean Class		1
Intermediate	8	5
Regional	3	3
Regional/Coastal	5	4
Local	5	4
Total Ships	26	23

Purpose and Objectives of the FIP Update

This update of the UNOLS Fleet Improvement Plan is based upon the needs envisioned through the year 2025. As FIC updated their Fleet Improvement Plan, the federal Interagency Working Group on Facilities (IWG-F) prepared a report, *Federal Oceanographic Fleet – Status Report,* that was published in December 2007 [2]. The IWG-F, which is composed of eight agencies, carries out fleet planning, but on a broader, federal level. The academic fleet is one part of the federal fleet. The IWG-F *Status Report* only considered those academic research vessels greater than 40 meters. A major assumption in the IWG-F planning process is that the federal budget for ocean research for the next five years will remain at present levels. This assumption places limits on the size and structure of the academic fleet. While FIC coordinates with IWG-F on fleet planning, the FIC recognized the need for a plan based on future science initiatives. The 2009 FIC Fleet Improvement Plan identifies future science initiatives, describes fleet trends, and makes future fleet projections beyond the IWG-F *Status Report*. The FIP considers the composition of the total academic fleet. The Plan looks at fleet expansion that is required to conduct the oceanographic research envisioned for the future.

The basic criteria brought forward from past Fleet Improvement Plans still apply. The plan must be:

- Responsive to the anticipated future trends and needs of oceanographic research, education and outreach,
- Realistic in terms of the national economy,
- Bear the general approval of the academic research community,
- Sufficiently credible to compete in the federal funding infrastructure,
- Provide a logical implementation scheme bridging the current and projected time frame, and
- Provide for periodic updating.

Ocean Sciences at the New Millennium (2001) [3]:

"A substantial, well-coordinated, multi-agency fleet replacement plan is needed to maintain United States leadership in sea-going capabilities in the coming decades. *Almost all the fundamental discoveries in ocean science have come from direct observation of the sea with increasingly sophisticated research and drilling vessels that can support advanced scientific teams. Maintaining a modern, well-equipped research fleet is the most basic requirement for a healthy and vigorous research program in the ocean sciences. The research fleet must include a range of capabilities including highly specialized vessels, such as sophisticated drill ships and their associated tools, which allow sampling deep below the seafloor. The anticipated mix of research demands large vessels capable of mounting interdisciplinary studies both near to and far from land and supporting remotely operated vehicles and submersibles as well as versatile small- and intermediate-sized ships for studying the coastal ocean."*

II. Future Science Initiatives

A. Oceanographic Research - Introduction

The oceans play a critical role in our society, regardless of where we live. The oceans are inextricably linked with the atmosphere and land. The ocean transports and stores heat and water that helps to regulate the Earth's climate and weather. The marine ecosystem also plays an important role in our climate, as well as providing a source of food. However, the dynamics of the oceans, their ecosystems and chemistry are poorly understood.

Two recent studies, *America's Living Oceans: Charting a Course for Sea Change*, by the Pew Oceans Commission [4] and the *An Ocean Blueprint for the 21st Century*, by the U.S. Commission on Ocean Policy [5], have documented, in great detail, the importance of understanding biological, chemical, geological, and physical processes acting in the ocean. Both commissions called for a coordinated and effective national ocean policy and that this policy should be based on unbiased, credible, and up-to-date scientific information. The commissions recommended a significant increase of the oceanographic research budget. Also, the U.S. Commission on Ocean Policy recommended renewal of the UNOLS fleet.

The federal agencies, through the IWG-F, have prepared a status report of renewal activities for the federally owned research and survey vessels [2]. Most of the UNOLS vessels that are larger than 40 meters are included in the IWG-F status report. However, the report does not include the smaller, locally owned vessels. While the IWG-F report provides some examples of why research vessels are needed, the Fleet Improvement Committee decided to provide more detailed information on why the oceanographic community requires vessels to address key scientific questions.

Ship-supported oceanographic research spans a wide range of spatial and temporal scales (Figure 1). The following sections highlight some research areas of importance that require people to go to sea. The goal of these sections is not to provide a comprehensive list of research topics, but to show the breadth of topics that required ship-based observations.

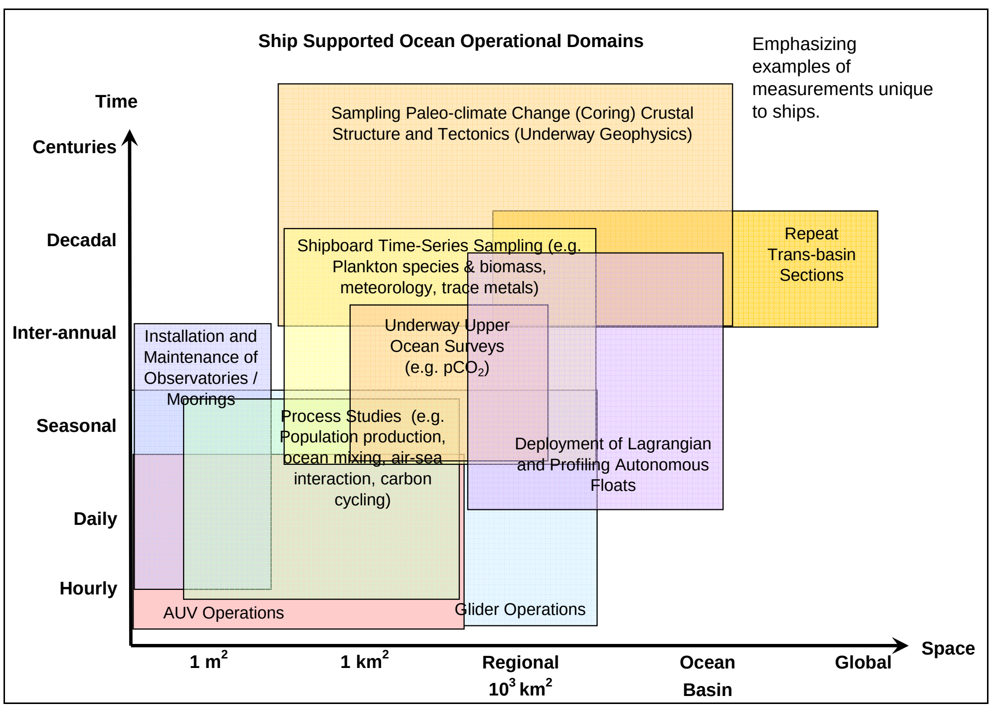


Figure 1. Relationships between different types of sampling platforms and approaches across different time and space scales. (Figure adapted from: Doney, S.C., et al. [6])

B. Physical Oceanography

Physical oceanography is the study of how water moves and mixes in the ocean, and how water carries and distributes dissolved chemicals (e.g., nutrients, pollutants) and plankton. Physical oceanography is the area of applied physics that observes (mainly from ships), models, and predicts ocean processes using mathematics and fluid mechanics. A central challenge of seagoing physical oceanographic research is the range of space and time scales that must be encompassed by any successful effort to understand the fluid.

The challenge of sampling the ocean adequately is enormous and has until now restrained physical oceanographers to focus upon either larger scale circulation or isolated case studies of smaller scale turbulent processes, thereby leaving unexplored processes at intermediate scales. The phenomena connecting the physics of large-scale and small-scale processes in the ocean are not well understood. It is difficult to make synoptic measurements on horizontal scales from 50 m to 50 km. Historically, this deficiency of measurement has also artificially limited studies of the coupling between physical, biological, and chemical processes operating on these scales.

Large-scale numerical models of the ocean, often used for climate studies, are the essential tools for casting the results of theory and observations into rigorous form. Models represent ways to capture data, and to give expression to theory. The real ocean contains energetic, 'mesoscale' eddy features that cannot be explicitly resolved in models; however, these features often dominate the scale of observations made from ships. Adding to this difficulty is the need to understand processes such as deep convection at high latitudes, the influence of topography, and the interactions near the surface and bottom of the ocean.

Research Trends, Findings and Initiatives in Physical Oceanography:

The transitions in ocean dynamics from the coast to the open ocean, the air-sea interface to the interior of the ocean, and the submesoscale to gyre circulations are all examples of areas of research crossing scales. If we can comprehend and capture the physics underlying these transfers we can make important contributions. A few examples are provided next. This is not meant to be all encompassing list or a prioritization of research areas.

Cross-shelf transports - How the coastal ocean couples to its surroundings on both the landward and seaward sides are a critical issue in oceanography. Cross-shelf transport needs to be understood if we are to understand topics such as biological productivity in the coastal ocean or the removal of contaminants from the coasts. Estuarine processes are important for determining the quantity and quality of terrestrial material that reaches the open shelves. The oceanic setting, including eddies, filaments, and boundary currents, in turn determines how effectively coastal influences can spread offshore. These cross-shelf transports are often inhibited by topography, and by river outflow. Our impact on the quality of the coastal ocean and how to regulate it depends on understanding this physics of the cross-shelf transport.

One recent area of research on this topic has been the study of the shelf-break front found along many continental margins. Many fishing areas are located adjacent to these fronts. Recently, rapid survey tools such as undulating towed Conductivity-Temperature-Depth (CTD) systems and shipboard Acoustic Doppler Current Profilers (ADCPs) have provided new high-resolution descriptions of the thermohaline and velocity structure of these fronts. The cross-front scale is only 10 to 20 km, resulting in strong horizontal density gradients and large vertical and horizontal current shears, with peak currents in the near-surface core of the jet of up to 40 to 80 cm/s. In addition, a vigorous secondary circulation has been observed using dye releases. While the importance of shelf-break jets in the cross-shelf transport is only starting to emerge, it is clear that they maintain their identity over long distances along the shelf and thus transport shelf water far along the continental margin.

Upper Ocean Processes - The main energy source for upper-ocean processes is atmospheric forcing both by wind stress and buoyancy loss through evaporation and cooling. A central research goal in physical oceanography is to determine these fluxes accurately. Similarly, the interaction of the mixed layer and the seasonal thermocline below determines how the atmosphere affects the stratified ocean over longer time periods. Despite 30 years of measurement and modeling, there are many basic

The Hawaii Ocean Mixing Experiment

The currents associated with the surface tide flow at +/- .05 m/s in Hawaiian waters, in a direction roughly normal to the orientation of the Hawaiian Island Chain. The topography interrupts this flow, generating, in theory, both large, propagating internal waves and local turbulence (Figure 2). While aspects of this process have been previously observed, it has proven difficult to produce a comprehensive picture of the full spectrum of associated phenomena.

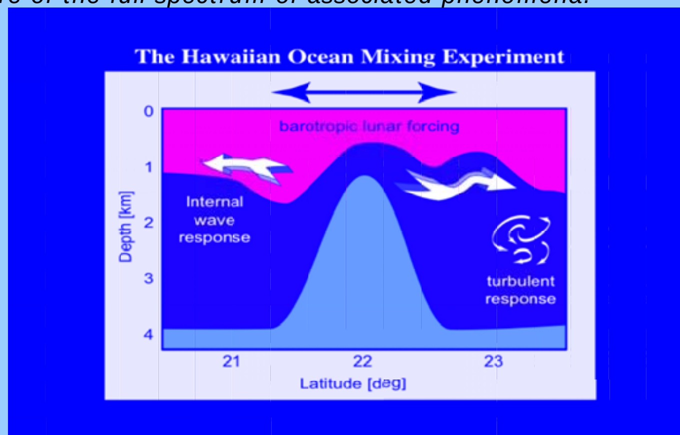


Figure 2. A schematic illustration of the interaction of the surface tide with a ridge-like obstacle. Internal waves can be generated, radiating the tidal energy to distant shores. Alternatively, wave breaking and associated turbulence production can dissipate the energy locally. Figure courtesy J. Nash

The Hawaii Ocean Mixing Experiment (HOME) is a 5-year study of the interaction between tides and topography [7]. More than 20 Investigators from 5 U.S. institutions are involved in this NSF sponsored effort.

In an attempt to penetrate the complexity of the process, three shipboard measurement campaigns (in Fall 2000, 2001, & 2002) were staged, supported by moored time-series, acoustic tomography, satellite and HF radar observations, as well as numerical modeling. The UNOLS vessels Revelle, Wecoma, and Kilo-Moana participated, along with the Research Platform FLIP. The platforms were closely coordinated: as discoveries were made, exploration effort could be redirected in real-time.

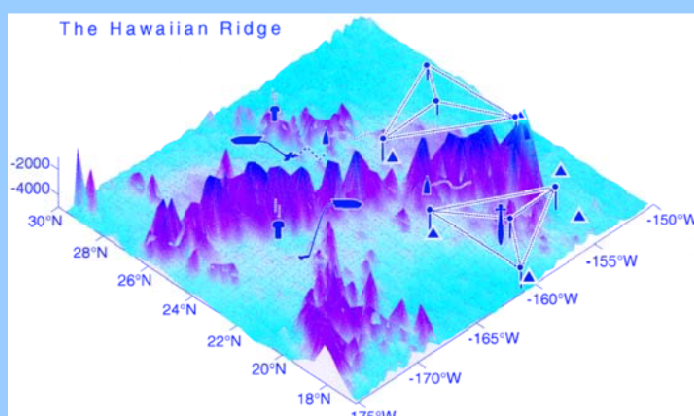


Figure 3. A schematic map of the Hawaiian Ridge extending from Hawaii in the east to French Frigate Shoals. An initial survey was conducted by Revelle and Wecoma in 2000, followed by examinations of escaping internal wave energy (2001) and the details of the generation process (2002). Both moored, free-fall, drifting and towed in-situ sensors were used, along with a variety of acoustic and radar remote sensing techniques.

A host of energetic phenomena were discovered, most modulated by the spring-neap fortnightly cycle of the tides. While the analysis is far from complete, a major finding is that most of the 18-24 10^9 (giga) Watts of energy lost by the surface tide at the Ridge is radiated away as low-mode internal tidal waves. Less than 30% of the total is involved in local turbulent mixing. With this knowledge, we can begin to estimate the large-scale consequences of this highly local ocean mixing.

unanswered questions. What processes are responsible for wind mixing of the mixed layer? What processes, in addition to the obvious buoyancy input by surface warming, cause the deep winter mixed layer to restratify? What is the relative importance of wind-driven turbulence, large eddies in the mixed layer, and turbulence generated by the strong shear found in the upper thermocline to entrainment of stratified waters into the mixed layer? It is critical to understand the dynamics in the upper ocean in order to address climate issues, like whether the ocean can take up CO_2 and at what rate.

***Benthic Boundary Layers* -** Recent observations and modeling efforts have revealed the importance of the benthic boundary in several areas, including transmission of benthic boundary mixing to the interior of the ocean, recirculation/ redistribution of material on continental shelves, determination of the fate of sinking organic matter, and establishment of appropriate boundary conditions for high-resolution circulation models. Making measurements in the benthic boundary layer is difficult. To date, most measurements have been point measurements made by placing instrumenttation on the ocean bottom. There is always a question of whether local topographic effects are dominating the observations. Thus, it is necessary to have accurate high-resolution bathymetry in these regions. It is possible that this small-scale bathymetry will change with time. It is also necessary to make high-resolution horizontal measurements within 5 m of the bottom. Finally, mixing processes are intermittent and require long time-series of measurements.

***Mesoscale Eddies* -** Present observational work has been successful in identifying many of the more energetic classes of surface and subsurface mesoscale eddy motions. The large number of eddies, and the contrast in their energies and properties with the surrounding fluid, make it clear that these eddies can contribute significantly to larger-scale property transport. Also, it is evident that the correlations of velocity and tracer concentrations (such as temperature) are too low in general to be reliably measured at a point with present techniques, thus preventing direct calculations of eddy fluxes. Nevertheless, recent efforts have shown that even small correlations between velocities and concentrations can lead to net transports that have a profound effect on circulation and large-scale distribution of properties in the ocean. This is especially true for climatic studies. More work using numerical circulation models is needed to investigate the effects of the mesoscale eddy field on the larger-scale ocean circulation and property distributions. Also required for significant progress are new field measurements of sufficient duration and spatial coverage to establish the magnitude of eddy fluxes and to test the relation of these fluxes with the larger-scale circulation and property distributions.

Future Facilities Needs and Advances in methodology and technology that will influence physical oceanography:

To address many of the research areas in physical oceanography, measurements will still need to be made from research vessels. Many of the sensors require large amounts of power and produce vast quantities of data such that autonomous sampling systems can only operate for a limited period. Likewise, in order to make as many synoptic measurements as possible, these sampling systems must move through the water at rapid speeds; this power requirement also limits the duration of their mission.

Modern towed and autonomous vehicles offer the chance to explore horizontal scales far shorter than traditionally sampled by the stopping and starting of a ship. It is these scales, typically ranging from the mesoscale (50 km) to the microscale (less than 10 m), that are important for biological processes and for providing critical physical linkages in mixing.

New shipboard sampling technologies need to be developed to improve our ability to study the air-sea interface without disturbing the water surface, the upper meter of the water column, and the atmosphere just above the sea surface. It is particularly important to incorporate new air-sea sampling technologies into the new vessel designs that will allow us to work in higher wind and sea state conditions than presently possible.

Ships must have the telecommunication bandwidth to acquire data from instruments from in the water and air (remote and autonomous vehicles) and communicate with satellites and land. Model and observational data must flow seamlessly from ship to sensor systems to land. Ships must have the ability to launch, retrieve, and communicate with multiple underwater vehicles and with drifting and fixed sensor systems.

C. Biological Oceanography

Biological oceanography is the study of marine organisms and their interactions with the environment. There is a growing appreciation of the role of ocean biology in processes of all scales. UNOLS provides biological oceanographers with access to the sea via surface ships, deep submergence vehicles, and associated instruments. In the coming years and decades, the need for such access will grow to support research needed by society to inform decision and policy makers.

Research Trends, Findings, and Initiatives in Biological Oceanography:

The topics listed below are examples of current and future areas of research in biological oceanography that depends on UNOLS facilities. This list is neither comprehensive nor exclusive. Biological oceanography includes diverse habitats often accessible only with the assistance of research vessels. They include the pelagic and mesopelagic, the shelf, slope, and deep sea, and the Great Lakes. High latitude regions, particularly in the Arctic, are of increasing interest due to their warming and possible loss of ice, increasing their access.

Marine Microbial Ecology – Organisms of the size of microns or less, including viruses, bacteria, and small multicellular organisms, are now known to be abundant and active in both the pelagic and benthic realms, representing a paradigm shift in our understanding of ocean ecology. Perhaps half of oceanic primary production is by autotrophic bacteria (e.g., *Prochlorococcus* and *Synechococcus*). Archaea, small, single-celled organisms that thrive in extreme environments, have recently been shown to comprise a major fraction of the assemblage of deep-sea microorganisms. The roles of microbes in processes ranging from nutrient regeneration to mortality are increasingly appreciated. Technologies ranging from molecular genetics to flow cytometry to confocal microscopy are enabling studies of microbial ecology at sea. Future investigations will include the composition and function of the microbial assemblage, its relation to the environment, and its role in elemental cycles.

Physical-Biological Interactions – This is an overarching theme, yet highlights the need for a capable fleet of research vessels. Variability of biological phenomena is often closely related to the variability of physical phenomena, indicating strong physical-biological interactions. Their investigation requires concurrent observations of physics and biology. Organisms are often aggregated in the pycnocline and at fronts. Such associations have been studied using ship-deployed instruments, including towed, undulating vehicles (e.g., SeaSoar), tethered (e.g., Fido-Phi and other imaging devices), and autonomous (e.g., floats, gliders, and autonomous underwater vehicles (AUVs)) platforms. Turbulence is known to affect small-scale interactions such as plankton feeding, mating, and mortality, and the formation and disruption of aggregates (‘marine snow’, Figure 5).

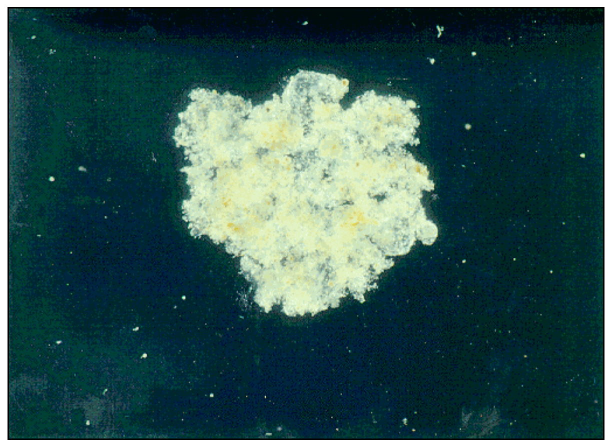


Figure 4. Aggregate (‘marine snow’) - *A marine snow particle of diameter 4mm. This specimen, in common with most from the Atlantic, comprises dead and decaying phytoplankton, zooplankton fecal matter and their exoskeletons. They sink at rates from a few tens of meters per day to several hundred meters per day in contrast to phytoplankton cells which individually sink at no more than 1 m/d and typically 0.1m/d.[10] (Image courtesy of Richard Lampitt, National Oceanography Centre, Southampton, [8]).*

Deep-Sea Biology – The discovery of hydrothermal vents and deep-water methane seeps with chemo-autotrophic production revolutionized biological oceanography and stimulated the investigation of possible life forms both on and beyond Earth. These discoveries were made from surface vessels and deep submergence vehicles (e.g., *Alvin*).

Ocean Perturbation Experiments Show Iron Limits Primary Production

Large areas of the open ocean are rich in nutrients but low in phytoplankton, so-called HNLC (high nitrate, low chlorophyll) regions. John Martin hypothesized that the micro-nutrient iron limited primary production in these areas. Shipboard incubation experiments with water from these regions were consistent with this hypothesis but were subject to container effects. Martin proposed the ultimate test – in situ fertilization of HNLC waters with iron and subsequent monitoring of its effects. Since then, numerous iron fertilization experiments have been conducted in HNLC regions around the globe, many using UNOLS vessels. The goal of these experiments is to understand the effects of added iron on ocean biogeochemistry, including primary production and its fate. In particular, great interest exists in whether primary production stimulated by added iron sinks below the surface ocean, thereby sequestering atmospheric carbon.

One such program was SOFex, the Southern Ocean Iron Enrichment Experiments [9]. Iron and SF_6 (a water mass tracer) were added to two regions in the Southern Ocean, north and south of the Antarctic Polar Front Zone. The RVs Revelle and Melville subsequently were used to sample these regions. This figure shows satellite images of the two patches (N, from MODIS; S, from SeaWiFS) with enhanced chlorophyll concentrations resulting from iron enrichment.

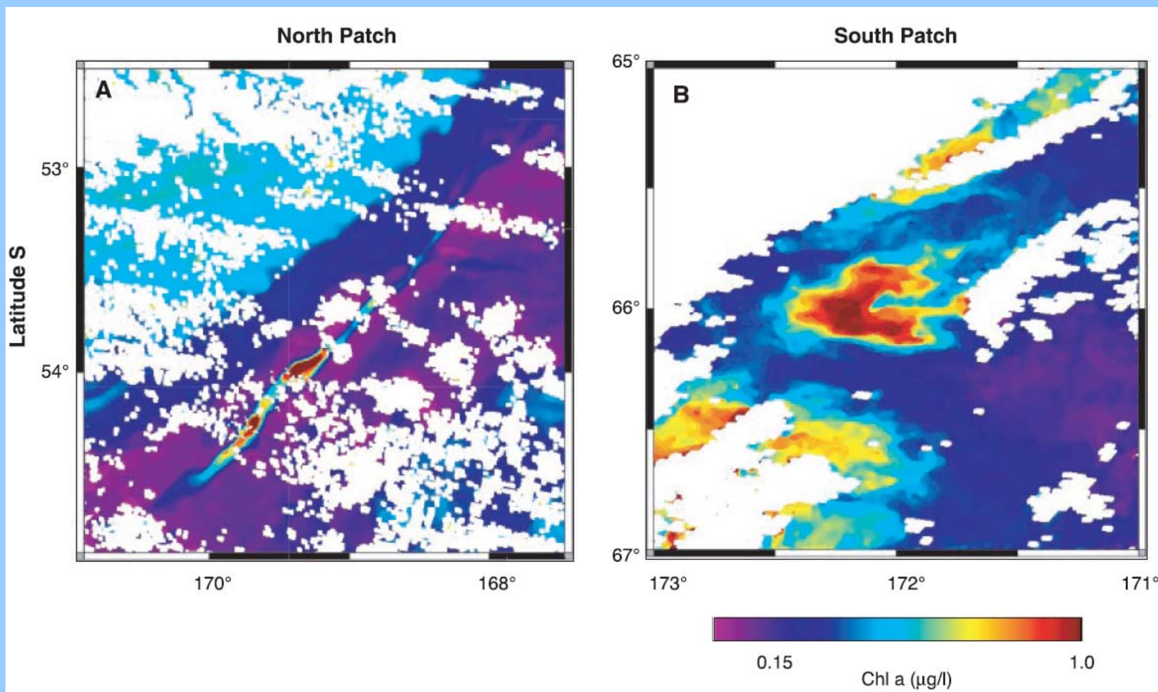


Figure 5. Satellite Images of Ocean Patches Enhanced with Chlorophyll. (Image provided by Kenneth Coale, Moss Landing Marine Laboratories))

Each of these blooms consumed over 30,000 tons of carbon dioxide, an important greenhouse gas. Much of the carbon sank to hundreds of meters below the surface. SOFeX showed that even where silicic acid levels are low, iron fertilization can result in blooms of phytoplankton that do not require silicon for growth yet still consume vast amounts of carbon dioxide. The debate over the effects and uses of iron fertilization and its potential for carbon sequestration continues [10].

The National Science Foundation's (NSF's) Ridge 2000 program focuses, in part, on ecosystems associated with volcanic and hydrothermal processes that occur along oceanic spreading centers and back arc basins (Figure 6) [11]. It includes both integrated, multidisciplinary studies and time-critical studies, the latter focusing on transient events (such as formation of new vents) and thus a rapid response of UNOLS vessels. Benthic-pelagic coupling and links to climate change are other areas of active interest. Variation in flux of organic matter to the sea floor, and its utilization has been shown to be related to upper ocean processes on time scales from days to decades. Ship-based sampling of the water column and benthos, and deployment of equipment, from sediment traps to autonomous benthic vehicles, has enabled these discoveries.

Figure 6. Hydrothermal vent fauna - Hydrothermal vent organisms, including vent fish, a brachyuran crab, and tube worms. [12]

Biological Pump – The downward flux of organic matter mediated by biological processes is an important component of the global carbon cycle. This flux – the biological pump – is comprised of passive and active components, e.g., sinking particles and vertically migrating plankton and fish, respectively. Ships have been and will be critical to study the biological pump using both observational and experimental approaches. The "Martin curve", showing an exponential decline in passive flux with depth, is widely accepted yet is also known to represent the average state of a highly variable process. Ship-intensive studies, such as of the North Atlantic bloom and iron enrichment experiments, strive to better understand the fate of surface primary production by studying particles and plankton using vessel-deployed instruments and platforms, and floating sediment traps, buoys, and moorings. The mesopelagic is a region of great importance to the biological pump, yet it remains poorly known. A major focus of research on the biological pump will therefore be in the mesopelagic, which is accessible primarily from research vessels.

Land-Sea Interactions – The margins of the sea, including the shelf and slope, and water column and bottom, are of increasing interest and importance to science and society. They are the oceanic regions most impacted by human activity. These impacts result from dams, pollution, and resource exploration and removal. The need to study the effects of these activities will only increase. Harmful algal blooms (HABs) and 'dead zones' are consequences of coastal eutrophication. Changes in temperature, stratification, and hydrography, predicted to result from climate change, will necessitate greater study of these phenomena and the coastal ocean to protect the health of humans as well as the ocean.

Population Connectivity – The connections between populations are now acknowledged as fundamental to their dynamics and our management of them, including the use of marine protected areas. Studies of connectivity are often coastal and rely on a combination of observation, experiment, and modeling. As marine populations and their environments continue to be impacted by humans, and human use of these populations increases, the need to study connectivity will grow, with particular needs for UNOLS vessels operating in the coastal zone.

Perturbation Experiments – Much has been learned, and many questions raised, from large-scale perturbations, primarily iron enrichment, experiments. Such perturbations usually are, but need not be, by humans. Rather, a patch of ocean can be 'marked', e.g., with SF_6, a chemical tracer, and resampled over time in a Lagrangian frame of reference. Added iron has been shown to stimulate, and thus has limited primary production in high-nitrate, low chlorophyll (HNLC) regions of the world ocean. Similarly, marked water can be followed and resampled to study, for example, the spring bloom. Such large-scale perturbation experiments are more natural than and complement those using enclosures. They also rely heavily on UNOLS vessels. Smaller-scale manipulations done via Remotely Operated Vehicle (ROV) and submersible provide different kinds of information about ecological processes (such as succession, habitat selection, and ecosystem engineering), biodiversity maintenance, physiological tolerances, and trophic interactions.

Ocean Acidification – The absorption by the ocean of carbon dioxide from the burning of fossil fuels is altering its chemistry. Total CO_2 is increasing and alkalinity and pH are decreasing; a phenomenon termed ocean acidification. These chemical changes, which are predicted to continue, have potentially profound impacts on ocean biology. Acidification increases the dissolution of biogenic carbonates, including coral skeletons, coccoliths of phytoplankton (Figure 7), mollusk larvae, and shells of pteropods (Figure 8), a type of zooplankton. Changes in the concentration of inorganic carbon also affect primary production and biomineralization. This is a new, active, and fast-developing area of research. Studies at sea of inorganic carbon chemistry, and its effects on biota, from individuals to ecosystems, will be a prominent focus in the future. Such studies might include manipulation and/or enclosure experiments in open water, requiring research vessels.

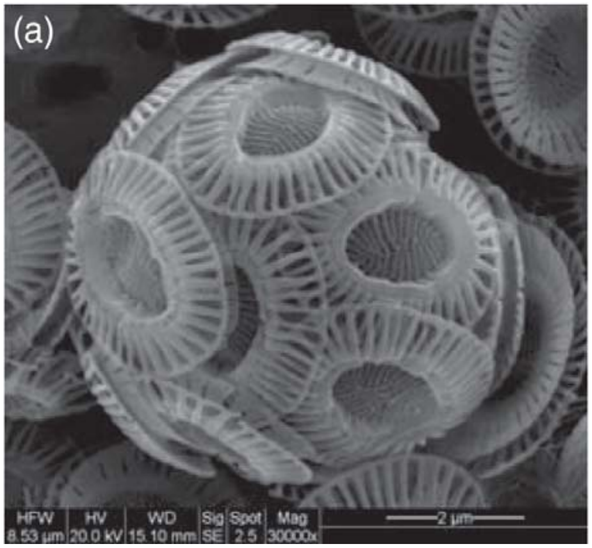


Figure 7. Coccoliths - The coccolithophore *Emiliania huxleyi* [13] (image courtesy of V. Fabry)

Figure 8. Limacina_leseuri - Pteropod mollusk (image courtesy of R. Hopcroft, UAF) [14]

Biodiversity and Conservation – Biodiversity is a key, emergent characteristic of marine ecosystems. Human activity reduces biodiversity by the alteration of habitat and removal of individuals. Activities such as fishing, eutrophication, and warming are now known to affect the diversity of pelagic and benthic communities. Jellyfish (e.g., Figure 9), in particular, are increasing in abundance worldwide, with potentially important implications for pelagic ecosystems and their use by humans. The conservation and sustainable use of resources depends on our knowledge of those resources and an understanding of how human activities affect them.

Figure 9. Jellyfish – Medusa (image courtesy of R. Hopcroft, UAF)

Exploration – The search for new species, habitats, and ecosystems in the sea continues. Recent sampling of marine microbes has revealed unexpectedly high diversity from the ocean surface to the deep sea. New species of marine fish continue to be described at the same rate as over past decades. Exploration of the mesopelagic has yielded new species of squid and other organisms. Vents and seeps were discovered relatively recently. Collectively, these and other discoveries demonstrate that much remains to be known of biology in the ocean.

Sustained Observing – Last in this list of examples, but by no means least, is observing. Change is measured against a baseline. Sustained, long-term observing is necessary to assess change, be it due to natural or anthropogenic causes. In fact, a major challenge is to distinguish the contribution of these two causes to observed variation. Example programs include the Hawaii Ocean Time-series (HOTS), the Bermuda Atlantic Time-series Study (BATS), the California Cooperative Fisheries Investigations, and the Long-Term Ecological Research (LTER) programs (e.g., in the California Current and the Antarctic). The Ocean Observatories Initiative (OOI), with related programs, will greatly enhance long-term observing of marine ecosystems. A variety of types of observing platforms will be used, including buoys, Autonomous Lagrangian Platforms and Sensors (ALPS), submersibles, and ships. Collectively, the resultant observations will provide an unprecedented view of the ocean, including its biology. In each case, however, ships are essential for both deploying and maintaining these platforms, but also for complimentary sampling and process studies. This is particularly true for biological oceanography.

Future Facility Needs, Advances in Methodology, and Technology that will Influence Biological Oceanography:

The future seagoing needs of biological oceanographers will grow, particularly in light of climate change and the increasing demands of decision makers. The wide range of scales and issues present significant challenges.

Sea-going research in biological oceanography will be increasingly interdisciplinary. Areas from physical-biological interactions to acidification require scientists from a wide range of disciplines to work at sea together. Research ships should have the capacity for such studies, including large science parties and adequate lab and deck space. Vessels should be adaptable for a range of activities, from ROV deployment with fiber optic cables, to mesopelagic trawling and deep-sea multi-coring, to the launch and recovery of ALPS, often with two or more such activities on one cruise. At times, more than one ship is warranted.

The technological demands of biological oceanography will also continue to grow. Water-column and sea-floor mapping is often desired, as is the continuous, underway measurement of physical, chemical, and biological variables. Dynamic positioning is needed for benthic sampling, ROV deployments, and the recovery of floating arrays and autonomous vehicles. Ship cleanliness is essential to ensure accurate measurements of water properties, from trace metals to primary productivity.

There is a particular need for increasingly capable remote observing and sampling from ships. Video-guided sampling both in the water column and on the bottom requires improved cameras, fiber optic cables, winches to deploy these, and command and control capabilities. The demand for ROVs will continue to increase. These should be more maneuverable with enhanced observing and sampling capabilities. Floats, gliders, and AUVs extend the capability of ships and their use will grow.

Instruments once used only on land will be used more at sea, both shipboard in the lab and, increasingly, in situ. Examples include flow cytometers, mass spectrometers, and gene sequencers. Often, a necessary step in the development of in situ technology is its use at sea on or from a research vessel.

Communications is a transcendent theme. This includes sea-to-ship, e.g., fiber optic cables and acoustics; within-ship, including fiber optic and wireless networks; and ship-to-shore, e.g., via satellite. Gene-sequencing machines, for example, now produce data on the terabyte scale. High-resolution cameras produce gigabytes of data. The remote operation and observation of instruments will require video links ashore. Retrieval of autonomous instruments requires constant communications, usually via satellite. Thus, biological oceanography is changing to depend more in the future on reliable, high-bandwidth communications between sea, ship, satellite, and shore. Reliable high-bandwidth communications will improve efficiency, maximize data return, sample at rates appropriate to the time scale of processes being studied, and sample long enough to capture seasonal to interannual variations that enable scientists to assess ocean health and guide political decisions on management of national and world resources.

D. Marine Geology and Geophysics (MG&G)

Marine geophysical techniques, combined with geological sampling and direct observation of the seafloor, provide the principal means of mapping and characterizing the seafloor. It provides a means for determining the stratigraphy, composition, and structure of the sub-seafloor and establishing the processes that shape seafloor morphology and the formation and development of the sub-seafloor, both within the sediments and the solid earth.

Research Trends, Findings, and Initiatives in MG&G:

There has been a general shift in the emphasis of MG&G research over the past several decades from global reconnaissance geophysical surveying and sampling to more detailed problem-oriented studies. This has been accompanied by the establishment of specific focus sites by both the Ridge 2000 and the MARGINS programs for intensive, multi-disciplinary investigations. As a result, research has tended to become more interdisciplinary in nature. It is often necessary to integrate perspectives/concepts, techniques, and data types not only from multiple subdisciplines of MG&G, but also from ocean engineering and biological, chemical, and physical oceanography to successfully address scientific problems. It is also often necessary to collect at least a portion of the data used in a research effort over a significant interval of time that may span weeks, to months, to years. In some cases, such as with a passive seismic array, long-term deployments are necessary to obtain sufficiently dense data. In other cases, the objective is to obtain a time-series of data, such as through a tectonic and/or magmatic cycle at a mid-ocean ridge.

Several of the main areas of geological research that are ongoing and likely to continue to be important in the foreseeable future are briefly described below. This list is not meant to be all encompassing nor does the order imply research priority.

Paleoceanography and paleoclimatology: climate and sea-level change **-** Changes in global climate and associated fluctuations in sea level have the potential to affect society in momentous ways during the next one to two hundred years. This reality provides great impetus to research designed to address scientific issues associated with climate and sea-level change in direct or ancillary ways.

Researchers investigate issues associated with climate variability that occur over a wide range of timescales. The following are a few examples of the current research foci: Climatic and oceanic conditions associated with interannual variations of global climate are well known for their impact on the tropics (e.g., El Niño/Southern Oscillation phenomena); significant interdecadal variations of extratropical climate also occur. Long, detailed records of climate are being constructed based upon analyses of corals, marine sediments, and other geologic archives to characterize the temporal and spatial nature of such variations during the past millennium. Understanding climate variability prior to the industrial revolution is necessary to evaluate the extent of anthropogenic influences. Investigations of marine sediments are also being used to address one of the most prominent issues in current climate research - the stability of global thermohaline circulation. It is well established that the thermohaline circulation was involved in the climate reorganizations that punctuated the late Pleistocene; resolution of the actual mechanisms that promoted an unstable thermohaline circulation during the late Pleistocene is a prerequisite for assessing whether past abrupt climate change events are relevant for present and future climate. Finally, by investigating certain periods of warm climatic conditions that occurred during the geologic past (e.g., during the Eocene and Oligocene) useful insight into aspects of potential future climatic conditions can be obtained.

Fluctuations in sea level are intimately linked with climate change. Investigations of the sea-level rise during the last glaciation provide constraints on the timing and mechanisms of global climate change. Since most of the world's population lives with a few meters of sea level, another significant research area addresses how and why sea level has varied during the past century and the trends predicted for the near future.

Climate and sea-level research commonly unites observational approaches, model simulations, and theory to characterize the aspects of the system and understand the mechanisms that drive change or enhance stability. Marine geological proxies preserve long, high-fidelity records of the global climate/sea level and the intimate roles played by oceanic processes in this system. The ultimate aim of this research is to provide a scientific basis for predicting future climate/sea level and developing sensible social policies.

Coastal, shelf, and slope sedimentary processes – Several major research programs currently focus on various aspects of the sedimentary systems associated with continental margins. Investigations consider the generation, transport, and dispersal of sediments along different types of margins, including the specific terrestrial and oceanic processes involved, as well as the overall controls by tectonic processes and sea level. One of the major programs shaping research in continental margin sedimentation is the "Source to Sink" (S2S) initiative of the MARGINS program [15]. This initiative mandates a comprehensive, integrated study of the entire system of sediment generation, transport, and deposition at two continental margins located in very different tectonic settings with the goal of both understanding the processes at work and of providing a physical basis for understanding and interpreting sedimentary deposits in the geologic record. The guiding questions developed at a series of S2S workshops are:

1) How do tectonics, climate, sea-level fluctuations, and other forcing parameters regulate the production, transfer, and storage of sediments and solutes from their sources to their sinks?

2) What processes initiate erosion and transfer, and how are these processes linked through feedbacks?

3) How do variations in sedimentary processes and fluxes and longer-term variations such as tectonics and sea level build the stratigraphic record to create a history of global change?

Scientists Discover Secrets of 'Lost City'

Figure 10. A 5-foot-wide flange, or ledge, on the side of a chimney in the Lost City Field is topped with dendritic carbonate growths that form when mineral-rich vent fluids seep through the flange and come into contact with the cold seawater. (Photo credit: University of Washington/Woods Hole Oceanographic Institution)

Hydrothermal vent structures discovered on Dec. 4, 2000, in the mid-Atlantic Ocean, including a massive 18-story vent structure taller than any seen before, are formed in a very different way than ocean-floor vents studied since the 1970s. This new class of hydrothermal vent apparently forms where circulating seawater reacts directly with mantle rocks, as opposed to where seawater interacts with basaltic rocks from magma chambers beneath the seafloor. Until this discovery, scientists may have underestimated the extent of hydrothermal venting, the amount of heat and chemicals pouring into the world's oceans and the abundance of life that thrives in such conditions.

The Lost City Field was discovered during an NSF-funded expedition on the R/V Atlantis led by Scripps Institution of Oceanography's Donna Blackman, University of Washington's Deborah Kelley, and Duke University's Jeffrey Karson.

The Lost City Field is unlike other hydrothermal vent systems in a number of ways. First, there is the height attained by some of the structures; the 180-foot vent scientists named Poseidon compares to previously studied vents that reach 80 feet or less. The new vents are nearly 100 percent carbonate, the same material as limestone in caves, and range in color from a clean white to cream or gray, in contrast to black smoker vents that are a darkly mottled mix of sulfide minerals. And perhaps the Lost City's most distinctive feature is that it is sitting on 1.5 million-year-old crust formed from mantle material. [16]

In addition to the large-scale programs, there is and will continue to be a large amount of research aimed at understanding the sedimentary, ecological, and tectonic history of bays, estuaries, and the continental shelf along the entire coast of the United States. These studies, which are one of the primary uses of the coastal and regional class ships, are aimed at answering the same type of questions, but on a local scale. They are essential for undertaking knowledgeable policy decisions on development and for understanding, conserving, and managing local environments and resources.

MG&G studies of coastal, shelf, and slope sedimentary processes generally require high resolution swath bathymetry (using systems designed for shallow water) and sidescan data, high resolution sub-bottom profiling systems including CHIRP, and in some cases high-resolution Multi-Channel Seismic (MCS) reflection systems, piston coring, and other nominally "oceanographic" equipment such as current meters. High-resolution navigation systems are necessary. AUVs and ROVs will play an increasingly important role in these studies as they become smaller and easier to deploy from small vessels.

Geologic hazards - While geologic hazards are partially addressed by studies of tectonic processes and continental margin sedimentary processes, the topic has recently gained prominence on its own. Large near-shore earthquakes, typically associated with subduction zones, have significant societal implications by themselves and may also generate destructive tsunamis affecting areas far beyond the actual earthquake. Other mechanisms for tsunami generation under investigation include slope failures associated with sediment mass loading, or instabilities created by the disassociation of gas hydrate deposits. As the tragic events associated with the 2004 Southeast Asian tsunami demonstrated, there is a vital societal need to understand and predict where tsunami effects may occur.

All of these studies require, in particular, high resolution swath mapping and seismic reflection studies to understand both the geological setting and the nature of the deformation resulting from the event. In the case of mass wasting, coring to determine the nature of the detachment surface is also necessary.

Gas hydrates – Gas hydrates, hydrocarbons - mainly methane - trapped in an ice-like crystalline lattice consisting of water molecules, were mentioned above as a possible source of continental slope instability when environmental changes cause their disassociation and changes in sediment pore pressure. Hydrates are also the subject of intense investigation because of their potential as an energy resource and their role in carbon sequestration. Potential gas hydrate stability zones occur in two distinct locations, continental slopes at water depths greater than a few hundred meters and areas of permafrost in the Polar Regions. There have been several Ocean Drilling Program (ODP) and Integrated Ocean Drilling Program (IODP) drilling legs specifically aimed at investigating gas hydrates in various settings, as well as other geophysical studies, primarily seismic, aimed at understanding the extent and nature of gas hydrate formations.

Much research effort is presently going into to studying how hydrate deposits are formed and the amount of gas actually present in potential regions of potential instability. This is of interest both to determine the extent to which they are exploitable as an energy resource and to assess the potential release of methane as the result of global warming. Such destabilization could result in a strong feedback mechanism accelerating global warming. The latter issue is particularly crucial in the Arctic, where large areas of permafrost exist on broad continental shelves, particularly north of Siberia.

Mid-ocean ridges – Mid-ocean ridges have been the subject of geophysical investigation since they were first recognized in the early 1950s. Reconnaissance geophysical data, in particular bathymetry and magnetics data were crucial to establishing the reality of plate tectonics and establishing many of its tenets including the systematic relationship between seafloor depth and plate age, and the long-term stability of rotational poles. Submersibles, and recently ROVs and deep towed instrument packages, have been extensively used for detailed studies of ridge axis processes. Gravity data have been particularly useful in investigating magmatic segmentation and melt distribution, and flow beneath ridge axes.

Under the NSF Ridge program, a philosophy developed of reconnaissance and regional studies to understand the nature of the mid-ocean ridge system through its entire range of environmental parameters combined with intensive study of "type-areas" such as the 9°-10°N section of the East Pacific Rise. The current Ridge 2000 program [11] has adopted a different philosophy of concentrating on a few Integrated Study Sites (ISS) that will be developed as "type areas" for intensive multidisciplinary studies to thoroughly characterize these segments as integrated volcanic, hydrothermal, and biological systems. The emphasis on developing observatories at a few locations will require the ability to deploy, maintain and retrieve instruments at these sites. This will also include a greater emphasis on human-occupied submersibles, ROVs, and AUVs to carry out these studies. The Ridge 2000 program also includes a "time critical studies" component that requires the ability to assemble and deploy necessary instruments for rapid response to volcanic and other transient events on oceanic spreading centers to observe, record, and sample critical transient phenomena as they happen. This initiative will require both a pool of available instrumentation and flexibility in ship deployment to be able to carry out these studies on short notice.

In addition to the intensive local studies supported by the Ridge 2000 program, regional studies of the entire global mid-ocean ridge system will continue. These studies investigate a wide range of problems; origins of magma and the mechanisms by which it is emplaced beneath ridges; processes associated with the architecture and structural evolution of ridge systems; formation and characteristics of lithospheric components; hydrothermal circulation and related rock deposits, communities of organisms, and alteration of rocks and sediments; etc. Much of the present and probable future emphasis in these studies is on intermediate (Galapagos, Juan de Fuca, and Southeast Indian) and extremely slow (Southwest Indian and Gakkel) spreading rate ridges. Intermediate spreading rate ridges are important because they are a class of ridges where a wide variety of axial morphologies are found at similar spreading rates. They thus represent an opportunity to determine exactly how small variations in a number of geophysical parameters such as mantle temperature affect the process of crustal and lithospheric creation. Extremely slow spreading rate ridges are important because they represent an end member situation and allow predictions of models developed at higher spreading rates to be investigated. Also, because of the low amount of melt generated at very low spreading rates, they represent an opportunity to sample nearly unaltered mantle. In addition to swath-bathymetry and sidescan mapping, seismic reflection and refraction experiments, and potential field measurements, studies of these areas will also include an important rock-sampling component.

Convergent plate boundaries – While divergent plate boundaries (mid-ocean ridges) are of interest as the location where oceanic crust and lithosphere are created, convergent boundaries (subduction zones) are equally important as the site of the creation of most continental crust. These regions are also of societal import because they host the majority of large destructive earthquakes, explosive volcanism, and important ore deposits.

The NSF MARGINS program has two major initiatives aimed at understanding plate convergence and subduction. One initiative, the “Seismogenic Zone Experiment” (SEIZE), focuses on the physics and mechanics of the shallow subduction plate interface that is locked and accumulates elastic strain that is periodically released in large or great earthquakes, often tsunamigenic. These studies will require the deployment and retrieval of arrays of Ocean Bottom Seismometers (OBSs) for passive seismic monitoring, the emplacing and servicing (by IODP drilling) of long-term observatories sampling deeply sourced fluids and monitoring fluid temperatures, pressures, flow rates, and compositions through the seismic cycle. They also will require significant 2-D and particularly 3-D seismic reflection studies to image the plate interface.

A second MARGINS initiative the “Subduction Factory” focuses on the role of plate subduction in the development of ore deposits, geothermal energy and the creation of continental crust. The program addresses problems related to magmatism and fluid flow, volatile cycles through continental margins, mass balance, and the growth of continents. These studies will require bathymetric swath mapping to provide data from the subducting plate and leading edge of the upper plate as well as from the submarine portions of the arc and backarc regions. The mapping data provide bathymetric images of the interaction between the plates including faults that may become conduits for fluid flow and give information on processes such as sediment prism evolution, frontal accretion, development of the deformation front, and subduction erosion. They will also require active source seismic techniques, including 3-D seismic reflection studies that can provide detailed images of the décollement zone and the structures above and below. For example, a 3-D data set from Barbados mapped the location of aqueous fluids along the décollement as well as in faults extending into the overlying sediments. Deployment of OBS arrays for active seismic experiments to provide tomographic images and velocity information within the sediment prism will also be needed.

Rifted continental margins – “Passive” continental margins mark locations at which the continental lithosphere was ruptured to form new ocean basins. The rupturing of continental lithosphere to establish new ocean basins is one of the fundamental processes shaping the development of the Earth's surface with important consequences for oceanic circulation, climate, and the distribution and concentration of natural resources. Nearly all of the passive continental margins of the Atlantic, Indian, and Arctic Oceans were formed by the nucleation of an oceanic spreading center within a continental rift that developed within old "cratonic" lithosphere. Other areas of continental rifting, such as the Gulf of California and the Woodlark basin have developed by the propagation of a mid-ocean ridge through young, weak, continental lithosphere in active orogenic areas.

The NSF MARGINS program, Rupturing Continental Lithosphere (RSL) initiative, focuses on studying two actively rifting and complete rifts. The problems to be investigated during these programs center on a set of themes laid out in the MARGINS Science Plan [15]:

- How does the strength of the lithosphere evolve during rupturing?
- How is strain partitioned during lithospheric rupturing?
- What is the role of magmatism (and volatiles) during extension and in the transition to sea-floor spreading, and what is the relationship between magma petrogenesis and the deformation magnitude and history?
- What is the stratigraphic response to lithospheric rupturing?
- How are fluid fluxes modified or controlled by lithospheric rupturing?

In addition to the MARGINS sponsored work on two actively rifting continental margins, intensive study will continue on older "passive" continental margins with the goal of understanding both how magma-rich and magma-starved margins form and evolve in a number of different tectonic settings. Studies of magma-rich margins, typically characterized by packages of dipping reflectors in MCS reflection images are particularly timely because both MARGINS sites are not characterized by the copious magmatic activity. Also studies of many magma-starved continental margins, notably the conjugate Iberian and Canadian margins in the North Atlantic show many features not found at the MARGINS sites, such as large areas in which isolated blocks of continental upper crust are found resting on exposed mantle rocks. Understanding how these margins formed and how and why they are different from the current actively forming continental margins is essential for obtaining a full understanding of continental rifting.

Archeological oceanography - Archeological oceanography is allied closely with geological oceanography. It is the integrated application of archeological and oceanographic techniques to investigate the cultural significance of submerged sites (beyond the capability of a diver) and their impact on the environment. This nascent field has come about because as nautical archeologists conducted research in deeper waters several things were apparent: First, non-intrusive marine geophysical techniques are essential for archeologists to locate and determine the extent of submerged cultural sites (e.g., shipwrecks, habitation sites, modern cultural artifacts, etc). Second, techniques employed by geological oceanographers provide archeologists with the effective means to excavate sites in deep water. And finally, to best understand the cultural and environmental significance of such sites as well as their impact on the environment, archeologists must consider their findings in the context of the oceanographic processes active at the sites.

Integrated Ocean Drilling Program - The IODP is a large international program that conducts expeditions to study the history and structure of the Earth as recorded in sediments and rocks beneath the seafloor [17]. The three major components of the IODP Science Plan are the deep biosphere, environmental change and solid earth cycles, and geodynamics. IODP operations are carried out on two drilling vessels, *Chikyu* and *JOIDES Resolution* as well as mission specific platforms of opportunity. These vessels are not part of the UNOLS fleet. However, the NSF ODP Program does fund research activities utilizing UNOLS vessels in support of future IODP drilling. This work includes site surveys, instrument development and testing, and other necessary activities to prepare for future drilling endeavors. Because of the need to carry out site surveys, ODP is a significant user of the UNOLS dedicated seismic vessel (*R/V Ewing* in the past, *R/V Marcus G. Langseth* in the future).

Future Facility Needs and Advances in Methodology and Technology that will Influence MG&G:

The success of current and future research in marine geology and geophysics depends upon continual improvements in several aspects of shipboard facilities. Very precise and accurate navigation is essential. All types of research require more accurate and detailed knowledge of the seafloor bathymetry and character of surficial sediments within study area sites. Consequently, state-of-the-art multibeam, sidescan, and high-resolution subbottom profiling systems are necessities for all regional and larger-sized vessels. Availability of portable multibeam systems for deployment on ships of opportunity is also desirable. High resolution multi-channel seismic reflection data are necessary for many studies of sediment stratigraphy and a portable system that can be deployed on regional and larger ships should be maintained as a national facility. Similarly, underway geophysical sensors including gravimeters and magnetometers should be available as needed on ships where they are not permanently installed.

Increased utilization of ROVs and AUVs to collect precisely-located high-resolution images, deploy sensors, and collect samples will be needed to achieve research goals. Ships must have an effective dynamic positioning system to utilize these tools. Sediment coring and rock dredging are mainstays for many types of marine geological and climate research, and the ability to collect surficial sediment by box core or multi core needs to be fostered. Continued advances in climate and geological research require long, high-resolution marine sediment records with sufficient volumes of sediment to allow the application of the array of recently developed geochemical techniques. This requirement means that the ability to collect sediments with wide-diameter piston cores of 10 to 50 meters in length needs to become readily available on a range of ship sizes in the oceanographic fleet.

The riserless and riser drilling ships of IODP now provide the only existing means to collect smaller-diameter, but much longer cores essential for studies of older portions of the marine geologic record from a range of environments, as well as providing the means to collect rock samples and a suite of down-hole geophysical data. Such facilities need to be maintained for the foreseeable future.

Finally, for our research efforts in certain areas of MG&G to remain competitive, the ability to collect high-resolution 2D and 3D multi-channel seismic data must exist. While 3D multi-channel systems have been standard in the oil and gas industry for a number of years, this capability has just recently been introduced to the UNOLS research fleet with the arrival of *R/V Marcus Langseth* in 2008.

E. Chemical Oceanography:

Historical and Developmental Aspects:

The field of chemical oceanography occupies a pivotal position in the ocean sciences and forms a number of essential interdisciplinary linkages between other fields of study. For much of the 19th and 20th centuries, chemical oceanography had as its charge assessing the distributions of the elements and their key molecular forms throughout the oceans, and understanding the processes controlling material inputs to and removal from seawater. At its most fundamental, the study of chemical substances in seawater has long been among the most difficult due to formidable challenges in associated analytical chemistry (e.g., issues of detection limits, accuracy, and precision) and in the development of specialized sampling and sample handling protocols (i.e., to minimize background levels of the target substance), that are often entirely unique for different elements. As a result, much of the history of chemical oceanography has been concerned with establishing the validity of analytical measurements and accurately determining the amounts and distributions of the various substances (e.g., minor and trace elements and materials) in seawater.

It was not until the last few decades of the 20th century that marine chemists were able to systematically confront the analytical and sampling challenges that had plagued the field for much of its history. These advances resulted largely from i) new technologies in chemical analyses and measurements, and ii) new methods and approaches of clean sample collection, assisted by the development of new and more widely available "clean" materials and protocols for sample collection and handling. The result has been a fuller and more accurate appreciation of the exceedingly low concentrations that many elements and substances occur in seawater, and the dominant processes controlling their distributions throughout the oceans. At the root of these advances has been access by chemical oceanographers to remote, relatively non-impacted open ocean environments in order to collect seawater and other materials on which to conduct these analyses.

Chemical oceanography has also evolved over the past several decades from a discipline concerned primarily with measurements of "static" parameters such as simple solute concentrations and their two and three-dimensional distributions, to a robust, multi-faceted and highly dynamic field that uses inorganic and organic chemical (including isotopic) tracers as forensic tools to decipher both gross and ultra-fine-scale processes in i) ocean physics (e.g., from advective basinal to diffusional cellular scales), ii) ecosystem processes (e.g., gross and net primary production, to trace element limitation of enzyme activity and molecular biological tools), iii) geochemistry (e.g., global elemental mass balances, to microscale exchanges across interfaces), and iv) paleoenvironmental studies (e.g., from glacial-interglacial timescales, to decadal and shorter).

Starting in approximately the 1970s and the era of the ambitious Geochemical Ocean Section Study (GEOSECS) and Transient Tracers in the Oceans (TTO) global ocean surveys, chemical oceanography has been recognized as a primary Earth sciences discipline for understanding ocean and global mass balances and processes across all scales and sub-disciplines. Large-scale ocean survey programs for chemical and geochemical measurements will continue for the foreseeable future (for example, the Climate Variability and Predictability (CLIVAR) and World Ocean Circulation Experiment (WOCE) programs repeat survey lines and transects as well as new programs on the horizon) in an attempt to better constrain and understand temporal and spatial changes in various parameters resulting from both natural and anthropogenic drivers. As a result, and with some notable exceptions (see below), chemical oceanography will in the future rely to at least as great an extent as other fields of oceanography on reliable, state-of-the-art sea-going platforms for in situ sampling, analyses, and experimentation. These activities include not only collections of contamination-free seawater for solute analyses, but also for heterogeneous particulates, sediments and associated pore waters, dissolved and atmospheric gases as well as other phases of materials (e.g., colloidals, aerosols, etc.). Without the capability of directly collecting seawater and other sample types with the highest levels of quality and degrees of temporal and spatial resolution, our ability to follow and predict numerous critical parameters and processes in the ocean and in coupled air-sea and land-sea systems will be significantly compromised, and is ill-affordable at such a time of unprecedented global environmental change.

Access to direct sampling platforms will continue to be supplemented to an increasing extent by autonomous and remote sampling platforms (e.g., moored chemical sensor arrays and earth-orbiting satellites) as new technologies are developed and perfected for long-term global ocean monitoring efforts (see Figure 1). However, these developing technologies will not supplant the need for at-sea sampling and analyses from oceanographic vessels.

Ongoing and Future Research Trends and Initiatives in Chemical Oceanography:

Following the conclusion of the Joint Global Ocean Flux Study (JGOFS) [18] in the early 21st century, and in addition to independent research and core programmatic research, the U.S. chemical oceanography community participated in a number of planning exercises for next-generation large-scale ocean chemistry research programs. Among these have been the Future of Ocean Chemistry in the U.S. (FOCUS) workshop and report [19] and the Ocean Carbon and Climate Change (OCCC) Program component of the U.S. Global Change Research Program Carbon Cycle Science Program and the U.S. Climate Change Science Program [6]. These community efforts have helped to identify a number of key ongoing and future research trends and initiatives in chemical oceanography and related disciplines that have a significant bearing on sea-going sampling platforms and related needs. A noninclusive selection of these major trends and initiatives is highlighted below.

Air-sea interactions, atmospheric chemistry and photochemistry **-** Continued improvement in our models and estimates of radiatively important trace gas fluxes between the atmosphere and oceans depends critically on enhanced capabilities for measuring both the concentrations of these gases, and the properties of the sea surface microlayer that control their fluxes over a variety of scales of time, space, and sea state (see, e.g., the Surface Ocean Lower Atmosphere Study, (SOLAS) [20]). In addition to trace gases, our understanding of atmospheric inputs of nutrient elements (both major and trace) and organic matter (both natural and anthropogenic) and the importance of these atmospheric inputs to ocean biogeochemistry has undergone major revision over the past decade, and will continue to do so. As a result, the ability of earth and ocean scientists to measure geochemically relevant constituents in air in remote oceanic environments will be increasingly important as our appreciation for the role and impact of air-sea fluxes of these materials grows. Similarly, recent insights into the significant effects of natural sunlight on both inorganic and organic chemical reactions and processes in the ocean, on the biological availability of substances to microorganisms, and the effects of sunlight on planktonic organisms themselves has resulted from our ability to deploy increasingly advanced instrumentation at sea for these experiments and measurements. These efforts often require significant time at sea to evaluate the full range of natural seawater, light, and meteorological conditions affecting temporally integrated fluxes.

Upper ocean biogeochemistry **-** The past decade has witnessed a significant improvement in our conceptual models of the coupling between chemical, physical, and biological oceanographic processes, and their synergies controlling the packaging and movement of materials and elements in the upper ocean (including the transfer of climatologically relevant materials across the air-sea interface), as well as in the movement of biologically repackaged materials between the surface and deep ocean (including the seafloor). The further pursuit of such efforts in the future (e.g., in programs such as the Integrated Marine Biogeochemistry and Ecosystem Research (IMBER) program [21]) is of fundamental importance to improving our understanding of the role of the ocean's biological pump in modulating the effects of radiatively important trace gases on the global climate and environment. Many, if not most, of the recent large-scale ocean biogeochemistry programs (e.g., JGOFS and many of the ocean iron fertilization experiments) have often required multiple sampling platforms (specifically, Global and Ocean Class vessels) working together simultaneously in order to execute the full range of interdisciplinary field science. In a similar way, interdisciplinary time-series studies (e.g., BATS and HOTS programs, among others) require coordinated and dedicated use of vessels for deploying and maintaining moored and floating arrays for particle flux and export production studies. The continued growth of interdisciplinary biogeochemical oceanographic studies, and the increasing sophistication of the methods and multi-disciplinary approaches being used, requires the continued availability of not only adequate sampling platforms, but of the number of sampling platforms and available ship days.

Interactions between ocean margins and interior **-** An increasing appreciation by the ocean sciences community of the significance of lateral advective and eddy diffusive processes has led to a concomitant enhancement in our understanding of the magnitudes of material and chemical fluxes that occur between rivers and continental margin environments, and between margins and the interior ocean. In a number of recent studies, it is striking that estimates of lateral fluxes are equivalent to and sometimes exceed estimates attributable to traditionally assumed vertical flux models. A number of continuing research initiatives (e.g., Coastal Ocean Processes (CoOP) [22], River-dominated to Ocean Margins (RiOMaR) program [23], and Land-Ocean Interactions in the Coastal Zone (LOICZ) [24] program) have arisen to specifically address the range of material fluxes and transformations that occur across the continuum of land-river-estuarine-continental margin and oceanic environments. Such needs may require a revised view of the mission requirements and capabilities of the sampling platforms required by the chemical oceanography community in order to be able to sample across such different environments and on disparate time scales.

Recent Observations of Decreasing pH of the Ocean has Significant Repercussions

Without the ability to directly collect seawater and other sample types with high levels of quality and degrees of temporal and spatial resolution, our ability to follow and predict numerous critical parameters and processes in the ocean and in coupled air-sea and land-sea systems will be significantly compromised, and is ill-affordable at such a time of unprecedented global environmental change. One example of this has been the recent observations, and the even more significant extrapolations into both the pre-industrial past and post-industrial oceans, of the decreasing pH of the ocean due to its uptake of anthropogenic CO_2 [25]. The repercussions and implications of this shift in such a fundamental chemical parameter are both manifold and significant – ranging from physiological effects on plankton and higher organisms, to changing rates of aragonite and calcite precipitation and dissolution, and many others. Thus, our ability to track present and future changes in both simple and complex chemical parameters and processes in seawater will be key for evaluating the impact of global change on the oceans, and of the ocean's impact on modulating these changes.

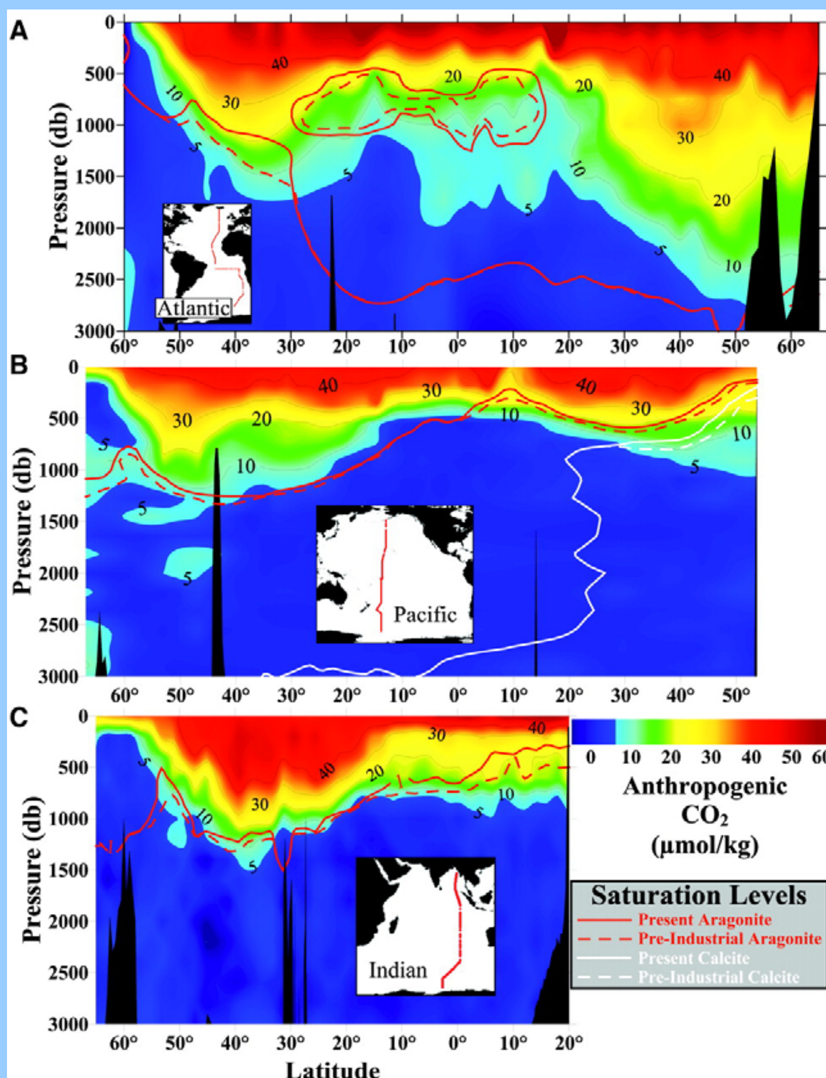


Figure 11. Calcium carbonate saturation horizons and anthropogenic CO_2 concentrations in the A) Atlantic, B) Pacific, and C) Indian Oceans. Red lines are the aragonite saturation horizons in the pre-industrial (dashed) and present-day (solid) oceans; white lines are the saturation horizons for calcite in the pre-industrial (dashed) and present-day (solid) oceans [25].

Coupled benthic-pelagic fluxes - Our understanding of global elemental mass balances continues to be refined by chemical studies of the seafloor and its interaction with the pelagic water column. These studies include the rain, burial, and storage of biologically relevant elements on various timescales ranging from seasonal to geological, the remineralization of major, minor and trace elements within sediments and sediment porewaters, the diffusive flux of these remineralized materials back to the water column, and seawater-crustal rock interactions. The nature of the approaches used for these seafloor chemical studies is often profoundly different from the instrumentation and methods used to sample the surface and deep pelagic water column, and require sampling platforms with sufficient capabilities for heavy lift, ROV, and submersible operations.

Global surveys of ocean chemical properties - The number and intensity (both spatial and temporal) of global ocean surveys for constraining decadal, annual, and shorter-term fluxes of climatologically relevant trace gases and other substances has increased dramatically over the past several decades, and promises to continue growing as researchers attempt to better constrain the terms of, for example, the global carbon budget and the ocean's role in modulating the accumulation of anthropogenic CO_2. Existing programs such as CLIVAR [26] and the U.S. Global Repeat Hydrographic Survey component of WOCE [27]), as well as recently established programs such as GEOTRACES [28] are designed to evaluate spatial differences and temporal changes in ocean chemistry across increasingly scales. These types of survey programs are also providing marine chemists with views of basin-scale distributions of properties and parameters that rival or exceed those of the GEOSECS, TTO and JGOFS programs, and include substances not previously measurable on these earlier surveys due to analytical limitations. As a result, it is anticipated that there will be a corresponding commitment and allocation of ship capacity to help accommodate these needs for viewing the ocean as an integrated system in the face of increasingly rapid global change.

Development of non-shipboard sampling platforms in chemical oceanography - The use of shipboard platforms in chemical oceanography is certainly to be supplemented in the future by autonomously and remotely deployed platforms such as ROVs, moored arrays, observing systems, volunteer observing ships (VOS), etc. (e.g., see OCEAN.US [29] and OOI [30] programs) . Indeed, a primary recommendation of the OCCC Program 2004 Report is "aggressive investment to bring an integrated suite of carbon system sensors to operational status over the next several years" [6]. The past decade has seen significant advances in, for example, remotely deployable sensors for dissolved nutrients, pCO_2, O_2, and DOM fluorescence, and POM abundance and flux by transmissometry - if not for large-scale projects then at least as demonstration and proof-of concept studies. However, numerous analytical and developmental challenges must first be resolved before chemical parameters can be sampled remotely with the same precision, accuracy, and long-term stability as physical parameters. Coastal observatories containing chemical sensors may over the long-term (i.e., decades into the future) occupy an increasing role in fulfillment one of the OCCC's mission goals of establishing a North American coastal observing system. Nonetheless, for the foreseeable future, these approaches are anticipated to at best augment the use of shipboard sampling for both focused regional studies and global scale surveys. In addition, if and when numbers and types of remote chemical sensors are deployed in the oceans, they will likely have significant upkeep requirements that necessitate at least the periodic use of ships to maintain and recalibrate sensors, re-supply sensors with reagents, and mitigate bio-fouling.

Future Facilities Needs and Advances in Methodology and Technology that will Influence Chemical Oceanography:

The accurate and successful measurement of elements and chemical substances is, and will continue to be, one of the most important and over-arching goals in the earth sciences given the large number of climate-relevant compounds and materials that are transferred across the ocean-atmosphere and land-ocean interfaces. The oceans represent a major repository of these materials, mitigating the climate impacts for some, and serving as a potentially significant source back to the atmosphere for others. In order to adequately survey the distributions of specific chemical substances in the ocean and their fluxes across the ocean-atmosphere boundary, large spatial expanses of the ocean must be measured that cross biologically and geochemically unique realms. In a similar way, temporal and spatial changes in these distributions and fluxes must be assessed on timeframes that are relevant for assessing changes in the oceanic and concomitant atmospheric reservoirs. The need for significant shipboard platforms for conducting these large-scale surveys and monitoring efforts is therefore likely to be even greater in the future as the impacts of radiatively important traces gases and other substances on climate change becomes more pronounced. Because of the large potential demand on future ship time, shipboard programs in chemical oceanography should be as comprehensive as possible, with the number and type of measurements being optimized for any given cruise.

The intensive nature of many of the chemical assessments in oceanography will be increasingly expanded by autonomous sensors deployed variously on moored, floating, and/or observatory arrays. While the value of the data from these sensors is generally high, as is their temporal coverage at very small scales, the spatial coverage for most is still very low. Thus, ocean basin or even regionally comprehensive assessments of chemical distributions, fluxes, and their changes over large globally relevant scales will continue to rely on ships for many decades.

Similar to future facilities needs in physical oceanography (see section II.B), future shipboard facilities needs in chemical oceanography will include new and innovative means of sampling the air-sea interface, the upper meter of the water column, and the atmosphere immediately above the interface, all in order to accurately estimate air-sea fluxes of gases and other materials and under a range of sea states. In addition, vessels will be called upon to a greater extent in the future for collection of contamination-free samples of air and atmospheric aerosols in order to measure substances such as trace metals and organic compounds - increasingly recognized to play critical roles in ocean biogeochemical cycles and processes - that are atmospherically transported from land to the oceans.

F. Education and Public Outreach

Education and Public Outreach are cross-cutting and two of the broader impacts resulting from oceanographic research initiatives. An improved oceanographic fleet will be better equipped for communicating scientific thought and discovery readily from the field in partnership with teachers, students, journalists, and members of the public.

The goals of structured education and outreach activities involving research vessels are generally to interest and prepare students from diverse backgrounds for entering any of the science, technology, engineering, or mathematics disciplines that are represented by oceanographic endeavors, or to inform the general public and the formal and informal education communities about the relevance and implications of major ongoing science projects. Two additional areas of outreach and information sharing involve cooperative activities between oceanographers and international observers, and similar activities with representatives of regional commercial fishing communities.

Current education and outreach programs, initiatives, and opportunities include:

- At sea programs for K-12 teachers
- At sea programs for college and high school students
- Informal education activities
- Virtual programs
- Facility open house events

"At sea programs for teachers" sponsor opportunities for K-12 teachers to take part in expeditionary marine science and to share their experiences with the public, usually through journals posted on the Internet, live broadcasts, and/or follow-up classroom activities. These programs help teachers learn and convey the importance of observation and hands-on experiences in science learning, and they also promote teamwork and networking. As a result the research is enriched and new inquiry approaches are incorporated into teaching practices. Examples are NSF's Polar Teachers and Researchers Exploring and Collaborating (PolarTREC) in the Arctic and Antarctic program

Research and Education: Volcanoes, Exploration and Life (REVEL) Project

University of Washington's REVEL Project provides the opportunity for middle and high school science teachers to participate in research expeditions at sea and bring these experiences back to their classrooms.

Figure 12. A REVEL teacher assists in the science operations of the cruise (Photo courtesy of Mitch Eland (UW))

In 2005, five REVEL teachers joined scientists aboard the R/V Thompson to study the underwater volcanoes of the Northeast Pacific. Underwater robots along with a suite of scientific equipment and instrumentation were used to explore, sample, monitor, and map one of the most extreme environments on Earth. This cruise also featured the first real-time broadcast of high-definition video from the seafloor. High-definition video is the most capable imaging medium in existence for viewing and sharing the deep seascapes with its exotic life forms.

The REVEL teachers shared their thoughts with us:

> *"Educators teach current science concepts that evolve because scientists are constantly looking for answers to new questions. The ocean cannot be properly studied by standing on land. The pioneering science of exploring the ocean's deep hydrothermal vents helps teachers develop an understanding for true scientific method as they collaborate with leading scientists in the field. Real-time, real-life experiences provide unique professional development that encourages an interdisciplinary approach and a true inquiry curriculum in the classroom. The REVEL project, an at sea experience, provides a network of peers for curricular support and tools to meet the science standards. Through educational programs like REVEL an audience of oceanography-savvy teachers and students can better enhance their ocean learning by bringing genuine research into their classrooms.*
>
> *Without access to the sea, there is a loss of continuous up-to-date data, which generally are available to the public, including educators. There is no substitute for an experience at sea, practicing scientific method, decision making at the moment, and creative problem solving that can be brought back to the classroom. Loss of this type of professional development impairs educators' need to maintain current information and training in the constantly changing world of science and technology. Teachers must be informed in order to help students and the community be informed.*
>
> *Teachers are ambassadors for the community. The power of the program at sea enables teachers to influence people in their community to be more knowledgeable about oceanography and to present new methods and approaches to scientists who want to disseminate useful information to the generally community. Building the public's knowledge of the ocean empowers them to make effective decisions regarding the oceans connection and influence on climate, earthquakes, volcanoes, tsunamis, hurricanes, and food productivity."*

[31], NOAA's Teacher At Sea program [32], the Research and Education: Volcanoes, Exploration and Life (REVEL) project [33], and the ARMADA Project [34].

College and high school students may learn at sea by participating in competitive internship programs such as the Marine Advanced Technology Education (MATE) Internship Program [35] or through formal and informal opportunities designed by individual scientists who seek to engage students in their research and outreach activities. Although relatively few students are able to participate in these kinds of at sea programs, the richness of a cruise experience will often shape the career of an aspiring marine scientist. One recent example was the ALIA Expedition in April 2005 on the Hawaiian Research Vessel *Kilo Moana*. During this cruise, scientists from Woods Hole Oceanographic Institution and Scripps Institution of Oceanography engaged three high school students, three undergraduate students, and four graduate students in an expedition that collected data and rocks needed to explore the Samoan Hotspot. The high school students prepared daily web reports about cruise activities as well as a Java Applet that plotted the 22-day cruise track. All the students assisted in the field work and came to understand theories of how ocean island and seamount chains are formed [36].

Virtual programs are educational Internet offerings, such as the Dive and Discover program [37], that have the distinct advantage of availability for all who wish to learn about, discover, and virtually explore the ocean realm. Often linked to an individual expedition or a theme such as natural history in deep environments, these postings provide public access to current information on the marine environment. Virtual programs may also provide links to educational resources such as educational funding opportunities, lesson plans, classroom activities, teacher-training opportunities, and library materials. Other examples are listed on the UNOLS website at
<http://www.unols.org/info/outreach.html>.

However, probably the most popular outreach program is the traditional facility open house. These are events when operators open vessels for public tours, and seagoing scientists and crew team together to explain oceanographic operations and science objectives to the visiting public. Many institutions combine these events with other education and outreach activities such as the University of Delaware's award winning Coast Day event that is estimated to attract over 10,000 participants a year [38]. Open houses in foreign ports are also popular and help to communicate the importance of global science and international cooperation.

Future Facility Needs and Advances in Methodology and Technology that will Influence Education and Outreach Programs:

Future UNOLS vessels will need to be designed to provide far greater opportunities for offering marine science education to diverse and interactive audiences. In terms of infrastructure, 24-hour high-speed Internet access and other means of inexpensive around the clock ship-to-shore communications are needed. Other features that would enhance and promote education/outreach are providing shipboard work spaces for teachers, conference rooms, and library facilities. Larger ships with more available bunks may also facilitate teacher and student at sea programs, student recruiting, and informal education. For public tours, ships designed with gangways that are wide and safe for public entry, no matter what the tide level, would be an advance.

Figure 13. University of Delaware's Coast Day annual open house. *Photo – University of Delaware*

G. Ocean Observatory Initiatives

In his keynote lecture celebrating 50 years of ocean discovery, John Knauss stated "Just as I believe the operation of oceangoing ships did much to define the oceanographic institutions for the first half of NSF's 50 years, so I believe NSF's sponsorship of large multi-investigator programs has done much during the last 25 years to develop a level of cultural sophistication among the oceanographic community found in relatively few other fields of science." [39]

The previous five sections illustrate how the integrative and interdisciplinary nature of oceanography conducted by large programs is a keystone of the success of oceanography in the United States. While each section focuses on a particular field, each places the work in the context of overall integration. It is difficult to study any one aspect of the sea without also collecting the necessary observations to place the study in the larger context. Exploration of the sea has reached the stage where multi-investigator and multi-disciplinary cruises are the norm, not the exception. This has led to the creation of large observational programs that can be categorized as running the gauntlet from focusing on one aspect of oceanography to very integrative studies. Beginning with the successful early programs established prior to or during International Decade of Ocean Exploration (IDOE), NSF has a long history of large programs and there is every indication that this will continue into the future. One requirement for successful large programs is access to ships, often with more than one ship to be used concurrently in an expeditionary mode.

NSF is now moving forward with the next fundamental and major cultural change in how to observe the ocean, namely the creation of large and integrated observatories. It is critical for the community to recognize that the ships needed to support ocean observatories will require different capabilities than ships for expeditionary science.

Presented in this section are a summary of the existing and planned large scale expeditionary programs and the anticipated needs of supporting the observatory networks.

Capture of an Extreme Event: Hurricane Fabian Passage over the Bermuda Time-series Site

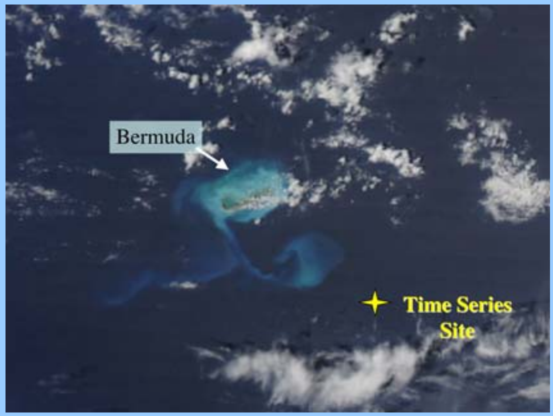


Figure 14. SeaWiFS image of Hurricane Fabian sediment plume and Bermuda

Hurricane Fabian, a category 3 hurricane, passed directly over Bermuda in September 2003. The time-series programs had the rare opportunity to capture the ocean response to the passage of Hurricane Fabian and also to witness the offshore transport of a massive sediment plume into the deep ocean. The study of this event illustrates the synergy among multidisciplinary observational programs and platforms co-located at ocean time-series sites. Sensors on the Bermuda Testbed Mooring measured sustained winds of >190 km hr^{-1} as Fabian passed. Strong rotational currents extended down to depths >200 m and large internal waves were induced down to depths exceeding 750m. These currents scoured the southern slopes of the Bermuda platform and remobilized massive quantities of detrital carbonate sediments. Large surface plumes of remobilized sediment were visible by satellite on September 6th. Plumes of advected sediment were intercepted by the OFP sediment traps, located 75 km to the southeast of Bermuda. This was, by far, the largest episodic flux event observed over the entire 30 year OFP time-series. This one event delivered as much carbonate to the deep ocean as that normally delivered over an entire year.

Current and Future Ocean Observatories Initiatives:

Seafloor observatories making long-term observations on the seafloor or within the water column are rapidly becoming a prominent component of the marine science effort. Observatories allow time-series measurements at a location to determine temporal change in measured parameters and to detect and characterize episodic events.

Long-Term Time-series - Another type of observatory that has developed over the past decades is long-term moorings of instruments. These are now widely used in oceanographic and biological studies, as well as acoustic studies of seismicity. These moorings may include a surface transponder to transmit data via satellite, or they may be serviced periodically to retrieve data and change batteries.

Ocean processes operate across multiple temporal and spatial scales (Figure 1, Section II.A). Complex, nonlinear phenomena and their effects on ocean processes can be fully understood only in the context of temporal and spatial variability. Thus, the ocean community has established several multi-decadal time-series observational programs in the Atlantic and Pacific central gyres and in key coastal areas and has placed increasing emphasis on long-term ocean observation programs.

The UNOLS fleet provides support for two mid-ocean ocean time-series sites located off Bermuda and Hawaii. The Bermuda site hosts several of the longest running oceanographic time-series in the world: The Hydrostation S time-series (since 1954) conducts biweekly sampling of 0-2600 m hydrographic properties; the Oceanic Flux Program sediment trap time-series (OFP, since 1978) continuously samples the deep ocean particle flux; the BATS (since 1988) conducts ~monthly sampling of upper ocean biogeochemical parameters; and the Bermuda Testbed and Science Mooring (BTSM, since 1994) continuously measures meteorological, physical, and bio-optical parameters and hosts a suite of sensors and instruments installed by ancillary users. The HOTS was established in 1988 and conducts ~monthly cruises to Station Aloha, located 100 km north of Oahu. Measurements of the thermohaline structure, water column chemistry, currents, optical properties, primary production, plankton community structure, and rates of particle export are made on each cruise. Numerous other short-term research activities utilizing both ship and moored observational platforms, as well as instrument development activities are routinely conducted at the Bermuda and Hawaii time-series sites.

These time-series programs have generated a wealth of information on variability in ocean properties over time scales of days to decades, and have especially contributed to understanding how the El Niño-Southern Oscillation (ENSO) and the North Atlantic Oscillation (NAO) affect ocean biogeochemistry and ecosystems. For example, the HOTS data have shown clear linkages between ENSO and biogeochemical parameters and also long-term ocean trends, such as the switch from nitrogen to phosphorus limitation of primary production that occurred in the mid 1990s [40]. The time-series have also clearly documented the importance of short-lived, episodic surface phenomena (e.g. the passage of mesoscale circulation features, hurricanes, and atmospheric dust deposition) in structuring ecosystems and biogeochemical cycles over longer time-scales. These phenomena, and their effects on ocean ecosystems and biogeochemical fluxes, can only be captured by sustained, ongoing observations. An example is the ocean response to the passage of Hurricane Fabian over Bermuda in 2003 (see highlight feature on previous page).

The role of ships in support of ocean time-series has evolved from that of mainly a sampling platform for deployment of tethered instruments and sample collection to an additional role of collecting multiple, semi-continuous spatial data streams using increasingly sophisticated suites of ship-mounted instruments. Hull-mounted transducers acoustically profile currents and biological structures, suites of sensors mounted in flow-through clean water systems make continuous measurements of the physical, chemical, and biological properties of surface waters, and sophisticated meteorological instruments and bow-mounted air collections systems sample the atmospheric properties, gases, and aerosols of the marine boundary layer. Complementing this expanded role of ships are moorings, autonomous vehicles and benthic landers, whose data may be transmitted to ships for processing.

Coastal time-series also provide key data that contributes to a better understanding of open ocean-shelf exchanges, fisheries resources, and the impacts of human activities on coastal ocean ecosystems. One of the longest is the California Cooperative Oceanic Fisheries Investigations (CalCOFI) time-series, which has documented decadal-scale variability in the California current ecosystems and linkages with the Pacific Decadal Oscillation. As regional and local human pressures on the coastal ocean increase, coastal time-series data are becoming increasingly valuable to assess human impacts on biogeochemical cycles and the marine food webs and for coastal resource management.

There are programmatic and operational tie-ins between the established ocean time-series programs and other global observatory initiatives. The objectives of the CLIVAR program, for example, are to assess climate variability and predictability on month to decadal time scales, and the role of the coupled ocean and atmosphere system in controlling the response of the climate system to anthropogenic forcing.

NSF Ocean Observatory Initiative - The increasing interest in ocean observatories has resulted in numerous workshops and reports including two undertaken by the National Research Council in (2000 [41] and in 2003 [42]). This planning and study effort culminated in the development of a Science Plan for the NSF OOI. This Science Plan lays out an ambitious program to establish “an interactive, globally distributed and integrated network of sensors in the ocean” and to broadly disseminate data from these observatories to “researchers, students, educators, government, industry, and the general public” in near real time.

The crosscutting science that drives the development of observatories is grouped into five topical areas in the OOI Science Plan. These are:

- Climate variability, food webs, and biogeochemical cycles
- Coastal Ocean dynamics and ecosystems
- Global and plate-scale geodynamics
- Turbulent mixing and biophysical interactions
- Deep biosphere interactions with the oceans

The first NRC report [41] found wide community support for an observatory concept that encompasses a wide spectrum of facilities and substantial flexibility in their geographic positioning. They also found that a single facility type or a discipline specific geographic approach is significantly less supported. In response to this community response, there are three components to the observatory program laid out in the OOI Science Plan. These components have been further defined and re-scoped over recent years. Current plans call for:

- ***Global Scale Nodes*** - The global observatory component will consist of paired surface and profiler moorings that would cover the full water column. The surface and profiler moorings would be flanked by two subsurface moorings with fixed depth sensors. Telemetry at each site would be via gliders. Three global sites are planned with one at Ocean Station Papa, one in the Irminger Sea in the North Atlantic, and one in the Southern Ocean (55 deg S) located southwest of Chile. Each site will support a range of interdisciplinary measurements from the air-sea interface to the deep seafloor. Satellite communication from each site is planned. Data collected are expected to include meteorological, air-sea flux, ocean properties, acoustic thermometry, seismic geodetic, and tsunami.

- ***Regional Scale Nodes (RSN)*** - The Regional Scale Nodes observatory is a cabled plate-scale observatory. The northeastern Pacific has been chosen as the RSN location and is proposed to consist of five primary nodes. This observatory would instrument the plate boundary of the Juan de Fuca plate and a portion of its interior with one or two lines across the continental margin connecting the network to the shore. The backbone of this system is a permanent electro-optical seafloor cable that will connect multiple seafloor nodes and provide power (10s of kW) and high-bandwidth (data transmission rates of 10-100 Gbps) for the sensors, instruments, and underwater vehicles, allowing access to the surrounding waters from the seafloor to the surface. Major cross-cutting science themes that the regional observatories could address include (1) observations of the dynamics of oceanic lithosphere along active plate boundaries, (2) temporal sampling of fluids and microbial life forms circulating in the hydrothermal oceanic crust and seafloor, and (3) turbulent mixing and biophysical interactions in the water column.

- ***Coastal Observatories*** - The third component of OOI is coastal-scale observatories. Two types of coastal arrays are planned; one at the Atlantic shelf-break (Pioneer Array) and the other at the NE Pacific continental margin (Endurance Array). Plans for the Endurance Array include an Oregon Line and a Washington Line. The Oregon Line will originate from Newport, Oregon and include surface moorings at threes sites and subsurface profiler moorings at all sites. The Oregon Line will connect to the RSN observatory via an extension line. The Washington Line will extend from Grays Harbor off central Washington and will include one surface mooring and two subsurface profiler moorings.

  The Pioneer array will be initially located in the Middle Atlantic Bight/Outer Continental Shelf and will consist of four electro-magnetic/sub-surface profiling mooring pairs plus four subsurface profiling moorings. AUVs will enable autonomous sampling. At least six to 12 gliders are envisioned for sampling far-field variability.

The three observatory components will be linked by a common instrument, infrastructure, and information-management system, or cyberinfrastructure. The cyberinfrastructure will allow users to remotely control their instruments and perform *in situ* experiments. It will allow access to data in near-real time from almost anywhere in the world’s oceans.

Ocean Observatory Facility Needs:

OOI will clearly impact the demands on research facilities, both in terms, of fleet size and makeup. The maintenance and operation of the observatories imply new and, to the extent that traditional marine operations are to be maintained, additional missions for the fleet. Suites of tools including tethered and autonomous vehicles will play a key role in data collection and site telemetry.

Intermediate and Global Class ships of the UNOLS fleet are envisioned in the observatory installation and Operations and Maintenance (O&M) projections, with the greatest demand placed on the Global Class vessels. Most of the required support of the Coastal Arrays in the Pacific and Atlantic can be met with Intermediate ships. The installation and O&M projections for the Global and RSN observatories call for Global Class vessels. Servicing of observatories will be highly dependent on ROVs. ROVs are included in the operation plans for the RSN, and the Oregon Endurance Array.

Ships must have the ability to maintain station-keeping at the observatory sites and to support ROVs, AUVs, and suites of gliders. Inherent in these requirements is the need for reliable dynamic positioning systems. Global ships should have sufficient lifting capabilities in order to service and handle the large components planned for the observatories. Heavy lift operations could entail upgrades to ship A-frames with concurrent increases in winch, cable, and crane capacity.

The Global-scale and RSN observatories are located in regions that do not always have optimal weather windows for at-sea operations. The weather and sea conditions outside the optimal weather windows are often too harsh for safe operations. Ships with features that enhance their ability to extend the seasonal operating window will be very attractive. As new ship designs are developed, innovative configurations and handlings systems should be considered.

Details of the OOI estimated facility needs are provided in Section IV. The estimate provides ship time and ROV time projections for each observatory type.

In addition to OOI, NOAA's Integrated Ocean Observing System program has been formed and represents a national partnership in which 17 Federal agencies and 11 Regional Associations (RAs) share responsibility for the design, operation, and improvement of the national, coastal network of observations. They collect data and work to make it broadly available to scientists. Ship time support for these observational systems might be a consideration in the future.

H. Summary of Science Initiatives and their Impact on Facility Needs

In the previous sections, many examples of the wide range of scientific questions that will be addressed in the future with a more capable research fleet and emerging technologies. As stated in the Atkinson/Cowles report "New observational tools and systems (e.g., AUVs, ROVs, and observatories) will address this need by ***extending*** the reach of the fleet, but these new systems ***will not replace*** or reduce the fundamental use of vessels to conduct specific observational and experimental research at sea." [43] For example, we can imagine the research vessel as a command center directing a fleet of autonomous platforms to map the hydrographic structure of the ocean in three dimensions. The knowledge of the ocean that we have today is based upon a background of continuing ocean observations, satellite data streams, assimilation schemes, and numerical models. It is essential that these continue. Without this network, prospects for more detailed understanding cannot be assured.

Although autonomous platforms and observatories will use more advanced and capable sensors in the future, research vessel support will still be required during the development of these sensors. Cutting edge instrumentation and sensors require significant power and data output during their development phase as well as on hand operation and trouble shooting. Sensor deployments and servicing from ships is expected until improvement in power usage and intelligent data processing methods are mature. The introduction of mass spectrometers and gene sequencers are recent examples of this development process.

The future science initiatives described in the previous sections will bring require new and enhanced vessel designs. There will be more demand for multidisciplinary science programs, such as ecosystem management, which will bring larger scientific parties aboard the research vessels. Laboratory and deck space required to support these programs will very likely be deficient in many ways. Future research vessel designs must include all the capabilities that are affordable and be as flexible as possible to meet expanding and changing mission requirements. There is an increasing need for more accurate and precise navigation as we investigate processes on smaller and smaller scales. In turn, dynamic positioning systems will be required on all new vessels. There is increasing evidence that ocean bottom topography influences various research areas and the capability to generate accurate bathymetric maps while at sea is needed. Ships will require multibeam sonar systems to generate these maps. With the increasing sophistication and complexity of the instrumentation envisioned for future shipboard cruises, skilled technical support groups will be required to operate these systems. Designs of new research vessels should take into consideration factors that would allow contamination-free sampling of air and atmospheric aerosols as well as uncontaminated near surface seawater.

With the greater demand on available berthing for these future scientific endeavors, the need for continuously available, two-way high-speed connectivity to the shore is critical. Enhanced ship-to-shore communications would allow maximum participation of science personnel both at-sea and on-shore. Such systems would also enable video conferencing for educational outreach programs. Teachers could interact with their students in their classrooms. Based on past participation, at-sea experiences for K-12 teachers greatly enhances the interaction with the students both at the time of the cruise and afterwards.

In summary, future science initiatives along with educational and outreach activities will require a capable research fleet that can support diverse missions. Vessels of all size classes will continue to be required to provide access to all of the world’s oceans as well as the coastal regions of the U.S. and Great Lakes. Ship designs should be innovative and incorporate flexibility in order to accommodate the exciting oceanographic research programs on our horizon.

III. UNOLS, 2008 Facility Composition and Utilization Trends

A. The Role of UNOLS in Fleet Planning and Facility Management

The University-National Oceanographic Laboratory System (UNOLS) was founded in 1971 with 17 ship-operating academic institutions. By 2008, UNOLS had grown to a union of 61 academic institutions and national laboratories involved in oceanographic research. UNOLS coordinates and reviews the access to and utilization of facilities (e.g. ships, planes, submersibles) for academic oceanographic research. UNOLS reviews the current match of facilities to the needs of academic oceanographic programs and makes appropriate recommendations for replacing, modifying, or improving the numbers and mix of facilities, especially research vessels. UNOLS fosters federal and other support for academic oceanography, thereby continuing and enhancing the excellence of this nation's oceanographic program [44] (Figure 15).

UNOLS is governed by an elected Council of representatives from its member institutions. The Council makes recommendations to funding agencies regarding the needs for specialized or new facilities, the balance between facilities and funded research programs and accepts charges for special studies and reviews. In addition to the council, there are eight standing committees which oversee major UNOLS activities and facilities. All Council and committee members are volunteers. The committees are listed in the UNOLS organization chart in Figure 16 and a brief description of each is provided in the text below:

- *Ship Scheduling Committee (SSC)* – The SSC develops and coordinates ship schedules to assure the most effective, efficient, and economic utilization of UNOLS ships and associated facilities.

UNOLS in a Nutshell

The University-National Oceanographic Laboratory System is an organization of 61 U. S. institutions that have academic research and education programs in the ocean sciences and an interest in promoting the best possible national shared use facilities to support these programs. UNOLS was founded in 1971.

- Eighteen of the UNOLS institutions are operators of major shared use facilities, including:
  - Research vessels (23)
  - A National Deep Submergence Facility (*Alvin*, ROV *Jason*, and AUV *ABE*)
  - A National Oceanographic Aircraft Facility at CIRPAS/NPS
  - A National Oceanographic Seismic Facility (R/V *Marcus Langseth*)
- Facilities are either owned by one of the Federal agencies or by individual institutions.
- UNOLS is not a funding agency or a facility operator.
- UNOLS serves in an advisory role to facility operators and to supporting Federal agencies.
- UNOLS is governed by an elected Council & major committees (volunteers); and maintained by a small secretariat
- UNOLS is a coordinator or facilitator of community-wide efforts with these goals:
  - *Promote broad, coordinated access to oceanographic research facilities*
  - *Support continuous improvement of existing facilities*
  - ***Plan for and foster support for the oceanographic facilities of the future***

Figure 15. UNOLS in and Nutshell

- *Arctic Icebreaker Coordinating Committee (AICC)* – The AICC provides oversight and advice to the U.S. Coast Guard for the purpose of enhancing facilities and science aboard their icebreaker fleet.
- *DEep Submergence Science Committee (DESSC)* - The DESSC has oversight responsibilities for the use of the National Deep Submergence Facility (NDSF) assets and promotes new technology.
- *Research Vessel Technical Enhancement Committee (RVTEC)* - The RVTEC fosters activities and improvements that enhance technical support for sea-going scientific programs and oceanographic facilities.
- *Scientific Committee for Oceanographic Aircraft Research (SCOAR)* - The SCOAR provides advice and recommendations to aircraft facility managers and supporting federal agencies on aspects of operations, technology, aircraft fleet composition, utilization, and promotes collaborations and cooperation between facility stakeholders.
- *Marcus Langseth Science Over-sight Committee (MLSOC)* - The newest UNOLS committee is the MLSOC. MLSOC provides community input and oversees the scientific operation of the seismic survey ship *R/V Marcus Langseth* as a National Oceanographic Seismic Facility. [45]
- *Research Vessel Operators' Committee (RVOC)* - Actual fleet management is carried out on an individual ship level as well as on a fleet level. Marine superintendents at each of the respective UNOLS ship operating institutions are responsible for the day-to-day operation of their vessel(s). The RVOC is made up of marine superintendents from UNOLS and non-UNOLS research ship operators. They work to promote cooperation, fleet standards, marine safety, efficiency, and quality of service among marine science research and educational institutions.

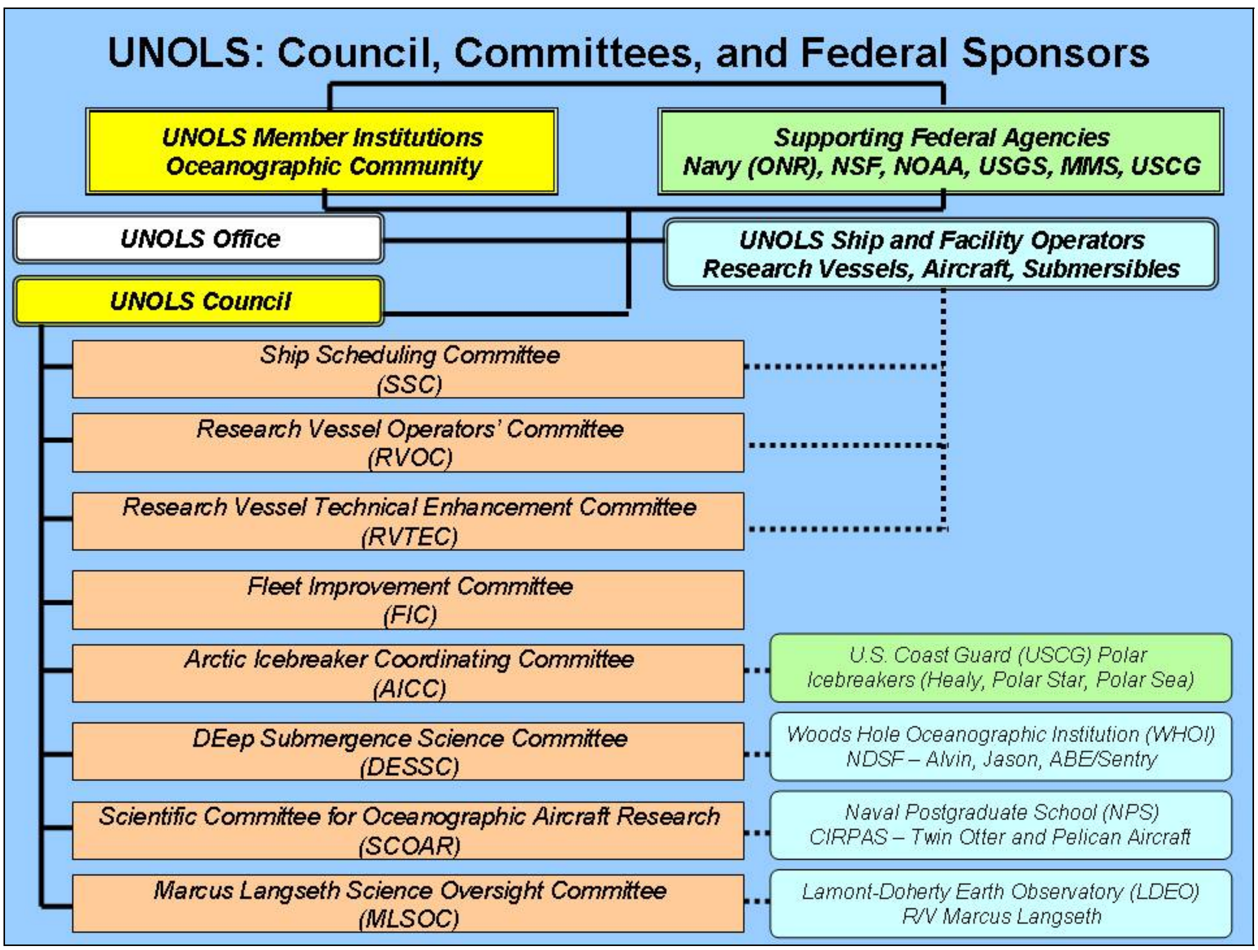


Figure 16. UNOLS Organization Chart

- *Fleet Improvement Committee (FIC)* - Fleet replacement, renewal, and planning have been a major function of UNOLS. Ships of all sizes have been planned, designed, and constructed to maintain a fleet capable of supporting the evolving oceanographic research needs. In 1986, UNOLS established the FIC and the purpose of the committee, as stated in Annex IV of the UNOLS Charter [44], is:

  "The Fleet Improvement Committee works to assure the continuing excellence of the UNOLS fleet, to improve the capability and effectiveness of individual ships and to assure that the number, mix and overall capability of ships in the UNOLS fleet match the science requirements of academic oceanography in the U.S. To this purpose, the Committee maintains the currency of a dynamic UNOLS Fleet Improvement."

In working to develop this Fleet Improvement Plan document, the Fleet Improvement Committee continues to carry out the mandate by which they were formed.

A goal of UNOLS, and one of the objectives for which UNOLS was established, is to develop and update a long-range plan for university oceanographic facilities. The importance of such a plan cannot be overstated. Most oceanographic facilities, especially ships, are built with federal funds, and all new acquisitions must compete in an increasingly rigorous contest for support. Unless requests for new ships and other facilities are accompanied by substantive, credible, and approved plans showing how such new facilities fit into the needs for future oceanographic research, those requests will have little likelihood of succeeding.

B. UNOLS Facility Descriptions

1. The UNOLS Academic Research Fleet

What is a UNOLS ship? According to the UNOLS charter, "*They are those United States research vessels generally operated in support of national oceanographic research programs, by academic institutions and are significantly funded by the federal government. They are operated in accordance with UNOLS safety standards, subject to regular, recognized ship inspection programs, scheduled by established UNOLS procedures and meet cruise reporting, cruise assessment, cost accounting and performance standards according to UNOLS uniform practices. UNOLS vessels...are regularly available to users outside of the operator institution provided that funding is available...*" [44]

Ships of the UNOLS fleet are geographically distributed along the U.S. Coast, Bermuda, Panama, and Great Lakes and support oceanographic research projects sponsored by federal agencies, states, and private institutions. The homeport locations of UNOLS vessels are shown in Figure 17. The major sponsors for the use of UNOLS ships are the National Science Foundation (NSF), the Navy, and the National Oceanic and Atmospheric Administration (NOAA). Other federal agencies, states, and private entities also support programs that use the UNOLS vessels.

Fleet Class Definitions - The UNOLS fleet consists of six basic vessel classes; Global, Ocean, Intermediate, Regional, Regional/Coastal, and Local. The vessels that comprise each of these classes are listed in Table 2.

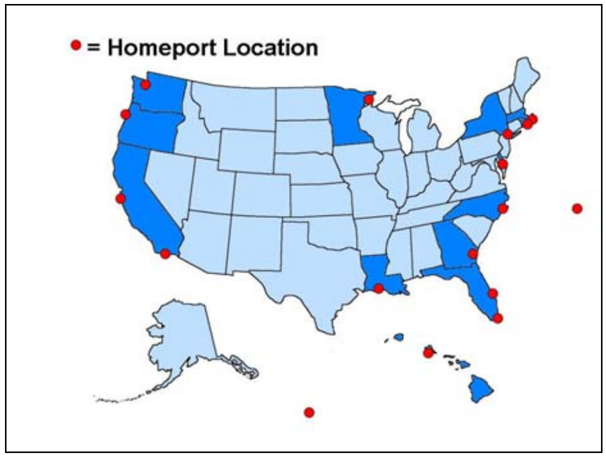


Figure 17. UNOLS Vessel Homeport Locations in 2008

The UNOLS Fleet – 2008						
SHIP/CLASS	Operator	Owner	BUILT	Conv/Mid-Life	LOA m (ft)	Science Berths
Global Class						
Melville	SIO	NAVY	1969	1991	85 (279)	38
Knorr	WHOI	NAVY	1970	1989	85 (279)	34
Thomas G. Thompson	UWASH	NAVY	1991		84 (274)	36
Roger Revelle	SIO	NAVY	1996		84 (274)	37
***Atlantis* (Submersible Support Ship)**	WHOI	NAVY	1997		84 (274)	37
***Marcus G. Langseth* (Seismic Ship)**	LDEO	NSF	1991	2005-2007	71 (235)	35
Ocean Class						
Kilo Moana	UHAWAII	NAVY	2002		57 (186)	29
Intermediate Class						
Seward Johnson	HBOI	HBOI	1985	1994	63 (204)	29
Wecoma	OSU	NSF	1976	1994	56 (185)	18
Endeavor	URI	NSF	1977	1993	56 (184)	18
Oceanus	WHOI	NSF	1976	1994	54 (177)	19
New Horizon	SIO	SIO	1978	1996	52 (170)	19
Regional Class						
Point Sur	MLML	NSF	1981		41 (135)	12
Cape Hatteras	DUKE	NSF	1981	2004	41 (135)	14
Atlantic Explorer	BIOS	BIOS	1982	2006	51 (168)	20
Regional/Coastal Class						
Robert Gordon Sproul	SIO	SIO	1981	1985	38 (125)	12
Pelican	LUMCON	LUMCON	1985	2003	32 (105)	14
Walton Smith	UMIAMI	UMIAMI	2000		30 (96)	16
Hugh R. Sharp	UDEL	UDEL	2005		44 (146)	14
Local Class						
***Urraca* (removed from UNOLS service in 2008)**	STRI	STRI	1986	1994	30 (96)	10
Savannah	SKID/UG	SKID/UG	2001		28 (92)	19
Blue Heron	UMINN	UMINN	1985	1999	26 (86)	6
Clifford Barnes	UWASH	NSF	1966	1984	20 (66)	6

Table 2. The 2008 UNOLS Fleet

Global Class: Global Class ships are the high endurance vessels, capable of operating world-wide. They are large general-purpose, multi-discipline oceanographic research ships capable of worldwide cruising (except in close pack ice) and able to support both over-the-side and laboratory work in high sea states. The ships can accommodate large scientific parties of 30 to 38 people. There are six Global ships. The newest vessels of this Class were built in the 1990s: *Marcus Langseth*, *Thompson*, *Atlantis*, and *Revelle*. *Knorr* and *Melville*, the oldest of the Global vessels, received extensive refits in 1989 and 1990, respectively. There are two special purpose vessels within the Global Class, *Atlantis*, support ship for the deep submersible *Alvin*, and *Marcus Langseth*, a modern seismic vessel. The *Langseth* began science operations in 2008 after completing shipyard modifications.

Ocean Class: The Ocean Class ships are a new Class that was defined by the 2001 Federal Oceanographic Facilities Committee (FOFC) Long-Range Plan for Renewal [46]. These ships will fulfill a critical need in fleet modernization by replacing the aging "Intermediate" ships with vessels of increased endurance, technological capability, and number of science berths. These will be ocean-going vessels, though not globally ranging. This new class of general-purpose research vessel, designed to support integrated, interdisciplinary research, should have many of the capabilities of modern Global Class vessels. These vessels will support scientific parties as large as 25. They will also be designed to support expeditions up to 40 days and a total range up to 20,000 km (10,800 nautical miles) at optimal transit speeds. Their design would maximize the sea-kindliness of these vessels and maximize their ability to work in sea states 5 and higher. The current fleet includes one Ocean Class vessel, *Kilo Moana*. *Kilo Moana*, a Small Waterplane Area Twin Hull (SWATH), was introduced to the fleet in 2002 and operates from Hawaii. It is a very stable platform.

Intermediate Class: The Intermediate ships are medium endurance general-purpose vessels. These are ocean-going vessels, though not globally ranging. There are five Intermediate vessels in the UNOLS fleet and they range in size from 52 m to 63 m (170 feet to 204 feet). Most have science accommodations for approximately 18 to 20. Many of the vessels of this class are approaching the end of their projected service life. *Endeavor*, *Oceanus* and *Wecoma* will all reach the end of their projected service lives in 2010. When the Intermediate vessels are removed from service, the Class will be replaced by the more capable Ocean Class vessels.

Regional Class: Regional Class ships work in and near the continental margins and coastal zone. They are general-purpose ships, designed to support integrated, interdisciplinary coastal oceanography in the broadest sense from shallow coastal bays and estuaries out to deep water beyond the shelf. The primary requirement is a maximum capability commensurate with ship size to support science, educational, and engineering operations in the coastal regions of the continental United States, including the Gulf of Mexico basin. In 2008 there are three Regional ships in the UNOLS fleet. Bermuda Institute for Ocean Sciences (BIOS) acquired *Atlantic Explorer* from Harbor Branch Oceanographic Institution (HBOI) (formerly *Seward Johnson II*) and began operating the ship as a Regional vessel from Bermuda in 2006. *Alpha Helix* was the oldest vessel in the fleet, serving the Alaska region. This ship was removed from UNOLS service in 2006 and will be replaced with a more capable, ice strengthened Ocean Class ship. The *Point Sur* and *Cape Hatteras* will both reach the end of their projected service life in 2011. New, more capable Regional ships called out by the 2001 FOFC plan will be designed with improved technology and more science berths than in current, comparably sized vessels [46].

Regional/Coastal Class: The Regional/-Coastal ships operate in a mode that is similar to the larger Regional ships; however, they are generally smaller in size and have lower operating costs. In 2008 there are four Regional/Coastal ships. *R/V Hugh R Sharp* is the newest vessel of the Class and entered service in 2006. The *Walton Smith* (a catamaran), entered the fleet in the 2000s. *Pelican* underwent major mid-life refit improvements in 2003. The *R.G. Sproul* is the oldest of this class and is over 25 years old.

Local Class: Local Class ships fulfill near-shore needs that do not require larger or higher-endurance ships. They are fully capable of continuous 24-hour operations. These ships are designed for multidisciplinary capability with small size and cost effectiveness. Vessels of this size often serve educational programs in addition to their research work. For this vessel, endurance and cruising speed are secondary to broad operational capabilities and seakeeping qualities. These vessels have traditionally been built using nonfederal dollars, but often receive federal operational and outfitting support. At the start of 2008, there were four Local vessels, three of which were built prior to 1990. The newest ship in this Class is *Savannah*, which was built in 2001. In fall 2008, *Urraca* was taken out of service from the UNOLS fleet.

Fleet Size and Ownership - The size of the UNOLS fleet has fluctuated over the past decade. In 1995, UNOLS ships comprised a 26-ship fleet operated by 19 institutions or consortia. In 2008, the UNOLS fleet consists of 23 ships operated by 17 institutions or consortia (Table 2). Vessels constructed or converted with federal funds are designated as federally owned. Academic institutions or consortia operate these vessels through cooperative agreements. Seven of the UNOLS ships were built or acquired under grants from NSF (one Global ship, three Intermediate ships, two Regional ships, and one Local vessel). Six ships, including five Global vessels and the Ocean Class ship, were built and are owned by the U.S.

Navy. The remaining ten ships of the fleet are either state-owned or privately owned.

Fleet Service Life - Figure 18 provides a representative timeline for mid-life refits and projected service life ends of the UNOLS vessels. The mid-life refit year is based approximately 15 years from the time of the ship's construction. In the past, a ship would typically undergo an extensive shipyard period to carryout improvements and upgrades. The Navy has moved away from this dedicated mid-life shipyard refit period and instead will implement improvements and upgrades incrementally over a course of a few years for the Navy owned vessels.

The ship projected service life end dates in Figure 18 were provided by the ship operators and are based on their knowledge of the condition of the ship, the 30-year rule of thumb (lifetime of 30 years or 15 years beyond a mid-life refit), and the projected construction dates for new vessels outlined in the 2001 FOFC Plan [46]. The ship's projected service life end date represents a full year of operation. This chart demonstrates the need for continued long-term planning for the refit and replacement of the academic fleet. By the end of 2015, all but two of the Intermediate and Regional ships will reach the end of their projected service life. Also during this same period the Global ships, *Knorr* and *Melville*, will reach the end of the projected service life. Past history has demonstrated that it normally takes in excess of 10 years to plan, acquire construction funds, design, and build a new research vessel.

SHIP/CLASS	BUILT	Conv/ Mid Life	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019	2020	2021	2022	2023	2024	2025
Global Class																				
Melville	1969	1991	----	----	----	----	----	----	--X											
Knorr	1970	1989	----	----	----	----	----	----	----	--X										
Thomas G. Thompson	1991		----	----	----	----	----	----	----	----	----	----	----	----	----	--X				
Roger Revelle	1996		----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	--->
***Atlantis* (Submersible Support Ship)**	1997		----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	--->
***Marcus G. Langseth* (Seismic Ship)**	1991	2007	>---	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	---X
Ocean Class																				
Kilo Moana	2002		----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	--->
Intermediate Class																				
Seward Johnson	1985	1994	----	----	----	----	----	----	----	--X										
Wecoma *	1976	1994	----	----	--X															
Endeavor *	1976	1993	----	----	--X															
Oceanus *	1976	1994	----	----	--X															
New Horizon	1978	1996	----	----	----	----	----	----	----	----	--X									
Regional Ships																				
Point Sur	1981		----	----	----	--X														
Cape Hatteras	1981	2004	----	----	----	--X														
Atlantic Explorer	1982	2006	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	--->
Regional/Coastal Ships																				
Robert Gordon Sproul	1981	1985	----	----	----	----	----	----	----	--X										
Pelican	1985	2003	----	----	----	----	----	--X												
Walton Smith	2000		----	----	----	----	----	----	----	----	-M-	----	----	----	----	----	----	----	----	--->
Hugh R. Sharp	2005		----	----	----	----	----	----	----	----	----	----	----	----	----	-M-	----	----	----	--->
Local Ships																				
Urraca	1986	1994	--X																	
Savannah	2001		----	----	----	----	----	----	----	----	----	-M-	----	----	----	----	----	----	----	--->
Blue Heron	1985	1999	----	----	----	----	----	----	----	--X										
Clifford Barnes	1966	1984	----	----	----	----	----	--X												

X = Projected End of Service Life
M = Midlife Refit
* Ships nearing the end of their projected service life will be evaluated to assess their condition.

Figure 18. UNOLS Vessel Service Life Projections

2. National Oceanographic Aircraft Facility

Figure 19. UV-18A Twin Otter. *Photo provided by: CIRPAS*

CIRPAS, the first National Oceanographic Aircraft Facility (NOAF) - UNOLS designated as its first NOAF, the Center for Interdisciplinary Remotely Piloted Aircraft Studies (CIRPAS), operated by the Naval Postgraduate School in Monterey, CA, in February, 2003. The UNOLS Committee, the Scientific Committee for Oceanographic Aircraft Research (SCOAR) serves as the oversight committee for activities at CIRPAS that have been initiated through UNOLS. CIRPAS has been in operation since 1996, and many of the research and engineering development programs served by CIRPAS have not come through UNOLS. Thus, the bulk of the platform, sensor, data system, and operational decisions at CIRPAS have been made by the facility with some input from SCOAR. It is envisioned that the oversight function of SCOAR will increase over time. CIRPAS operates several piloted aircraft and many remotely piloted or autonomous aerial vehicles. The workhorse for university oceanographic research projects is the UV-18A Twin Otter (Figure 19), a medium-size twin turboprop aircraft (see http://www.cirpas.org/).

Other Research Aircraft Facilities - There are several federal agencies that operate research aircraft that are available to the ocean science community, but the agencies are neither designated as NOAFs nor are they overseen by UNOLS. It is nonetheless important to consider these facilities and their platforms and instrumentation capabilities when advising UNOLS on how to look towards new and needed aircraft capabilities. These agencies include the Department of Energy (DOE), The National Aeronautics and Space Administration (NASA), NOAA, NSF, and the Naval Research Lab (NRL). There is good communication between UNOLS and these agencies through the Interagency Coordinating Committee for Airborne Geosciences Research and Applications (ICCAGRA), a committee that meets typically once per year jointly with SCOAR. ICCAGRA has a membership composed of representatives from the aircraft-operating agencies listed above, plus the chair of SCOAR.

Aircraft Science Capabilities - It is likely that oceanic, estuarine, and limnological research programs will continue to employ airborne methods for the foreseeable future. There are numerous operational characteristics that aircraft bring to these research efforts that are advantageous both by themselves and in combination with other, more traditional methods. Aircraft are capable of greater speed, and therefore greater range and spatial coverage during a short time period when compared to surface and subsurface ocean research platforms. Such speed and range attributes lead to better synoptic coverage of oceanic and atmospheric variability. Aircraft-mounted sensors provide data with much of the appeal of the aerial view provided by satellites, but with much greater specificity, spatial and temporal resolution, and scheduling flexibility, and they can provide resolution adaptable to phenomena of interest. Aircraft are ideal for both fast-response investigations and routine, long-term measurements, and they naturally combine atmospheric measurements with oceanographic measurements on similar temporal and spatial scales. Aircraft surveys reach across a wide range of environmental and geographic conditions. For example, an aircraft can survey and collect remote-sensing data over shallow estuaries, the coastline, and offshore with one deployment and can do so in weather that might preclude a surface vessel from covering the same areas. Using smaller, less-expensive aircraft for near-coastal work can result in more coverage for certain types of data at lower cost than using surface vessels. Aircraft have a particular advantage for coastal observing that comes from the combination of speed and range they make available for remote measurements and expendable instrument deployment. The issue of aliasing in space and time is especially significant in the coastal environment where scales of air-sea-land interaction can vary too rapidly to be adequately covered by any affordable combination of ships, moorings, or autonomous underwater vehicles. Satellite remote sensing is valuable, although coverage is sometimes limited by satellite orbit parameters or by cloud cover, especially in coastal marine layers. Using phased-array technology, high-frequency radars can provide excellent coverage of surface currents (except very close to the coast) and surface waves, but they offer very limited subsurface measurements. Airborne remote and expendable measurements of sea surface temperature, subsurface salinity and temperature, surface waves and currents, ocean color, coastal morphology, coastal bathymetry, and important atmospheric and terrestrial variables can significantly enhance data collected by fixed and mobile oceanographic platforms in coastal regions. The combination of satellite, aircraft, ship, and moored measurements has proven to be especially powerful in both coastal and open-ocean regions.

3. National Deep Submergence Facility

In 1974, NSF, the Office of Naval Research (ONR), and NOAA recognizing the significance of maintaining a core deep submergence operational team, established the National Deep Submergence Facility (NDSF). The UNOLS Standing Committee, DESSC, provides advice on the operation and upgrade of the NDSF. When first established, the NDSF operated by Woods Hole Oceanographic Institution (WHOI), consisted of *Alvin;* a human occupied vehicle with a depth rating of 4,000 m (13,123 ft). In 1994, *Alvin's* titanium sphere was recertified to 4500m (14,764 ft). That same year, *ROV Jason*, and sonar mapping systems, *Argo II* and *DSL-120,* were integrated into the NDSF, creating a significantly improved national deep submergence capability with access to depths as great as 6000 m (19,685 ft). In 2002 a more capable, deeper diving, ROV replaced *Jason*. The new ROV was also named *Jason*. The latest upgrade to the NDSF was in 2007 with the addition of the autonomous underwater vehicle (AUV), Autonomous Benthic Explorer (*ABE)*. The addition of *ABE* was concurrent with the removal of *Argo II* and *DSL-120* from the NDSF.

The current NDSF consists of an integrated suite of vehicles, *Alvin*, *Jason*, and *ABE*. Descriptions of each of these assets follow [47]:

Alvin is a U.S. Navy-owned Deep Submergence Vehicle (DSV) that can carry two scientists and a pilot (Figure 20). Three 12-inch diameter viewports allow direct human observation. Typically, four video cameras are mounted on *Alvin*'s exterior with zoom and focus controls.

Figure 20. DSV *Alvin*

Two hydraulic, robotic arms may be used to manipulate sampling and experimental gear. A basket mounted on the front of the submersible can carry a variety of instruments weighing up to 454 kg (1,000 pounds). *Alvin* began operations in 1964 and has made more than 4,000 dives. Although the vehicle is over 40 years old, it is completely over-hauled every three years, inspected and recertified. R/V *Atlantis* is the support ship for *Alvin*. Efforts are currently underway to upgrade Alvin with enhanced capabilities and a replacement sphere that can provide a deeper depth rating.

Jason - *Jason/Medea* is a two-body ROV system with *Medea* serving in a tether management role that decouples *Jason* from surface motion (Figure 21). Together they offer wide area survey capabilities with *Jason* as a precision multi-sensory imaging and sampling platform. Both *Medea* and *Jason* are designed to operate to a maximum depth of 6,500 meters (21,385 feet), are transportable, and can be operated from a variety of vessels. *Jason* is designed for detailed

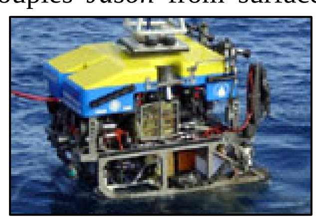


Figure 21. ROV *Jason/Medea*

survey and sampling tasks that require a high degree of maneuverability.

ABE/Sentry - The AUV *ABE* operates to depths of 4,500 meters (14,764 ft) and is used to produce bathymetric and magnetic maps of the seafloor (Figure 22). It has also been used for near-seabed oceanographic investigations, to quantify hydrothermal vent fluxes. *ABE* has taken digital bottom photographs in a variety of deep-sea terrains, including the first autonomous surveys of an active hydrothermal vent site. In 2009, *ABE* is expected to be replaced with a new AUV named *Sentry*. *Sentry* is faster, has greater depth capability, and is capable of longer deployments than *ABE*. *ABE* and *Sentry* are transportable and can be operated from a variety of vessels.

NDSF Vehicle Photos: Courtesy of Woods Hole Oceanographic Institution [47]

Figure 22. AUV *ABE*

4. National Oceanographic Seismic Facility

The R/V *Marcus G. Langseth* is a 71 m (235 ft) research vessel that is owned by NSF and operated by Lamont-Doherty Earth Observatory of Columbia University. It entered the UNOLS fleet in 2008 (Figure 23). Originally constructed as a commercial seismic vessel in 1991, the *Langseth* was acquired in 2004 and has been modified and outfitted to provide general purpose research support in addition to its seismic capabilities. After completion of this conversion period and required inspections, the ship was designated as a UNOLS National Oceanographic Seismic Facility (NOSF).

The ship provides the U.S. academic community with the resources to acquire state-of-the-art, two-dimensional (2-D) and three-dimensional (3-D) marine seismic-reflection data. Particularly unique to the academic research fleet, are the *Langseth*'s extensive geophysical capabilities that include a Syntrak 960-24 seismic recording system with four 6 km solid-state hydrophone streamer cables and a 2000 psi, 40 pneumatic sound source array towed in four "strings" that can be configured either as a single, 2-D source or dual, alternating 3-D source arrays. No other ship in the UNOLS fleet approaches the seismic acquisition capabilities of this vessel, and consequently the *Langseth* represents a unique national resource.

A UNOLS standing committee, Marcus Langseth Science Oversight Committee (MLSOC), was formed to serve as an advisory committee to the NOSF.

Figure 23. R/V *Marcus G. Langseth (Photo by: Lamont-Doherty Earth Observatory)*

5. Special Platforms – Non-UNOLS:

In addition to UNOLS Facilities, there are other oceanographic facilities that are used by academic researchers and in some cases coordinated by UNOLS Committees. These facilities often provide unique access by either their ability to operate in more remote regions or by their specialized hull configurations. A few of these facilities are described below.

a. Polar Icebreakers

U.S. Polar icebreakers supporting ocean scientists are operated by the U.S. Coast Guard (USCG) and by contractors on behalf of the NSF

Antarctic program. Foreign operated icebreakers are also used to support research cruises for U.S. funded researchers and on occasion for logistics support in the Antarctic.

Figure 24. USCGC *Healy. Photo: PA3 Jamie Bigelow*

The USCG operates three polar icebreakers. *USCGC Healy*, the United States' newest polar capable icebreaker, was commissioned as a U. S. Coast Guard Cutter (USCGC) in 2000 (Figure 24). *Healy's* primary mission is to function as a high latitude research platform with emphasis on Arctic science. This 128 m (420 foot) ship is capable of employment in icebreaking operations during any season in the Arctic and Antarctic with an endurance of 65-day missions. The vessel can accommodate science parties of 35 with expansion to 50 (three to a stateroom). The ship's systems have been designed with sufficient redundancy and robustness to meet national contingencies in the Polar Regions, including intentional wintering over. Other mission capabilities include escort for logistical resupply of polar land facilities, search and rescue in Polar Regions, and marine environmental protection response.

Planned deployments are expected to be multidisciplinary, in support of a wide range of science and engineering projects including, but not limited to: marine geology; physical, chemical and biological oceanography; and meteorology. Science working spaces and labs were designed to facilitate the latest approaches and techniques for conducting state of the art oceanographic research.

USCGC Polar Star and *Polar Sea* are 122 m (399 feet) heavy icebreakers commissioned in 1976 and 1978 (Figure 25). *Polar Star* and *Polar Sea* are used primarily to support the breakout of the channel to McMurdo station necessary for the annual re-supply of U.S. Antarctic facilities. These two vessels are at the end of a normal thirty-year lifespan with the *Polar Star* currently in a caretaker status. A study by the National Academy of Sciences, *Polar Icebreaker Roles and U.S. Future Needs: A Preliminary Assessment*, [48] has recommended building replacements for both of these vessels.

Figure 25. USCGC *Polar Sea* and *Polar Star. Photo: USCG*

Raytheon Polar Services/Edison Chouest operates the research icebreaker *Nathaniel B. Palmer*. The *Nathaniel B. Palmer* (Figure 26), delivered in 1992, is 94 m (308 ft) with icebreaking capability for use by the U.S. Antarctic Program (USAP) [49]. The *Palmer* is used for global change studies, including biological, oceanographic, geological, and geophysical components. It can operate year-round in Antarctic waters with accommodations for 37 scientists, and is capable of 75-day missions.

Figure 26. R/V *Nathaniel B. Palmer. Photo: USAP*

The USCG Icebreakers can be requested for research projects in the Arctic through the UNOLS ship time request system. Use of icebreakers in the Antarctic is scheduled by the USAP.

b. Semi-submersible Platforms and Spar Buoy Vessels

The UNOLS fleet does not at present include any spar buoy or semi-submersible special-purpose platforms. However, the Navy's Research Floating Instrument Platform (*FLIP*), a 108 m (355 ft) human occupied spar-buoy, is available to the academic marine science community (Figure 27). Operated by Scripps Institution of Oceanography (SIO), *FLIP* is frequently involved in joint experiments with UNOLS vessels and NSF principal investigators.

As a significant national asset, *FLIP*'s continued operation is important to UNOLS.

FLIP is towed to station in horizontal attitude. When flooded at the stern, it "flips" to a vertical attitude. In the vertical mode, *FLIP* is highly stable, heaving vertically less than 10% of the ambient wave height and pitching less than 5 degrees. The structure is designed to minimally perturb surrounding water and air flow. It serves as a mount for a variety of booms and winches, from which numerous sensors can be deployed. Living quarters and laboratories are found above the water-line.

FLIP has been in operation for over 45 years and there is renewed interest in its capabilities in the context of the Ocean Observatories Initiative (OOI). Specifically, there is a need for remote stable platforms that can be moored in the deep sea to provide electrical power to scientific sensors and broadband communications between sensors and satellites.

The possibility of using an unmanned spar as the hub of an offshore "observatory" is very exciting. In this context, the present *FLIP* might be used as a test-bed for the technologies involved, or with modification, become a first-generation unmanned ocean station.

Figure 27. *FLIP. (Photo provided by Rob Pinkel (SIO))*

C. UNOLS Ship Scheduling Process

The UNOLS Ship Scheduling Committee (SSC) is tasked with scheduling the UNOLS fleet. The Committee meets at least once each year and is in constant communication, coordinating ship time requests and ship schedules.

Although each federal agency operates differently with respect to Principal Investigators (PIs) that require ship time, all investigators in need of UNOLS ship time submit an on-line Ship Time Request (STR) form via the Ship Time Request System (STRS) at <http://www.unols.org/strs>. For the most part, project planning begins with proposals or letters of intent to the respective funding agency outlining the science to be performed. NSF requires that proposals must be submitted for panel review no later than 15 February of the year before the requested cruise year.

PIs are encouraged to complete requests for ship time as early as possible, usually well before funding has been received. PIs use the STR form to request a vessel or class of vessel and to identify their optimal cruise dates, number of ship days needed, geographic region of research, shipboard instrument needs, and equipment required for the field work. The ship time request allows coordination with collaborating scientists. Information on Department of State clearance requirements for work planned in waters of a foreign state can be found on the STR form or from the UNOLS homepage. Deep submergence facilities are scheduled in conjunction with the appropriate research vessels.

Once the PI completes and submits the on-line STR form, it is emailed automatically to the ship schedulers. A copy is also sent to the submitting PI, funding agency indicated, and to the UNOLS Office.

Funding agencies and other sponsors conduct program and peer reviews of the proposed science. If the PI's proposal is reviewed favorably and budget levels permit an award, the ship time associated with the proposal is scheduled. The STR is used by the ship schedulers to develop cost effective schedules. The schedules are refined as award decisions and agency budget levels become known. Final schedules do not typically firm up until late in the year prior to the requested cruise year. The scheduling process is a very iterative one.

Figure 28 graphically describes the process of requesting time aboard a UNOLS vessel, scheduling the ship time, and finally going to sea.

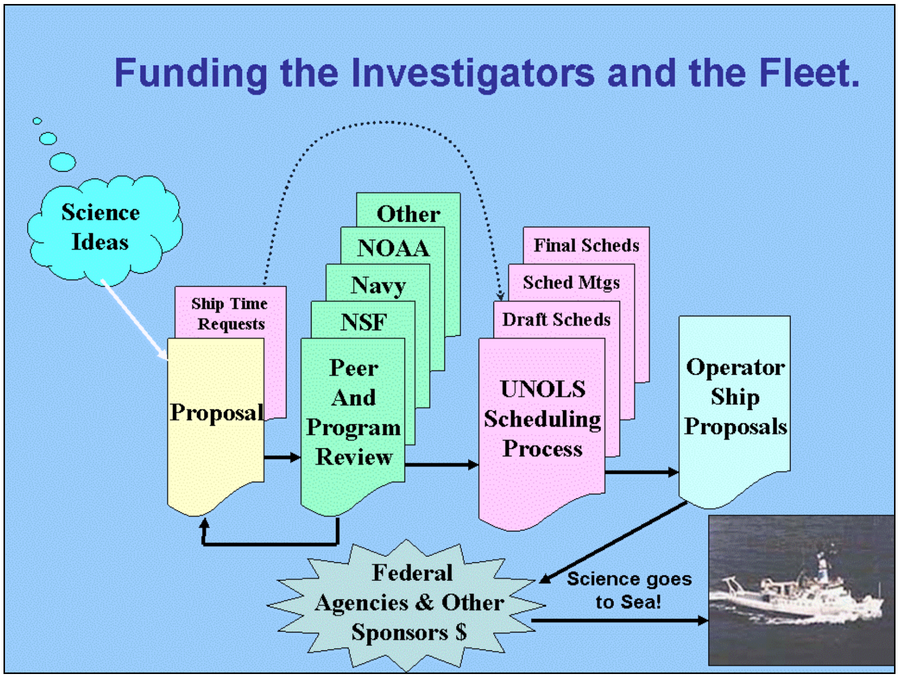


Figure 28. Ship Scheduling Process

D. Facility Trends

1. Fleet Utilization Trends and Ship Demand

Past utilization trends of the UNOLS fleet show how capacity (ship days available) compare to the ship operating days that are actually used annually. Operating days are those days incident to scientific missions, including sea days, day of arrival, day of departure, transit time, and days in port other than the ship's homeport. Fleet capacity is not based on a full calendar year of 365 days; instead it is based on the optimal utilization of the ship, or "Full Optimal Year" (FOY). The number of days that a ship normally spends at sea will depend on such variables as homeport location, mode of operation, region of operation, ship size, ship capability, etc. For example, a Local ship that usually operates near its homeport with many, short cruises (two to three days) and staging days between each cruise (homeport days are not counted as operating days) will have fewer annual operating days than a larger ship that is operated globally and visits its home port infrequently. FOY definitions for the Global, Ocean, and Regional Classes were established in the 2001 FOFC plan [46] and are adopted here. The FOY definitions for the Intermediate, Regional/Coastal, and Local ships were established by the RVOC and are applied here [1]. Table 3 provides the definitions:

Full Optimal Year Definitions:	**Days**
Global	300
Ocean	275
Intermediate	250
Regional	200
Regional/Coastal	180
Local	110

Table 3. Full Optimal Year (FOY) Definitions

Until 2005, the fleet as a whole typically operated at approximately 5000 days a year (Figure 29). In recent years, a decline in utilization has been experienced. This decline is not a result of a decrease in science demand; instead it is a reflection of reduced federal budgets. The total number of ship days available has also declined since 2005 as some of the older vessels have been removed from service.

Ship Time Demand

As described in the previous paragraphs, scientists whose research or proposed research requires the use of a research vessel will request ship time via the UNOLS on-line STR form. The days requested on the STR forms can be used as a measure of ship time demand. Peer and program reviews, along with budgetary constraints result in only a portion of these requests being funded and scheduled for operation each year.

During the period from 2001 to 2004, the number of ship days requested increased by more than 3000 days. Since 2004, ship day requests have leveled off at well over 10,000 days. Although, the funded ship time may have dropped in recent years, ship time demand remains high (Figure 30).

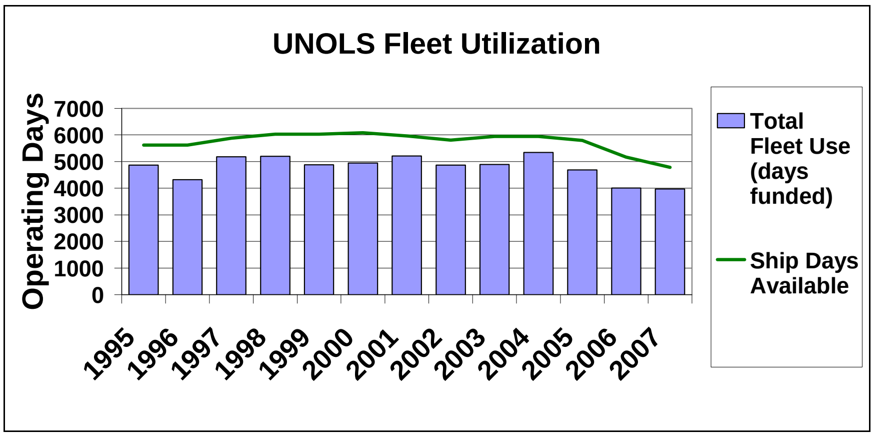


Figure 29: UNOLS Ship Days Funded

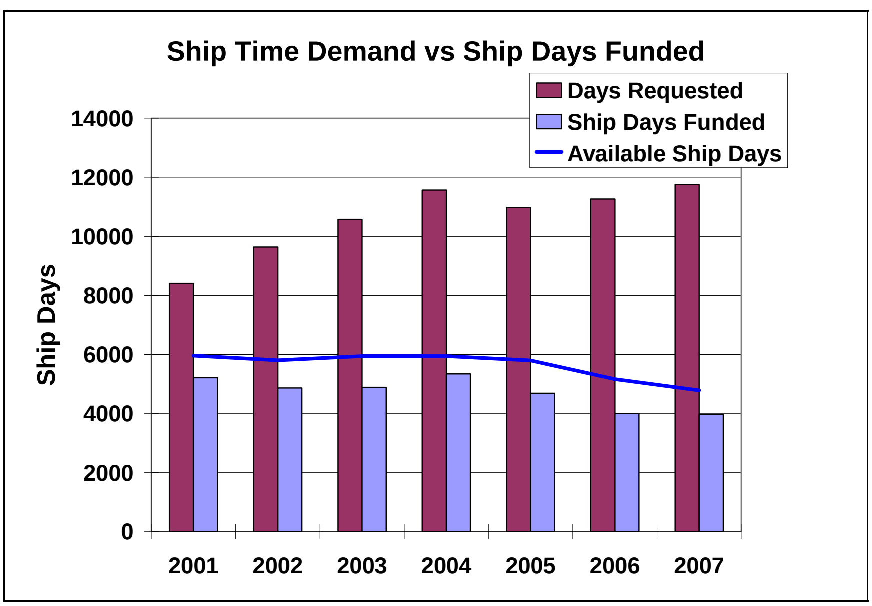


Figure 30: Ship Time Demand vs. Ship Days Funded

Ship Use Trends

To better understand the gap between the available ship days and the ship days funded, it is useful to evaluate each ship class separately.

The Global Class vessels have been operating at or close to their optimal usage (Figure 31a). Demand for these vessels is high. In 2005 and 2006, limited operating budgets along with logistical constraints resulted in work being deferred from the requested year to out years. In 2007, recognizing budget constraints, only those field programs that could be supported within the 2007 ship operations budgets were awarded and scheduled; ultimately resulting in fewer funded ship days. Since 2005, there were fewer Global Class days available as R/V *Ewing* was retired from UNOLS service. Its replacement, R/V *Marcus Langseth*, entered the fleet in 2008. (Ship projected service life end dates are shown in Figure 18, page 35.)

The Ocean Class is a new Class and currently includes only one ship, R/V *Kilo Moana*, which entered the fleet in fall 2002. Its funded ship days have mirrored the Global vessels; operating close to optimal usage (Figure 31b). Like the Global ships, budgetary constraints resulted in a light operating schedule in 2006. Funded ship days were slightly lower than optimal usage in 2007.

The Intermediate Class vessels include many of the oldest vessels in the fleet. Over the years, the number of funded ship days on the Intermediate Class has been less than the optimal capacity. Insufficient bunk and laboratory space for larger programs, lack of certain ship capabilities, and the smaller size of the ships, has had a negative impact on their utilization (Figure 31c). Recognizing that the Intermediate ships have become less capable of meeting the requirements of complex science experiments and that the ship's size hampers its ability to effectively carry out programs in high latitudes, this Class will be replaced by the larger, more capable Ocean Class. Since 1995, the Intermediate ship day capacity has declined as older ships have been removed from UNOLS service without replacement.

Regional Class utilization is primarily based on three vessels. From the late 1990's to early 2000's, ship usage typically approached optimal capacity (Figure 31d). In recent years there was a decline in funded ship days, and in 2005 and 2006 *Alpha Helix* was out of service due to lack of science requests and age. The ship was officially removed from the UNOLS fleet in 2006. The science community has expressed the need for a more capable, ice strengthened vessel for work in the Arctic region. In response, NSF is supporting the acquisition of an Ocean Class vessel for the Alaska region. Another change to the Regional Class was the addition of R/V *Atlantic Explorer* (formerly R/V *Seward Johnson II*) in 2006. The ship was transferred from Harbor Branch Oceanographic Institution, where it had been operated as an Intermediate vessel, to Bermuda Institute for Ocean Sciences. The ship will now be operated as a Regional vessel off of Bermuda. With the retirement of *Alpha Helix* from the UNOLS fleet, Regional Class capacity returned to 600 days in 2007.

The Regional/Coastal and Local ships have operated at or near optimal utilization (Figures 31e and 31f). Although there have been some fluctuations in capacity over the years, the ship days available in 2007 are at the same level as in 1995. Use of these ships has correlated to available capacity. Since most of these vessels are non-Federally owned, the owner will take them out of service if demand decreases. Alternatively, if a ship has been fully utilized throughout its service life, it will often be replaced by the operator when the ship reaches its projected end of service life. As examples, U. Miami replaced R/V *Calanus* with R/V *Walton Smith*, Skidaway Oceanographic Institution replaced R/V *Blue Fin* with R/V *Savannah*, and University of Delaware replaced R/V *Cape Henlopen* with R/V *Hugh R. Sharp*. In recent years two Regional/Coastal ships (R/V *Longhorn* and R/V *Weatherbird II*) and one Local ship were removed from service as a UNOLS vessel.

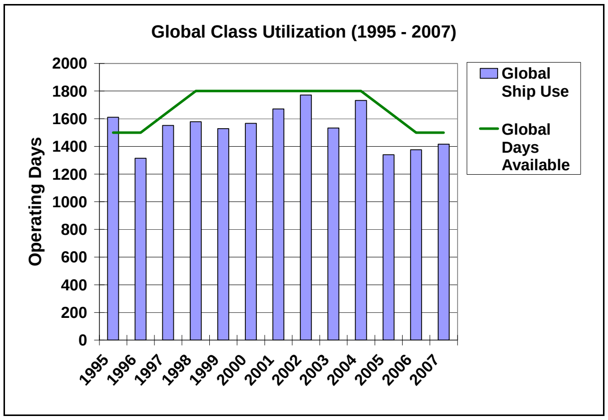


Figure 31a. Global Class Utilization

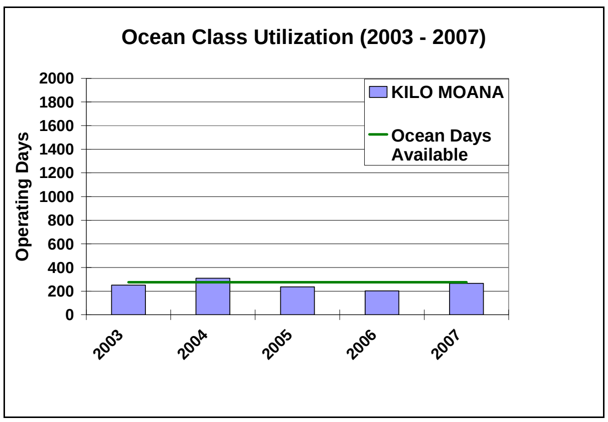


Figure 31b. Ocean Class Utilization

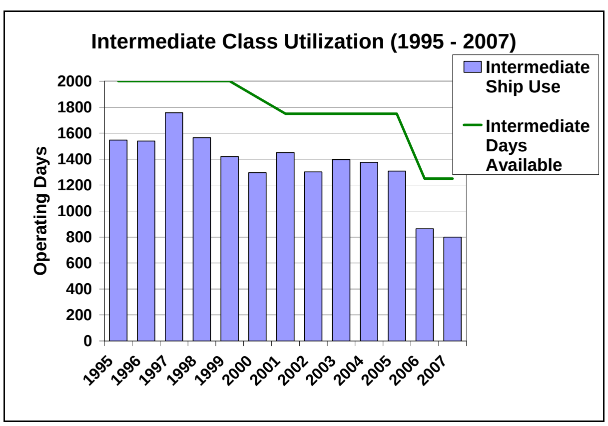


Figure 31c. Intermediate Class Utilization

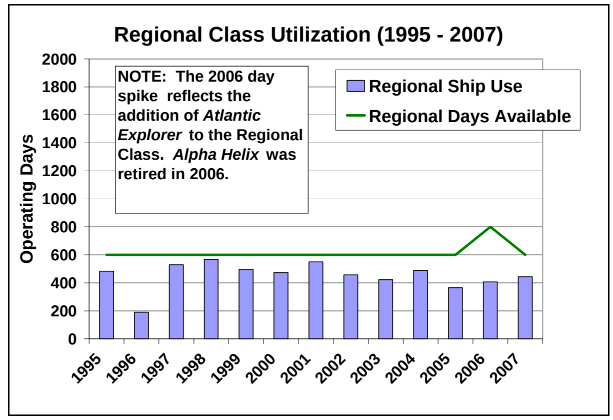


Figure 31d. Regional Class Utilization

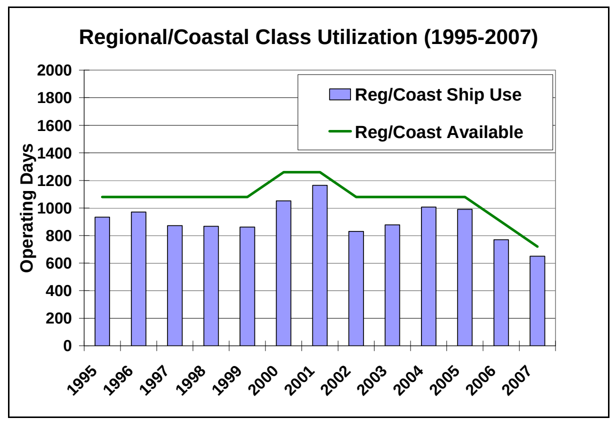


Figure 31e. Regional/Coastal Utilization

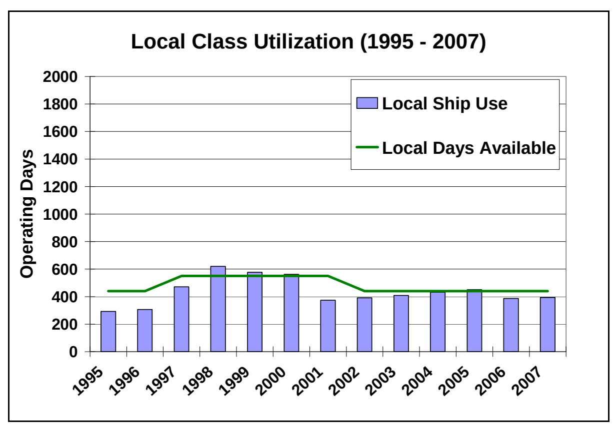


Figure 31f. Local Class Utilization

Figure 31. Fleet Utilization by Class

National Deep Submergence Facility Utilization

Utilization of the NDSF has fluctuated during the period of 1998 to 2007 (Figure 32). In Figure 32, *Alvin* use is broken out from the other NDSF vehicles. The vehicles included in the "ROV" category are *Jason*, *Argo II*, and *DSL120*/-*DSL120a*.

The fluctuation in *Alvin's* usage is in large part due to its requirement to be certified and completely overhauled every three years. The process typically takes approximately six months to accomplish and the vehicle is out of service during that period. Efforts are made to schedule *Alvin* overhauls and certifications so that they fall over two calendar years. The NDSF operator and UNOLS alert the community to upcoming overhauls so that they can plan accordingly.

Since 2002, utilization of the ROVs has increased as the science community has become more familiar with the capabilities of these facilities. ROVs can be used on ships of opportunity, allowing expeditionary research in areas of the world that in the past could not be reached economically by *Alvin* and its designated support ship, *Atlantis*. ROV demand in recent years has been high and often leads to challenging facility scheduling scenarios and logistics. Although the optimal utilization for the ROVs has not been defined, it is likely that they are at or have exceeded optimal usage.

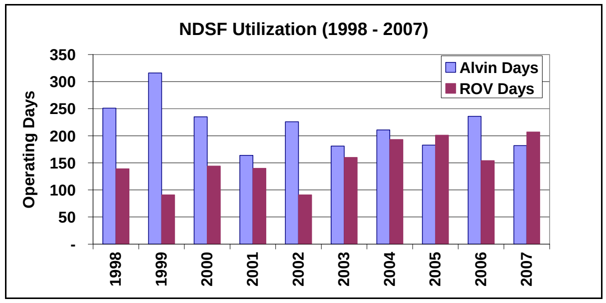


Figure 32. NDSF Utilization: 1998-2007

2. Trends in Berthing on UNOLS Vessels

Since the early days of fleet renewal, the trend has been that the new and the refitted vessels are larger and carry more scientists than did those of years past. Science berths represent non-crew bunks and include the berths for marine technicians. From 1972 to 2005, the number of berths available in the fleet expanded by about 100 bunks (Figure 33).

The increasing complexity of oceanographic programs has required larger seagoing science parties. Additionally, oceanographers plan increasing numbers of observations; and coupled, coincident observations into every major expedition. Each class of sample or type of measurement often requires its own scientist or technician to gather the materials or data and provide the necessary on board handling. When the need to keep observations running round-the-clock is added, the demand for berths rises. Over the years, new or refit ship designs incorporated additional berths to accommodate the multidisciplinary, larger science parties.

The recent decline since 2005 in available berths is due to the removal of *Gyre* (23 berths), *Ewing* (32 berths), *Alpha Helix* (15 berths), *Longhorn* (12 berths), and *Weatherbird II* (12 berths) from the UNOLS fleet. A decline in berth capacity is expected to continue as the current ships reach the end of their projected service life and fewer new ships enter the fleet.

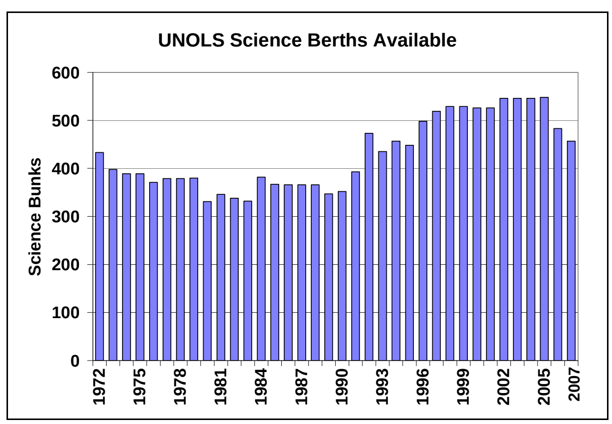


Figure 33. UNOLS Science Berth Capacity

3. Geographical Utilization

Geographic areas of interest for oceanographic research span the globe. When scientists submit ship time requests, they are asked to specify the geographic region for their proposed research. Areas are specified using the "Area of Operations Code" as defined by the standard Naval Chart. The world map in Figure 34 has been overlayed with the Naval chart areas. The total ship time requests for the years 2000 through 2006 contained in the UNOLS electronic database are plotted on the Naval Chart of the world (Figure 34). The boxes have been shaded using a color code to denote the number of requests for each area. With very few exceptions, requests have been made for ship time in every oceanographic area on the map. The greatest demand for ship time is off the east and west coasts of the U.S. This is likely due to a number of reasons including availability of ships, fewer logistical constraints, domestic support, and national and state interests in local waters.

The requests demonstrate the continued need for a distributed fleet of an appropriate size, vessel mix, and range of capabilities to meet the research programs planned in the world's oceans. The importance of the UNOLS coordinated scheduling process for efficient planning of expeditionary programs is imperative.

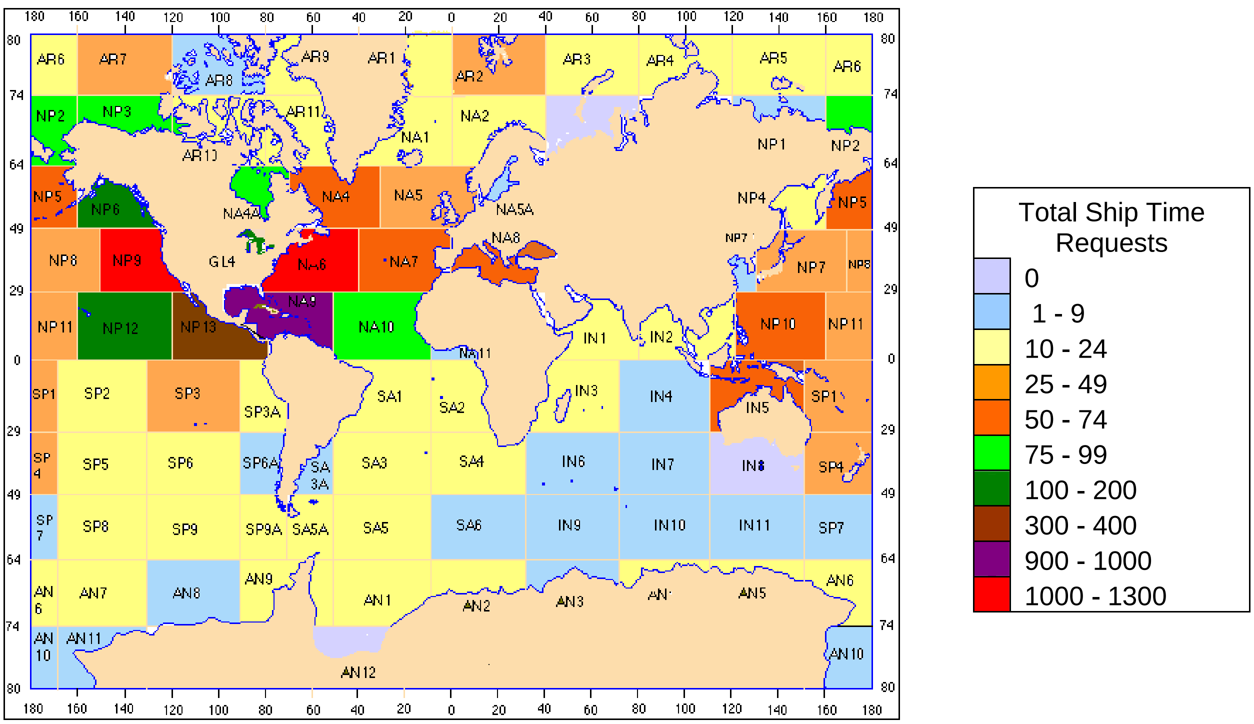


Figure 34. Geographic Distribution of Ship Time Requests (2000 to 2006)

4. Seasonal Utilization Trends

Ship usage often fluctuates throughout the year and peak utilization periods have been regularly observed during the summer months (Figure 35). In fact, during these peak periods, ship usage often reaches or exceeds optimal capacity. The utilization bars in Figure 35 represent the total days used by the four largest ship classes (Global, Ocean, Intermediate, and Regional). High ship time demand during the summer months can be attributed to a variety of factors including biological blooms and other biological events, weather windows, and science party availability. During winter months, when fleet utilization is often lower than other times of the year, ship operators and crew use the time to carry out maintenance and observe holidays (when feasible).

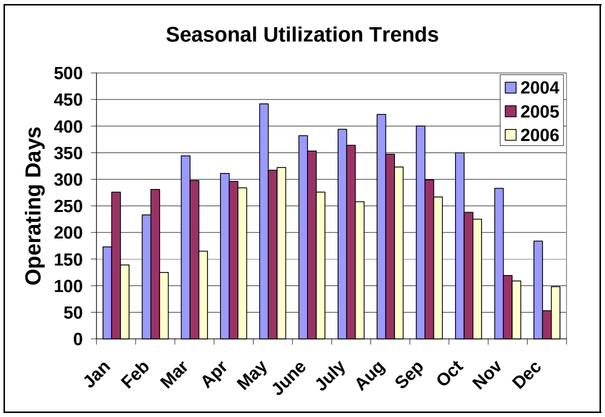


Figure 35. Fleet Seasonal Utilization Trends

Figure 36 shows the average monthly ship utilization for the years 2004, 2005 and 2006 by Class. To calculate the average, the total monthly utilization for the Class is calculated and then divided by the number of ships in operation.

Although Global ships operate worldwide and their larger size offers a longer operating weather window, seasonal peaks have been observed in the years 2004 to 2006 (Figure 36a). Ship usage is typically at its highest from May through September and often will exceed the optimal capacity.

The Ocean Class currently includes one vessel, *Kilo Moana,* homeported in Hawaii. Compared to other classes, the *Kilo Moana* has had little fluctuation in seasonal usage (Figure 36b). Perhaps this can be contributed to the moderate year-round weather in the ship's home-port area. Additionally, the ship's SWATH design allows it to operate effectively in higher sea states. *Kilo Moana* is used for support of the Hawaiian Ocean Time Series program with year-round cruises.

Seasonal peaks during the summer months were most notable in the Intermediate Class (Figure 36c) and Regional Class (Figure 36d). Weather and sea state conditions have greater impact on these vessels as a result of their smaller size and lower power. Schedulers and science users attempt to avoid scheduling programs outside optimal weather windows. The ships that eventually replace the Intermediate and Regional vessels need to be designed to operate in higher sea states and should allow longer weather windows of operation.

Although ship utilization of the Intermediate and Regional Ships is often reduced in the winter months, in summer months utilization reaches or exceeds capacity. Fewer vessels in these classes could result in the inability to accommodate ship time demand during peak times. As fleet reductions are considered, the impacts of fewer ships available to accommodate work during peak times must be addressed.

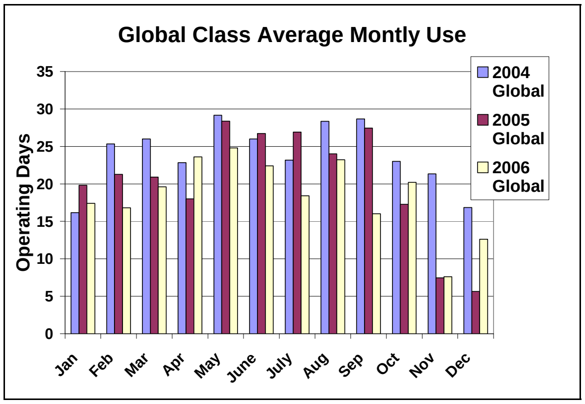


Figure 36a. Global Class Seasonal Trends

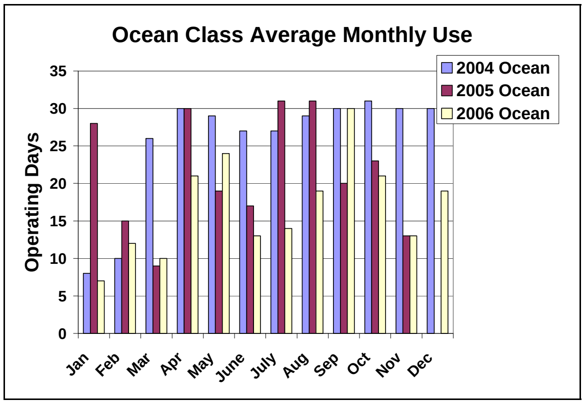


Figure 36b. Ocean Class Seasonal Trends

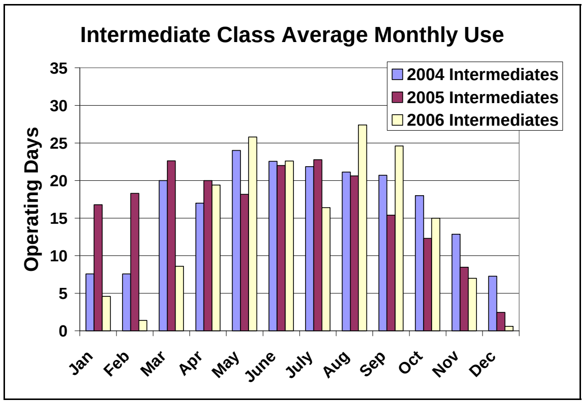


Figure 36c. Intermediate Class Seasonal Trends

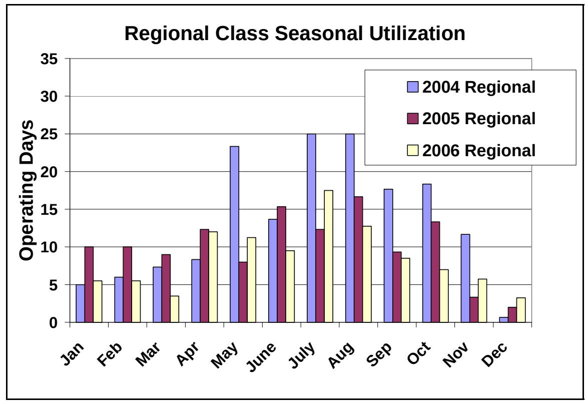


Figure 36d. Regional Class Seasonal Trends

Figure 36. Average Seasonal Ship Use by Class

5. The Cost of Fleet Operations

The cost of UNOLS Facility operations (ship and NDSF vehicles) includes but is not limited to fuel, crew salaries and benefits, technical services, maintenance, and costs associated with security and safety requirements. Total annual fleet operation costs from 1998 to 2007 in "real dollars," ignoring inflation increased and peaked in 2004 when fleet utilization was at an all time high (Figure 37). In 2005 and 2006, due to budgetary constraints and increased operation costs, fewer ship days could be accommodated. Ship operators have worked to keep costs to a minimum, but it has also been necessary to defer ship time into the out years to meet shrinking Federal budget levels. As an example, over 500 ship days were deferred in 2005. Although fewer ship days were utilized since 2005, the operation costs remain high. Escalating fuel costs have been a major factor in the cost increase, as well as the cost for implementing new security and safety regulations. This is a critical issue and strategies for lowering operating costs are needed. As fleet renewal plans move forward, the new ships that are built must be affordable to operate.

The total operating budget for the UNOLS fleet and NDSF in 2007 was close to $86M. A breakdown of these costs by Class shows that the Global ships accounted for 50% of all the operating costs (Figure 38). The Intermediate ships accounted for 17% of the costs. The one Ocean Class ship represented 9%, while the Regional Class and the NDSF vehicles each made up 7% of the total operating cost. The cost to operate the remaining Regional/Coastal and Local ships vessels is 10% of the operating budget.

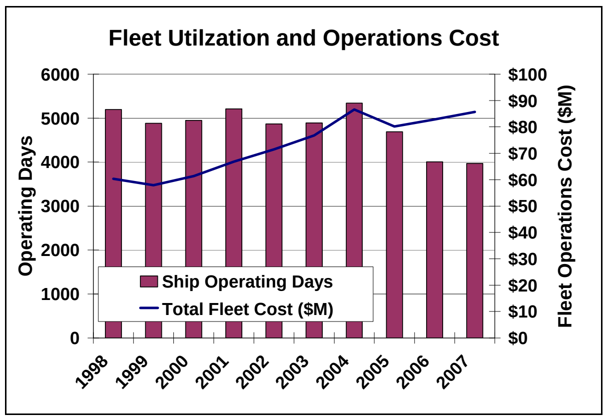


Figure 37. Fleet Utilization and Operation Costs (Total fleet cost includes ship operations, technical services, and NDSF costs).

Since 1998, the average annual cost for operating each Class of UNOLS ships has increased (Figure 39). The Global vessels have experienced the most dramatic annual cost increase. The average annual cost for operating a Global ship in 1998 was approximately $4.5M as compared to the 2007 cost of about $8.7M. This almost doubling in cost per ship is due to a number of factors, many of which are out of the control of the ship operators. As already stated, escalating fuel costs, and new security and safety regulations have been a major factor in the cost increase. The Global ships are influenced by these factors to a larger extent than any of the other ship Classes. A disturbing statistic is that while the annual operation cost of the Global ships has gone up, the total days that can be supported annually for this Class has dropped significantly since 2004 (Figure 40).

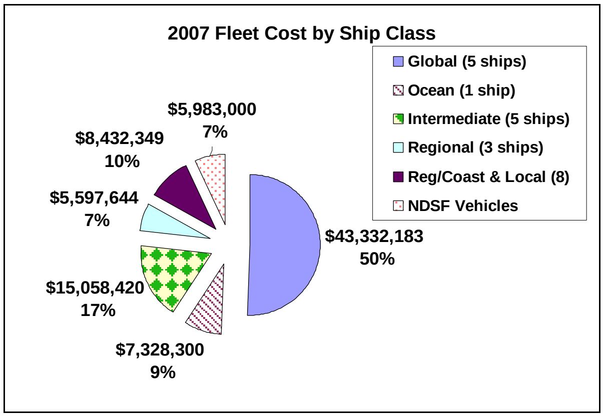


Figure 38. 2007 Fleet Cost by Class

The smaller UNOLS vessels (the Regional, Regional/Coastal, and Local Class ships) have experienced the smallest annual cost increase. These ships tend to operate close to their homeports and fuel usage is lower than that of the larger ships. Fuel usage for this class of ships in general is represents a smaller percent of the operating cost. Additionally, the smaller size of these ships exempt them from many of the security and safety regulations imposed on the larger, inspected vessels of the fleet.

The annual NDSF vehicles operation costs have increased by over $2M from 2001 to 2007 (Figure 39), while the utilization of these vehicles during this same period has been relatively level (Figures 40). The vehicle systems have become more sophisticated over the years and demand for use of these vehicles in remote geographic regions is more common. Further evaluation is needed to determine if these factors (and others) are influencing the NDSF cost increases.

Trends in the cost per ship berth again show an increase from 1998 to 2007 (Figure 41). To establish the daily berth cost, the total annual class operating cost was divided by the total Class operating days. This was then divided by the average number of science bunks on a ship of that Class. In 1998, the cost per bunk was in a range of $440 to $700 per day, depending on the Class of ship. In 2007, the cost per bunk was in the range of $600 to $920. Contrary to other cost patterns, the cost of a bunk of the Regional ships was greater than the bunk cost for the Intermediate and Global ships (except in 2007). This is due to the more limited number of bunks on the Regional Ships.

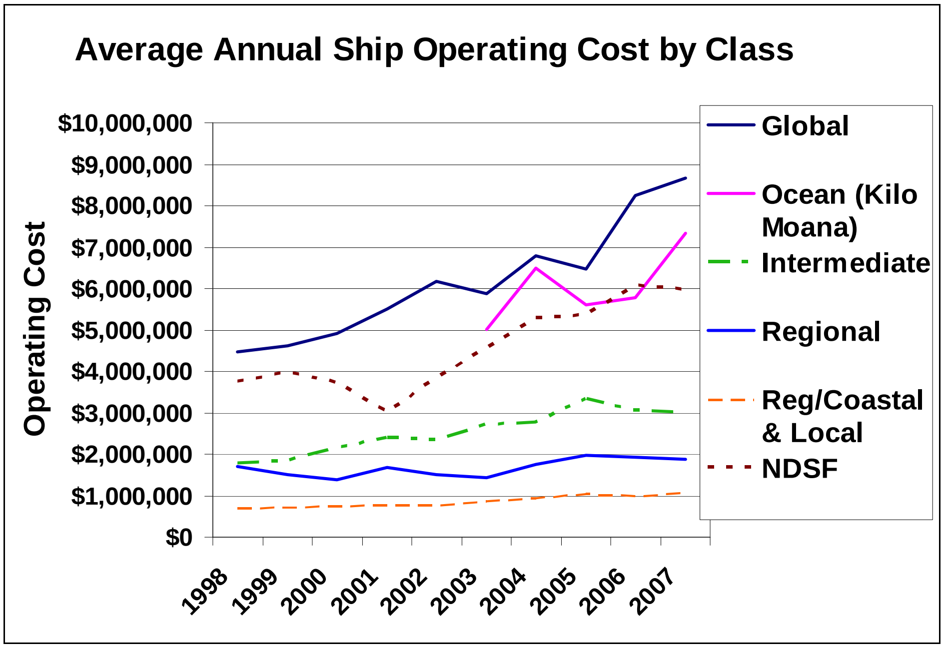


Figure 39. Average Annual Operating Cost by Class

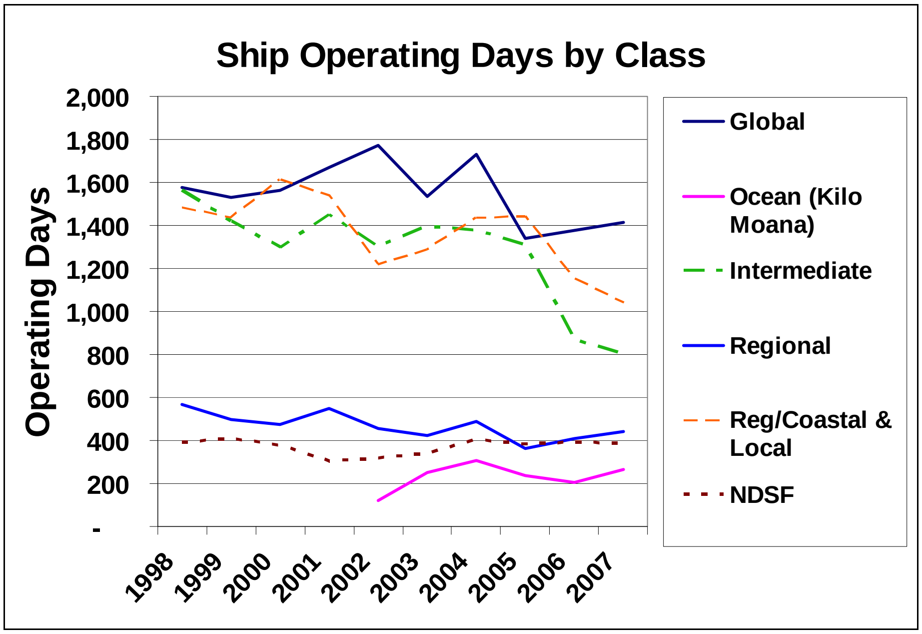


Figure 40. Total Utilization by Class

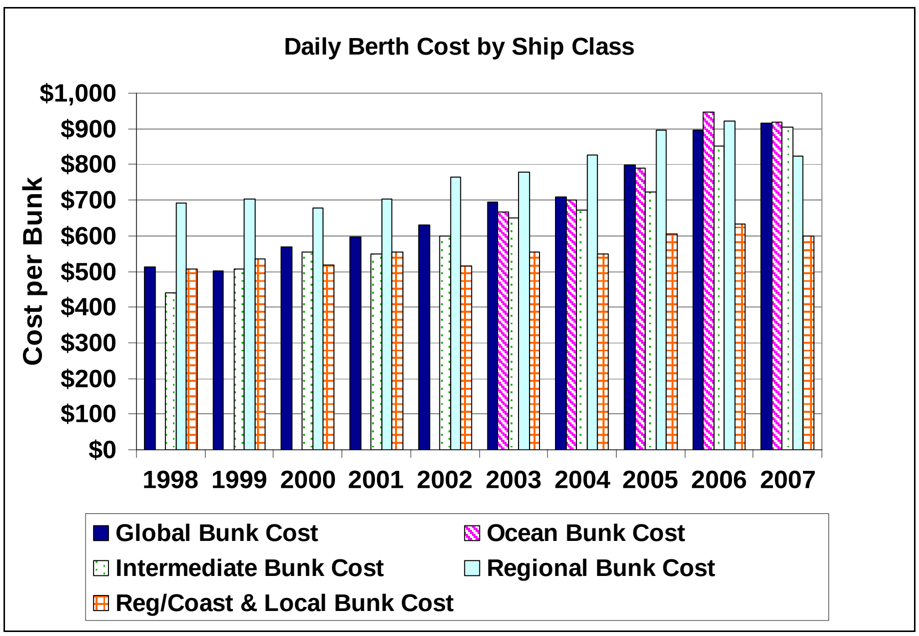


Figure 41. Daily Berth Cost by Ship Class

6. Funding Support for the UNOLS Fleet

The current UNOLS fleet and NDSF are supported by funds principally from NSF, the Navy, and NOAA. Other federal agencies that contribute to operations and technical services costs include the Environmental Protection Agency (EPA), U.S. Geological Survey (USGS), Mineral Management Service (MMS), Department of Energy (DOE), Army Corp of Engineers (ACOE), and the National Aeronautics and Space Administration (NASA). State and local governments, as well as private sources, also provide support.

In 2007, NSF provided 63% of the total fleet operational support, while Navy provided approximately 18% and NOAA 8%. State support represented 5% of the total operations budget. The other agencies and private sources made up the remaining 6% (Figure 42).

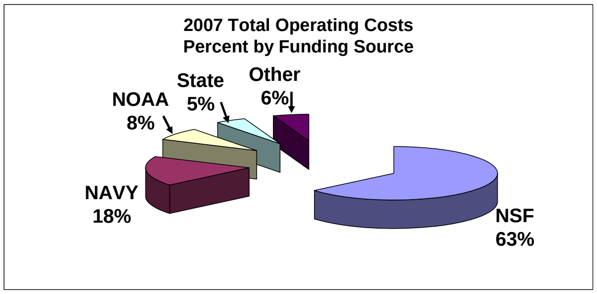


Figure 42. 2007 UNOLS Fleet Operations Cost - Percent by Funding Source

NSF funded ship time has increased since the late 1990s and peaked in 2004 with about 3300 days (Figure 43). NSF budgetary constraints since 2005 resulted in a sharp decline in the number of days that could be funded with a decrease of over 1000 days. Navy ship day use approached or exceeded 1000 days between 1998 and 2001, but has decreased since that time to below 800 days annually. In the late 1990's the Navy utilized UNOLS vessels for support of some of their Naval Oceanographic Center (NAVO) survey work. By about 2002, the survey work carried out on the UNOLS vessels had been completed and the NAVO support ended. NOAA ship days have remained relatively level from 2002 to 2006, typically between 500 and 600 days annually. In 2007, NOAA's ship days were at their lowest level in the past ten years, falling below 400 days. Since 1999, ship use funded by states and other sources has also remained level. State support has typically been between 200 and 300 days, while other support has generally been between 300 and 400 days.

NSF's operations funding rose sharply between 1999 and 2004, almost doubling to an all time high of close to $60M (Figure 44). Although NSF's ship day usage dropped by over 1000 days since 2004, the drop in funding support was not proportional. One of the reasons why the funding level did not decrease proportionally is because NSF supports much of the annual Global ship time and this Class has experienced the greatest operating cost increases (Figure 39). Navy support for fleet operations had been relatively level since 1998, but in 2007, support reached a high of over $15M. State and other support has also remained level over the years with funding levels below $5M annually each. NOAA funding of fleet operations rose by almost $5M between 1998 and 2006; however, in 2007 support dropped significantly by more than $5M. This reflected the decrease in NOAA's ship use. Budgetary constraints and agency priorities have impacted NOAA's use of the UNOLS fleet.

The increasing costs of fleet operations have required additional agency funding. Fewer ship days can be supported in recent years. These funding trends are of great concern. Unless Federal budget levels are increased to keep pace with the rising costs of fuel and regulatory requirements, fewer ship days can be accommodated.

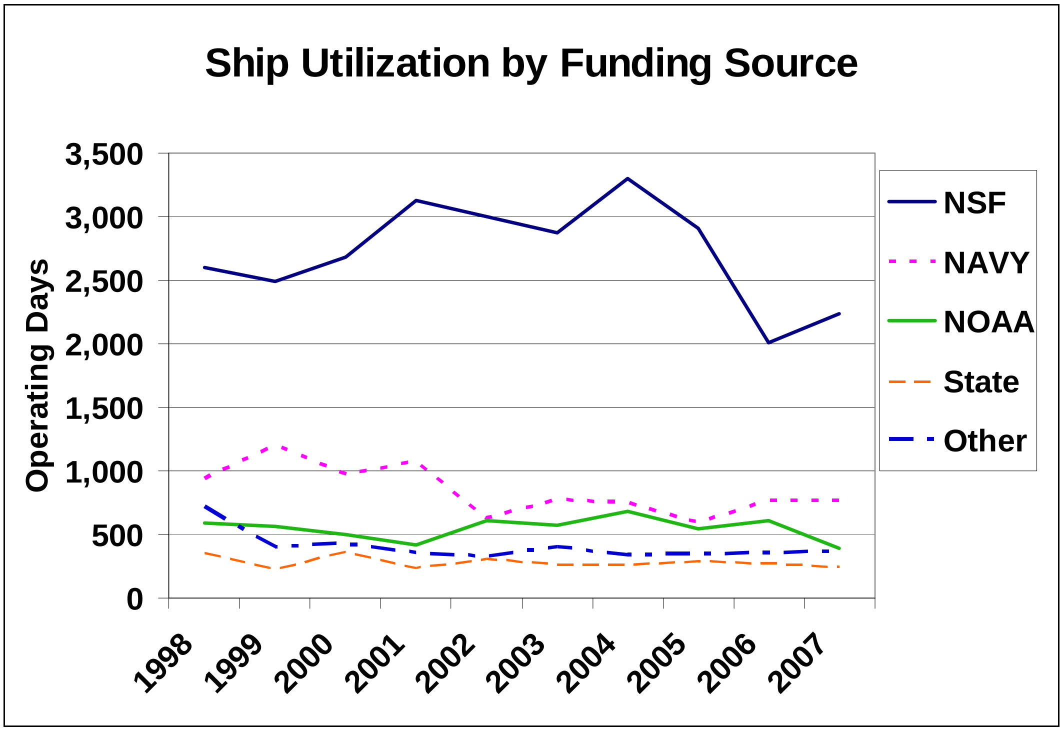


Figure 43. Fleet Utilization by Funding Source

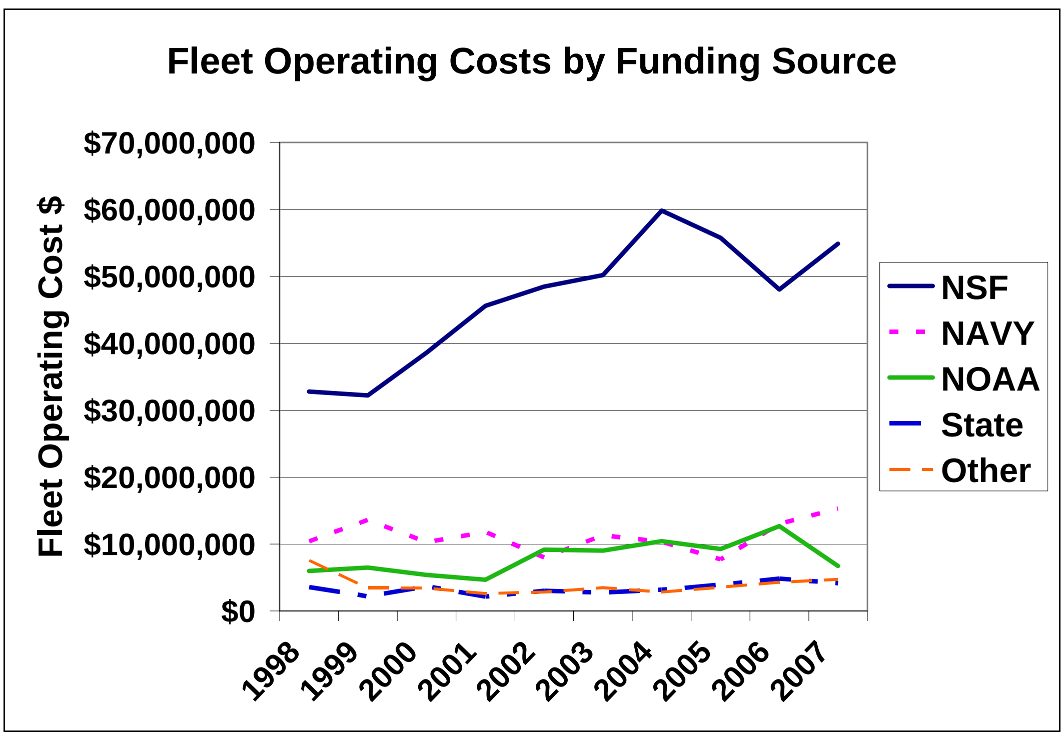


Figure 44. Fleet Operating Cost by Funding Source

IV. Future Fleet Utilization and Capacity Projections

A. Fleet Renewal Plans and Future Capacity

1. Fleet Renewal Activities, Plans, and Timeline

A diverse, modern, and distributed fleet will be required to carry out the recommendations of the nation's ocean research priorities plan. Fleet renewal is essential to ensure that highly-capable UNOLS facilities will be available to support future oceanographic research initiatives. Fourteen of the current 23 UNOLS vessels will reach the end of their projected service life within the next decade. The Federal agencies that support oceanographic research recognize the need to maintain a healthy fleet and are working to implement facility renewal.

Facility renewal activities that are currently under way include acquisition of an Alaska Region Research Vessel (ARRV) and up to three Regional Class ships with support from the National Science Foundation (NSF). The Office of Naval Research (ONR) is also working on plans to acquire two new Ocean Class vessels with Navy funds. Additionally, NSF is supporting the development of a Replacement Human Occupied Vehicle (RHOV) sphere and other systems that will be used to upgrade Deep Submergence Vehicle (DSV) *Alvin*. The upgraded HOV will initially have a depth rating of 4500 meters (14,764 feet) with the potential for an increased depth capability to 6500 meters (21,325 feet).

Alaska Region Research Vessel – After years of planning, the design of an ARRV, a 71.9 meter (236-foot), ice-capable vessel to support research in high latitudes was completed (Figure 45). Funds to support the ship's construction were included in NSF's Major Research and Equipment Facilities Construction (MREFC) account in FY2007. The University of Alaska Fairbanks (UAF) was selected as the ship operator and was awarded the first phase of funding for the design/construction effort. The estimated completion date for the vessel is 2014.

The new vessel will provide access to the waters of the Alaska region and will be the first vessel in the U.S. academic research fleet capable of breaking ice up to 0.76 meters (2.5 ft) thick. Additionally, the ship has been designed to the UNOLS Ocean Class Science Mission Requirements (SMRs) so that it can support future general-purpose oceanography [50]. The ARRV will have the ability to support Remotely Operated Vehicle (ROV) operations and will be equipped with a state-of-the art handling system that will allow deployment and recovery of a broad spectrum of scientific equipment. The ship will also be able to transmit real-time information directly to the shore and classrooms all over the world. The ARRV will have 26 science berths, including accommodations for individuals with disabilities.

Figure 45. Alaska Region Research Vessel. *Image from UAF*

ARRV Specifications:

- Overall length: 73-76 meters (240-250 feet)
- Draft: 5.5 meters (18 feet)
- Beam: 15.8 meters (52 feet)
- Speed, calm open water: 14.2 knots
- Endurance: 45 days
- Icebreaking: 0.76 meters (2.5 feet) at 2 knots
- Scientist berths: 26
- Crew berths: 17-20
- Science labs: 195 square meters (2100 square feet)
- Deck working area: 342.8 square meters (3,690 square feet)

Regional Class – Recognizing that the Regional Class ships are approaching the end of their service lives (*Alpha Helix* was removed from UNOLS service in 2006 and *Cape Hatteras* and *Point Sur* will reach the end of their projected service life by 2011), NSF plans to support the acquisition of up to three new Regional Class ships. Two competing contracts were awarded for the design of this Class and both designs were completed in 2008. The objective is to replace the older and less capable ships with more technically advanced and highly efficient Regional vessels. NSF plans to support the Regional ship construction through funds allocated to the Division of Ocean Sciences specifically for mid-size infrastructure projects. A prioritized set of Regional Class SMRs prepared by the UNOLS community are the basis for the Regional Class design [51]. A goal will be to infuse new technology and engineering equipment into the ships to optimize capabilities.

The Regional Class acquisition effort has been delayed due to a significant escalation in estimated construction costs. Funding for the Phase II detailed design and construction will not be forthcoming in the immediate future; however, NSF remains committed to providing Regional Class ships and will move forward when funds are available. Selection of operators for these vessels will be by open competition and home ports are anticipated to be in widely separate geographic regions.

For planning purposes of this document, a start date of 2013 has been assumed for the first Regional Class ship entering service with subsequent ships entering the fleet every other year. These dates are not endorsed by NSF, nor is there a commitment by the agency to construct all three ships.

Ocean Class – The UNOLS five intermediate ships will all reach their projected end of service life by 2016. ONR has requested funding for two Ocean Class ships with entry into the fleet in 2014 and 2015. The new vessels will be designed using the Ocean Class SMRs and, like the Regional Class ships, must be affordable both in terms of construction and operation. The ships are envisioned to be much more technically advanced and capable than the intermediate ships that they will replace. It is planned that the operation of the new Ocean Class vessels will be competed among the operator institutions.

Renewal Timeline - Figure 46 shows a projected timeline for UNOLS fleet renewal up to 2020. If current renewal efforts are fully implemented, all of the new vessels that are planned would be in service by 2017. The black ships in Figure 46 are those vessels that have already entered the fleet. There are no renewal plans yet in place for beyond 2020.

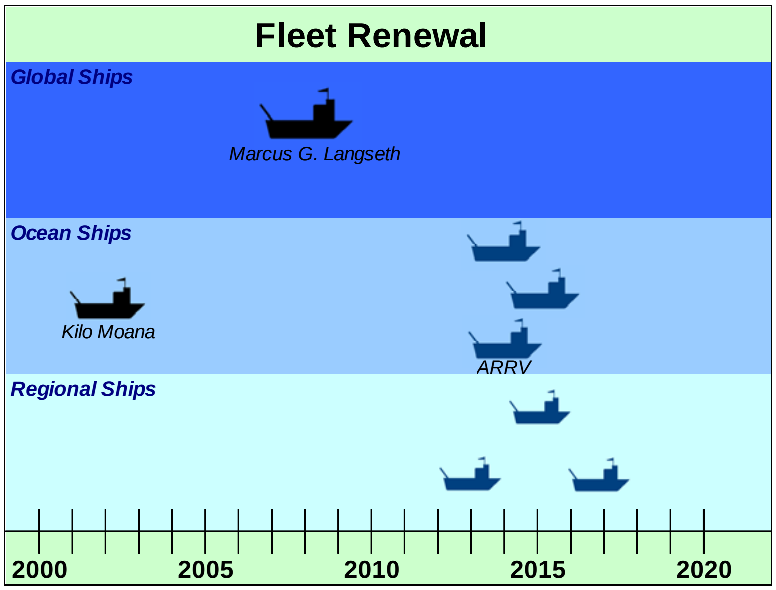


Figure 46. Fleet Renewal Timeline through 2020

2. Projected Fleet Size and Configuration

As the fleet renewal implementation plans come to fruition, the size and configuration of the fleet will change significantly. Figure 47 provides a snapshot of the fleet size by year through 2025. The projected end of service life for the current ships is based on input provided by the ship operators.

SHIP/CLASS*	BUILT/ Conv	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019	2020	2021	2022	2023	2024	2025
Global Class																			
Melville	1969																		
Knorr	1970																		
Thomas G. Thompson	1991																		
Roger Revelle	1996																		
Atlantis **(Submersible Support Ship)**	1997																		
Marcus G. Langseth **(Seismic Ship)**	2008																		
Total Global Ships		6	6	6	6	6	6	6	5	4	4	4	4	4	4	3	3	3	3
Ocean Class																			
Kilo Moana	2002																		
ARRV	*2014*																		
OC #1	*2014*																		
OC #2	*2015*																		
Total Ocean Ships		1	1	1	1	1	1	3	4	4	4	4	4	4	4	4	4	4	4
Intermediate Class																			
Seward Johnson	1985																		
Wecoma*	1976																		
Endeavor*	1976																		
Oceanus*	1976																		
New Horizon	1978																		
Total Intermediate Ships		5	5	5	2	2	2	2	2	1	0	0	0	0	0	0	0	0	0
Regional Ships																			
Point Sur	1981																		
Cape Hatteras	1981																		
Atlantic Explorer	2006																		
RC #1	*2013*																		
RC #2	*2015*																		
RC #3	*2017*																		
Total Regional Ships		3	3	3	3	1	2	2	3	3	4	4	4	4	4	4	4	4	4
Regional/Coastal Ships																			
Robert Gordon Sproul	1981																		
Pelican	1985																		
Walton Smith	2000																		
Hugh R. Sharp	2005																		
Total Small Regional/Coastal Ships		4	4	4	4	4	4	3	3	2	2	2	2	2	2	2	2	2	2
Local Ships																			
Urraca	1986																		
Savannah	2001																		
Blue Heron	1985																		
Clifford Barnes	1966																		
Total Local Ships		4	3	3	3	3	3	2	2	1	1	1	1	1	1	1	1	1	1
Total Ships		**23**	**22**	**22**	**19**	**17**	**18**	**18**	**19**	**15**	**15**	**15**	**15**	**15**	**15**	**14**	**14**	**14**	**14**

* Ships approaching the end of their projected service life will be evaluated to assess their condition.

Figure 47: UNOLS Vessel Projected Service Life Timeline

By the year 2025, the overall fleet size will shrink from 23 ships in 2008 to 14 ships (Figure 48). Three Global ships will reach the end of the projected service life without replacement. All five Intermediate ships and two Regional Class ships will reach the end of their service life by 2017. During that same time frame two new Ocean Class ships and up to three Regional Ships will be built as their replacement. Of the eight Regional/Coastal and Local ships that serve the UNOLS community today, only three will still be in operation in the year 2025.

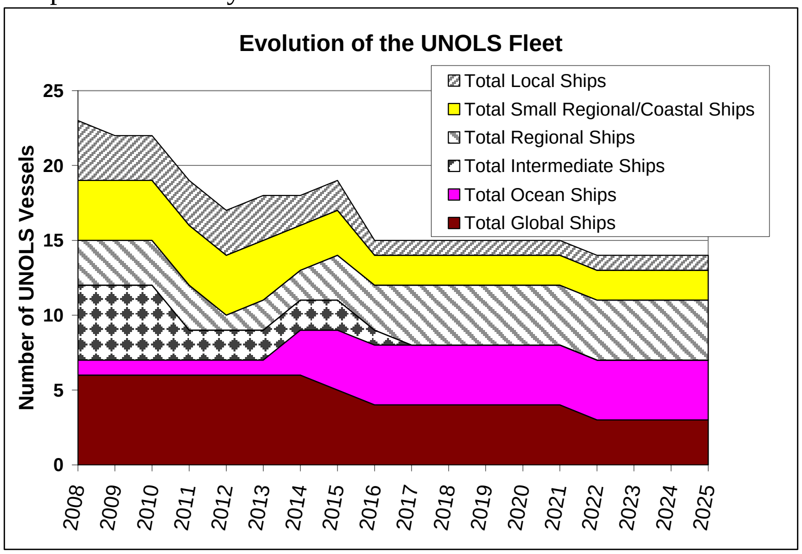


Figure 48. Evolution of the UNOLS Fleet

The 2025 Academic Fleet - The 2025 UNOLS fleet will consist of the vessels listed in Table 4. There will be only one general-purpose Global Class vessel in operation, R/V *Revelle*, and this ship will be one year from the end of its projected service life. The other two remaining Global ships, although capable of general-purpose operations, will likely continue to conduct primarily specialized submersible and geophysical operations.

The four Ocean Class vessels in 2025 will be expected to carry out much of the anticipated Global Class work that would have previously been scheduled on R/V *Melville* and R/V *Knorr*. Additionally, the Ocean Class ships will be needed for operations that have typically been carried out by the five Intermediate ships (all will reach the end of their projected service life by 2017). Until the new Ocean Class ships are built, it is unclear if they will be capable of supporting science missions that are typically scheduled on the Global Class vessels today. Current federal funding constraints as well as escalating ship construction cost will likely impact the Ocean Class ship size and design features that will be affordable to build and operate.

If all three Regional Class ships are built by NSF, the Regional Class size will remain level with four ships in 2025. However, these ships will be expected to not only carry out all of the operations currently carried out by the Regional Class but also some of the work presently supported by the Intermediate vessels. Like the Ocean Class vessels, the new Regional Ships' ability to fulfill the missions currently carried out by the Intermediate ships is unclear. Funding constraints have already resulted in ship designs that are scaled back to make the vessels more affordable to build and operate.

In summary, by 2025 only eight Ocean and Regional Class ships will be in operation to support the work left unscheduled by those vessels that reached the end of their projected service life and were removed from UNOLS service; three general-purpose Global ships, five Intermediate ships, and three Regional vessels.

The small Regional/Coastal and Local ships will also experience a dramatic reduction in number of ships. These ships are typically owned and operated by states and institutions. Although some institutions have expressed an interest in replacing their vessel if ship time demand remains high and funds are available, there are no formal plans in place for the replacement of these ships. By 2025, the eight Regional/Coastal and Local ships will be reduced to three ships.

SHIP/CLASS	Operator	Owner	BUILT	CONV	LOA ft (m)	SCIENCE BERTHS
Global Class						
Roger Revelle	SIO	NAVY	1996		84 (274)	37
***Atlantis* (Submersible Support Ship)**	WHOI	NAVY	1997		84 (274)	37
***Marcus G. Langseth* (Seismic Ship)**	LDEO	NSF	1991	2007	71 (235)	35
Ocean Class						
Kilo Moana	UHAWAII	NAVY	2002		57 (186)	29
Alaska Region Research Vessel	UAF	NSF	2014		72 (236)	26
Ocean Class #1	?	NAVY	2014		55-70 (180-228)	20 - 25
Ocean Class #2	?	NAVY	2015		55-70 (180-228)	20 - 25
Regional Ships						
Atlantic Explorer	BIOS	BIOS		2006	51 (168)	20
Regional Class #1	?	NSF	2013		40-55 (131-180)	15 – 20
Regional Class #2	?	NSF	2015		40-55 (131-180)	15 – 20
Regional Class #3	?	NSF	2017		40-55 (131-180)	15 – 20
Regional/Coastal and Local Ships						
Hugh R. Sharp	UDEL	UDEL	2005		44 (146)	14
Walton Smith	UMIAMI	UMIAMI	2000		30 (96)	16
Savannah	SKID/UG	SKID/UG	2001		28 (92)	19

Table 4. The 2025 UNOLS Fleet

3. Projected Fleet Capacity

In recent years budgetary constraints and rising fleet operating costs have resulted in fewer ship days being funded. The number of ship days funded from 2000 to 2004 was approximately 5000 days each year (Figure 49). In 2006 and 2007, the number of ship days funded declined to approximately 4000 days. Demand for ship time has remained high, but federal budgets have supported fewer ship days due to shrinking allocations and escalating operating costs. In 2008, there was an increase of about 300 days funded by non-federal sources from 2007 level, and as a result, over 4300 days were scheduled.

The "Ship Days Available" line in Figure 49 represents the number of ships in operation and the sum of their respective Full Optimal Year (FOY) definitions (see Table 3, page 41). The number of ships in operation is based on the projected end of service life dates of the current vessels and the service life start dates for the planned new vessels.

In 2007, ship days funded were at their lowest level in a decade and the fleet had excess capacity of about 826 ship days. Excess capacity is primarily driven by limitations in funding for science rather than ship user demand, and is not distributed evenly over the year. From 2005 to 2008 some of the older, less utilized vessels of the UNOLS fleet were removed from service. The total number of UNOLS ships in operation will continue to decrease as the ships reach the end of their projected service life and are removed from UNOLS service and fewer ships replace those that are removed. By 2016 the fleet's ship day capacity will fall below the 2007 day usage. Thus, we will be increasingly unable to meet science user demands during peak periods in spring and summer (Figure 35, page 47). We will lose the required flexibility in fleet scheduling that allows for multi-ship operations and for science expeditions in remote areas.

Unless additional vessels are added to the fleet renewal plans currently underway, by 2025 only 3,270 ship days will be available to carry out our nation's oceanographic research initiatives.

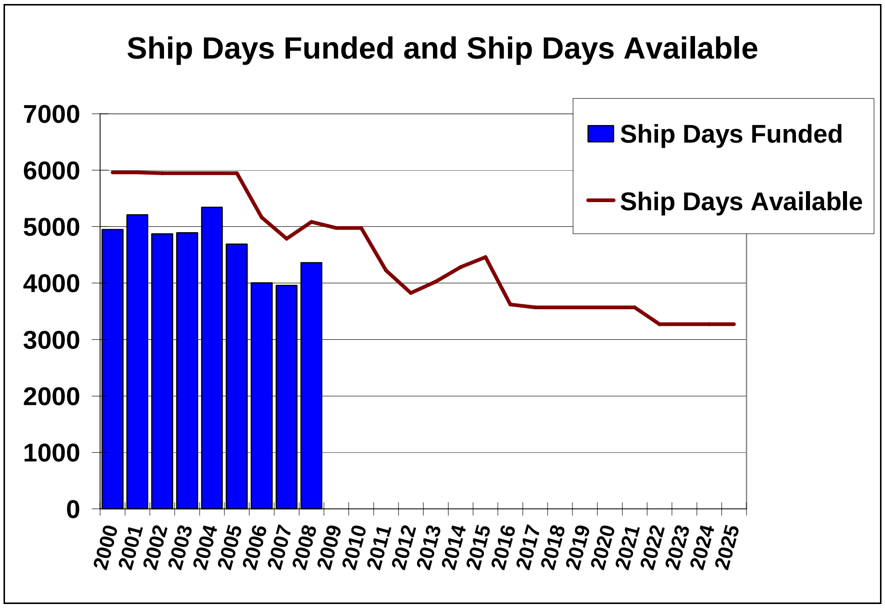


Figure 49. Ship Days Funded and Future Fleet Capacity

4. A Comparison of the 2008 UNOLS Fleet with the Fleet of 2025

Fleet renewal plans call for fewer, but more capable, vessels to replace the aging ships in the fleet. Table 5 provides a comparison of the 2008 fleet with the fleet of 2025. By 2025, there will be a significantly reduced capacity to support large science programs that require general-purpose, global-ranging ships, as well as a reduced capacity to support local near-shore research that requires smaller, shallow-draft vessels. In 2025, the fleet size will be reduced by eight ships overall and the number of science berths will decrease by more than 100 bunks. With fewer ships in the fleet, there will be less ship day capacity. Projections indicate that the ship day capacity in 2025 will be about 1500 days less than that in 2008. The reduced berth availability combined with the decrease in ship day capacity (berths available x ship day capacity) will represent a 57% decline in the capacity to send U.S. scientists and educators to sea from 2008 to 2025.

In 2008, the ship days funded for research totaled more than 4300 days. If the science requiring this level of ship days were funded in 2025, the fleet capacity would fall short by over 1000 days unless additional ships are included in the fleet renewal plans. Chapter II of this report has described the science drivers for continued high ship use by the nation's oceanographic research community well into the future. The ability to efficiently and effectively carry out this research will certainly be challenged on our present course of fleet renewal.

Current fleet renewal plans include no additional Global Class vessels. As ships in this Class reach the end of their service life, there will be no replacements and the Global Class will be reduced by half in 2025. The 2025 Global Class will consist of three ships (R/Vs *Revelle*, *Langseth*, and *Atlantis*) that can support general-purpose science operations. Additionally, R/V *Langseth* can support seismic operations and R/V *Atlantis* is a submersible support platform. All of these ships will be nearing the end of their service life by 2025. Oceanographic research has clearly relied on a fleet that can work globally (see Figure 34, page 46). Global Class scheduled operations in 2008 include work off the U.S. in the Atlantic and Pacific, off Australia, the Philippines, and Iceland, in the Lau Basin, Indian Ocean, Patagonia Shelf, and Guaymas Basin. In 2025, the three Global Class ships will be expected to support general-purpose, seismic, and submersible operations as well as carrying out expeditionary missions. With only three Global vessels in 2025, it would take years to visit all of the work areas that were studied in 2008. Funded programs will take much longer to get to sea and will impact the way researchers can support their students, science, laboratories, and other personnel. In 2008, the Global Class has 1,661 funded operational ship days. The 2025 Global ships could accommodate 900 days of this ship time, leaving over 700 days on shore; or about the work of two Global ships. Arguably, science in 2025 will be more global in nature, due to the global scale of the issues before society, particularly climate change. New technologies, increased collaboration, but also Global Ship capacity for the US science research fleet, will be necessary.

Until the Ocean Class ships are built and their sea keeping, endurance, range, and size are known, it will be unclear whether or not the new vessels will have the specifications required to support future large science programs. Many of the science initiatives discussed in Chapter I would benefit by the availability of Global vessels that meet or exceed the specification standards of the current Global Class ships. Additionally, with the installation of ocean observatories and additional time-series programs, the new Ocean Class vessels may be committed to designated locations and not available for work in more remote and seldom studied geographic regions.

The smaller UNOLS ship classes will also be significantly reduced in number by 2025. Only three of the eight vessels in the Regional/Coastal and Local Classes will still be in operation. Those still in operation will all be approaching the end of their service lives. These smaller vessels play an important role in the academic fleet. They provide access to near-shore regions, where the effects from land use and human interactions often have the greatest impacts. The lower operating costs and mode of operation (shorter cruises) associated with the smaller UNOLS vessels make them attractive for educational and outreach exercises. The three ships that will still be in operation are all located along the U.S. east coast; leaving the west coast, Gulf of Mexico, and Great Lakes without smaller UNOLS vessels. In 2008, the Regional/Coastal and Local Class ships have over 1000 ship days scheduled. In 2025, only 470 ship days will be available.

Class	Number of Ships in 2008	Total # Science Berths in 2008	Days Available		Number of Ships in 2025	Total # Science Berths in 2025	Available Days
Global	6	217	1800		3	109	900
Ocean	1	29	275		4	105	1100
Intermed.	5	103	1250		0	0	0
Regional	3	46	600		4	68	800
Reg/Coastal and Local	8	97	1160		3	49	470
Fleet Total	23	492	5085		14	331	3270

Table 5. Comparison of the 2008 Fleet with the Fleet of 2025

5. Can the Future Fleet Accommodate Current Ship Time Demand?

The previous sections and figures show that the future UNOLS fleet will change in configuration and be smaller in number. To better understand if the future fleet can accommodate funded ship time demand that is carried out by the current fleet, a model was created that schedules the 2006 UNOLS cruises on the 2017 fleet. By the year 2017, *Knorr*, *Melville*, all of the Intermediate ships, two Regional ships, and many of the smaller ships would have reached the end of their service life. During this same period, all of the new Ocean Class and Regional Class ships that are planned would have entered the fleet. Although the operators have not been selected for these ships, for the purposes of this model one Ocean ship and one Regional ship were each assigned to the Atlantic and the Pacific. The third Regional ship was assigned to the Gulf of Mexico region.

The model used the 2006 final ship schedules as the starting point. In 2006 funded ship time was approximately 4,000 days and lower than previous years (see Figure 49). In transferring the 2006 cruises to the 2017 fleet, the model attempted to keep the 2006 cruises on the same ship and in the scheduled time frame as feasible. Cruises that were on ships that will be "removed from UNOLS service" before 2017 were rescheduled as feasible on the remaining ships, using the ship time request as a guide when moving dates or ships.

The model is helpful in identifying which cruises cannot be accommodated with a reduced fleet size. It can estimate the excess or shortfalls in capacity by vessel class. The model also helps to identify where the ship time shortfalls are geographically or seasonally. The model helps to quantify any excess capacity in the 2017 fleet to identify the extent additional work for OOI and other future initiatives can be accommodated.

The 2017 model does not include ship time for work in the Alaska region or seismic operations. In 2006, the ARRV and the R/V *Marcus Langseth* were not in service and therefore there were no UNOLS assets available to support work in the Alaska region or for seismic work. Once these ships come into service, there will be requests for their use. The 2017 model includes the ARRV, but cruises scheduled on the vessel were for general oceanographic operations in the Pacific. Accommodating seismic and Alaska region work is an important element of future operations that must be considered when developing future fleet capacity projections. Another item to note is that the model includes the smaller ships that are will reach the end of their projected service life before 2017. These ships are the *Pelican*, *Sproul*, *Blue Heron, Urraca*, and *Barnes*. The model assumes that these ships would be replaced by states and institutions when the service life end dates are reached.

The model does not consider changes in the way the fleet will be used in the future. Larger, more capable vessels will be able to accommodate larger science parties and will have the potential for combining projects onto the same cruise. Additionally, the enhanced capabilities of the new ships should optimize the research potential of these vessels and result in the need for fewer days to accomplish cruise objectives. In modeling the 2006 cruises on the 2017 fleet, the larger ships were generally scheduled without taking into account the possibility of combining projects on the larger ship. The larger more capable ships would be used this way to take advantage of their larger bunk space and lab space.

In 2006, there were 23 active ships in the fleet. The 2017 model of the fleet includes 19 active ships. Initial conclusions from the model indicate that many of the 2006 cruises could not be scheduled in 2017, leaving at least 200 days on shore. Programs that requested multi-ship operations at a specific time of the year for a particular geographic region could not be scheduled because of fewer ships available due to them reaching the end of their projected service life. Also, research in remote locations (Mediterranean) was left unscheduled because of a lack of assets. Some cruises that required the use of specialized equipment; such as, Harbor Branch Oceanographic Institution's *Johnson Sea Link* submersible could not be accommodated because the sub's support ship reached the end of its projected service life. The 2006 cruises that were scheduled on the 2017 model actually required additional operational days; the fewer ships in operation required more transit days to reach the research stations.

To accommodate the 2006 cruises in 2017, the three Global ships still in operation (*Thompson*, *Atlantis*, and *Revelle*) would operate at a level that exceeds their optimal year capacity. The four Ocean Class ships may have excess capacity that could potentially accommodate some of the Global ship time; however, the model assumes that the ARRV is available for work outside of the Alaska Region. Until the new Ocean Class ships are designed and in operation, we won't understand their full potential for accommodating large global science programs. The two new Regional Class ships located in the Pacific and Atlantic will exceed their FOY capacity levels. This can be expected because these ships are replacing three Pacific ships and four Atlantic ships. *Hugh R. Sharp*'s 2017 schedule is very full, and like the Regional ships, it is picking up some of the ship time orphaned by the Atlantic Intermediate vessels and *Cape Hatteras* that reached the end of their projected service life and were removed from UNOLS service. Most of the smaller ships in the fleet were scheduled at levels similar to those in 2006; however, unless replacement plans for these vessels are carried out, the ship time requests for work in near-shore local areas will go unmet.

In summary, the model identified some key shortfalls in the future fleet size and configuration:

- The 2006 schedules could not be fully scheduled on the 2017 fleet.
- The future fleet won't be able to support all of the missions than the current fleet can accommodate and there will be fewer opportunities for ship selection available to the science community.
- Ship time demand will be difficult to meet during seasonal peak periods.
- Multi-ship operations may not be possible.
- Operations in remote locations will be difficult to schedule.
- Fewer ships will result in less scheduling flexibility.
- More days will be needed for transit between research areas due to fewer ships in operation.
- Excess capacity to accommodate future science initiatives (such as OOI) will be severely limited.
- By 2025, the fleet will have four fewer ships than in 2017 and the shortfalls identified in this model will be even greater.

B. The Impact of Future Research Facility Requirements on Ship Operations

1. Alternate and Emerging Technologies

In preparing the Fleet Improvement Plan it is essential to consider other technologies that could impact the usage of research vessels. For example, Autonomous and Lagrangian Platforms and Sensors (ALPS), such as AUVs, gliders, floats and drifters, are able to provide survey capabilities in the upper ocean. Aircraft, both human occupied and unoccupied, can provide rapid survey capabilities of the sea surface. Ocean observatories will occupy a new role in ocean research with cabled or moored platforms that will allow the collection of long time series data, as well as real time monitoring of ocean conditions. Near the shore, surface currents can be measured using high frequency radars. These systems, depending on the broadcast frequency, can measure surface currents out to 40 km (13 MHz) or 130 km (5 MHz) from the coast. Satellites offer the ability to survey the physical characteristics of large area of the ocean surface remotely.

The alternate and emerging technologies will greatly enhance our ability to monitor the ocean, but they are not going to replace the need to send ships and people to sea for science. Surveys by aircraft and satellites are limited to those properties that can be measured by remote sensing. The ALPS are limited by their speed, power and payload capabilities and will require supplementary support from surface ships with their sampling tools. Sensor stability on ALPS is also limited and thus ship-based calibrations continue to be needed. Many of the ALPS require surface ships for launch and recovery operations. Alternate technology systems when used in conjunction with surface ships will allow multi-faceted, comprehensive studies of ocean properties.

A recent NSF-funded project provides an excellent example of how alternate technologies can enhance a sea-going research project. A frontal region near the 50 m isobath off the U.S. east coast was recently identified in satellite Sea Surface Temperature (SST) imagery. The mechanism responsible for the formation of the Mid-Shelf Front (MSF) has yet to be identified. Obtaining answers to this basic question are a necessary precursor to more complete understanding of the effect of MSFs on cross-shelf transport of dissolved and particulate materials. A field program to study the front's genesis, maintenance and general hydrography involved three ten-day cruises over a four month period during the winter of 2007. Underway hydrographic surveys were conducted with a towed undulating vehicle (Scanfish) and shipboard 300 kHz ADCP [52]. Moored observations of currents and temperature in the mid-shelf frontal region were used to describe the cross-frontal structure of velocity and hydrography between these cruises [53]. Additionally, three glider deployments obtained 15 temperature/salinity sections through the front over the same period [54]. These sections were used to track the temporal and spatial variability of the front over the study period. Finally, the seasonal progression of the surface temperature and velocity fields, using satellite and high-frequency radar (Coastal Ocean Dynamics Applications Radar [CODAR]) data, respectively, are being studied [55].

Although the demand for ships will continue, the onset of alternate and emerging technologies will likely change the ways that ships are used. Ocean observing systems will require dedicated ship support for installation, maintenance, and operations. In addition, the time series at these fixed locations will probably result in new demands for research cruises to support companion studies of variables that cannot be measured by the infrastructure of an observatory. The events that the observing systems are sure to detect will require the availability and geographic placement of ships that will permit timely response.

Alternate and emerging technologies offer new, exciting systems and methods for observing the oceans. They will not reduce the demand for research vessel access, but instead will place different types of demand on the research fleet. Access to these technologies along with a modern fleet of research vessels that can accommodate them will provide the U.S. oceanographic community with the optimal suite of assets to carry out future research programs at sea.

2. Ocean Observatory Facility Projections – Installation, Operation, and Maintenance

The construction of new ocean sciences observing systems will change the way we use existing ocean sciences facilities and also increase demand for their use, especially oceanographic research ships and deep submergence vehicles. Ships and vehicles must have specific capabilities and be equipped with the suites of tools needed to service the observatory components and their associated instrumentation. AUVs and gliders will be an important standard tool at ocean observatories. Routine access to assets at designated observatory geographic sites and during specific times of the year will be a requirement.

NSF's Ocean Observatory Initiative (OOI) Coastal and Global Scale Nodes (CGSN) and the Regional Scale Nodes (RSN) observatory sites were described in Section II.G. The locations of these OOI sites are shown on the map in Figure 50. OOI plans to carry out their observatory installation operations using commercial cable-laying ships, as well as UNOLS research vessels and ROVs. Funds to support the use of UNOLS facilities for installation are included in the NSF's OOI MREFC budget. As the observatories are installed, there will also be annual Operations and Maintenance (O&M) requirements. OOI projections indicate that most of the O&M efforts can be supported by UNOLS vessels. The OOI MREFC budget includes funds for UNOLS facilities to support O&M in the initial years. Once OOI is considered fully operational, O&M can no longer be supported from the MREFC account and funds will have to come from NSF's program budgets. NSF has set an annual budget cap of $50M for support of O&M and the OOI infrastructure has been scoped and designed with this O&M budget constraint in mind.

Installation of the ocean observatories have been delayed because of budget constraints and to allow time for the development of accurate, detailed design and cost estimates. Once the detail designs and cost estimates are accepted, the project will move forward with the installation phase. The OOI designs have undergone many iterations of scoping. The scope of the system designs are directly related to the facility (ship and ROV) requirements for installation and servicing of the nodes and arrays. The projections described in this section are based on the information provided by the OOI Office in October 2008. The actual OOI installation start year will depend on federal budget decisions and acceptance of the OOI design and cost estimates. If all proceeds on course, installation could begin in 2011. The OOI ship time estimates include days on station as well as days required for transit to the site. The transit days are calculated using port locations closest to the observatory site. Some of the OOI sites are located in areas that can be serviced by local area vessels and port days are not included in the ship time estimates [home port days are not included as chargeable days in ship operation proposals].

Figure 50. Ocean Observatory Initiative Sites

The Coastal Scale Nodes (CSN), Endurance and Pioneer Arrays, will be the first OOI components to be installed. The Endurance Array off Washington and Oregon states will require ship support beginning in 2011 of the installation phase and the Pioneer Array in the Mid-Atlantic Bight will require support beginning in 2012. Once fully installed, Intermediate vessels will be required at each site for two visits annually for an estimated total of 14 days at Endurance and 18 days at the Pioneer Array. Additionally, an ROV with a Global support ship will be required for 5 days a year at the Endurance Array.

In 2012, the installation of the RSN will begin. Installation and servicing of this cabled observatory requires specialized equipment and technical support requirements. The OOI planners have indicated that support for cable laying and servicing will be carried out primarily by commercial cable vessels. Maintenance and operation of the RSN infrastructure will be supported by UNOLS Global Class ships with ROV assets. Once the RSN is installed, it is estimated that 60 days of Global ship and ROV time would be needed annually.

UNOLS Global vessels will be required for support at each of the three Global Scale Nodes (GSN). The first GSN, Station Papa in the North Pacific will be operational in 2013, and will be followed by the Irminger Sea site in the North Atlantic in 2014. The third Global node, Southern Ocean in the Pacific, will be operational in 2015. Once operational, the GSNs will require annual servicing visits of 22 ship days for Station Papa, 24 days for the Southern Ocean, and 28 days for the Irminger Sea. These sites are located in remote ocean regions and the servicing schedules must coincide with the ship's weather window for that area.

A summary of the OOI estimated UNOLS ship day requirements is provided in Table 6. The specific ship day requirements by observatory are listed, as well as, an annual total of ship days required estimated by class.

OOI Facility Projections and Considerations for the UNOLS Fleet:

The current vessels that are homeported in the vicinity of the CSN sites are the aging Intermediate Class and will all reach the end of their projected service lives by 2011 (*Wecoma*, *Endeavor*, and *Oceanus*); which is the projected year that OOI installation will begin. It is unclear if the new Regional Class can meet the O&M servicing requirements at these sites. It is important to note that under the current ship service life and renewal timelines; there will clearly be a gap of about two years between the time the Intermediate vessels reach the end of their projected service life and the time that the new Regional vessels come into service (see Figure 47). Additionally, if the institutions that are selected for operation of the Regional Ships are not located near the CSN sites, alternative options must be considered. This could include service life extension programs for the current Intermediate vessels or chartering days on non-UNOLS vessels.

Once all of the ocean observatories are installed, O&M projections indicate that about 139 days of Global ship support will be required annually to support observatories in the Irminger Sea, Southern Ocean, Station Papa, and off of the U.S Pacific Northwest. By the time the OOI sites are fully installed, there could potentially be only four Global ships (*Atlantis*, *Langseth*, *Revelle* and *Thompson*) available to carry out all of the traditional science initiatives, submersible support, and seismic operations, as well as the new O&M annual facility requirements. Scheduling two ships for operations in the OOI remote regions with specific weather windows, as well as operations required for other large science programs will exceed the day capacity offered by these ships. Lengthy transit cruises will be required. Flexibility in scheduling will be lost.

Ocean Observatories will offer the opportunity to detect episodic events, most of which are unpredictable. Studies of such events pose tremensdous scientific opportunities and major technical and logistical challenges. These events evolve rapidly, requiring swift deployment of observational and sampling systems. Effective event responses are constrained by the availability of personnel and equipment at extremely short notice, funding availability, and weather constraints on over-the-side operations. Many event response studies can best, or only, be accomplished using a submergence vehicle or tool, the availability and capabilities of submergence assets and their support ships are particularly critical [56]. The UNOLS operating mode will require modification and the fleet would require excess capacity in order to offer an event response capability.

OOI Infrastructure	Vessel Class	Days at Sea by Year 2011	2012	2013	2014	2015	2016	2017
Atlantic								
Pioneer Array	Intermediate			18	18	18	18	18
Irminger Sea	Global				28	28	28	28
Pacific								
Regional Scale Nodes	Global + ROV			30	60	60	60	60
Station Papa	Global			22	22	22	22	22
Southern Ocean	Global					24	24	24
Endurance Array - OR	Global + ROV	4	0	0	5	5	5	5
	Intermediate	6	9	5	10	14	14	14
Total by Vessel Class	Global	0	0	22	50	74	74	74
	Global + ROV	4	0	30	65	65	65	65
	Intermediate	6	9	23	28	32	32	32

Table 6: OOI Estimated Ship Day Requirements for UNOLS Vessels

3. UNOLS National Facilities – Future Requirements

UNOLS designated National Facilities include the seismic vessel, R/V *Marcus G. Langseth*, the National Deep Submergence Facility (NDSF), and the National Oceanographic Aircraft Facility (NOAF). Each of these facilities has a designated UNOLS standing committee that provides oversight and advice (MLSOC, DESSC, and SCOAR). This document summarizes recommendations of the National Facility oversight committees in terms of facility renewal direction.

There are other non-UNOLS specialized facilities that are overseen by UNOLS Standing Committees. As an example the AICC provides advice on the science operation and technical upgrades for the USCGC Icebreaker *Healy*. These non-UNOLS special facilities are important and efforts by UNOLS to ensure their future availability for oceanographic research will continue. However, this particular document will not address the non-UNOLS facilities; other studies at the national level have addressed them.

Deep Submergence Vehicles – Future Needs - Since the 1990s there have been several committees, workshops, reports, and technical publications that have focused on the facilities that are required to continue and expand our nation's ability to conduct deep submergence science. These studies have explored the capabilities offered by HOVs, ROVs, AUVs, as well as the sensors and instrumentation technology, and have provided recommendations on the mix of assets that would benefit future research initiatives in the deep ocean and on the seafloor. A summary of these recommendations include the following [57]:

- ROVs have offered important benefits and more of them may be required to augment US vehicle capabilities and provide access to globally diverse study areas at depths to 6500m. ROVs will be needed to support expeditionary research as well as for support of ocean observatory initiatives.
- AUVs provide excellent mapping capabilities and are an important tool for deep submergence science. More AUVs with diverse operational characteristics are necessary.
- There continues to be a need for *in situ* observation and sampling of seafloor processes for deep submergence research. An HOV with improved capabilities and a depth range of 6500-7000m is recommended that could provide access for the next several decades.
- Innovative deep ocean sensors and instrumentation are required for the diverse array of ocean floor observatories and other basic research programs that are being planned.

Aircraft Facility Future Needs - Rapid developments in ocean-observing systems and research observatories within the nation's coastal oceans and in international deep-ocean regions have prompted SCOAR to consider the utility of airborne observations within these activities. Aircraft will be useful in three principle ways: (1) routine observations in areas that do not have fixed, *in situ* instrumentation (*e.g.*, to obtain data for the initialization or verification of oceanic and atmospheric models), (2) observations surrounding observatory sites or moorings to provide more complete, three-dimensional views of the environment, and (3) intense observations for specific, short-term events such as algal blooms, high-runoff episodes, atmospheric storms, Gulf Stream intrusions, and ocean-eddy events. Long-range aircraft operated by agencies such as the National Oceanographic and Atmospheric Administration (NOAA), National Center for Atmospheric Research (NCAR), National Aeronautics and Space Administration (NASA), and the Naval Research Laboratory (NRL) are presently available for deep-ocean observatory needs far from a land base. To best serve the nation's growing coastal observing systems and observatories, SCOAR foresees the need for regional research aircraft centers. These centers would operate shorter-range aircraft, such as the Twin Otter and smaller, slow, good-visibility, single- or twin-engine aircraft over coastal and inshore waters. CIRPAS is already filling this role on the U.S. West Coast. A strong case can be made for centers on the U.S. East Coast, in Alaska, on the Gulf of Mexico coast, and in Hawaii to enhance coastal observing systems that are either operating or planned in those regions.

C. Constraints and Challenges

1. Federal Budgets and Escalating Fleet Costs

Oceanographic research initiatives and their ship time demand along with the funds available to support science and facility requirements ultimately define the composition and operation of the UNOLS fleet. Since the publication of the last Fleet Improvement Plan in 1995, federal priorities and budget initiatives have changed significantly. The current administration is faced with the high costs associated with homeland security, war efforts, and Wall Street bail outs at a time when the federal budget deficit is already at a record high level. Administration priorities to support these efforts lead UNOLS to forecast that the ocean science community will continue to face budget constraints in the coming years. Federal budgets have either been flat or increasing below the inflation rate. The percentage of federal research funds allocated for ocean sciences has decreased from 7 percent of the total research funds allocation 25 years ago to just 3.5 percent by 2004 [5].

UNOLS fleet operations have certainly felt the impacts of increased security requirements and federal budget limitations. Operating ships in accordance with new environmental, safety, and security regulations have come at a high cost. These new measures have required increased crew training and increased staffing requirements. Adding to the problem, fuel prices, that represent a large percent of the fleet's operating budget, have skyrocketed. In 2006 and 2007, about 1000 fewer ship days annually were funded compared to previous years. However, instead of fleet operating costs decreasing during this two year period, the total fleet cost rose approximately $5M (see Figure 37).

The UNOLS Global ships represent about 50% of the total annual fleet operating budget (see Figure 38) and are influenced by escalating fuel prices and new regulatory requirements to a larger extent than any of the other ship classes (Figure 39). Global vessels must be compliant with both U.S and international regulations to operate in the world's ocean. The remote geographic regions that the Global ships operate in require lengthy transits and fuel consumption is high.

The operating costs of five Global Class ships (*Atlantis, Knorr, Melville, Revelle,* and *Thompson*) were examined for the period from 2000 through 2008. During this period, the total funded days for these ships were relatively level (Figure 51). The operating days and costs for 2008 are based on estimated values included in the ship operation proposals prepared by the operator institutions.

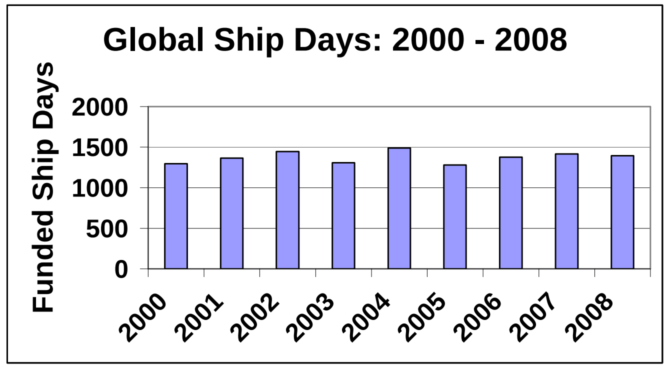


Figure 51. Funded Ship Days for *Atlantis, Knorr, Melville, Revelle*, and *Thompson* (2000-2008)

In 2000, many of the new regulatory requirements had not yet been enacted and the fuel prices had not begun their sharp increase. Three of the largest cost drivers influencing ship operating costs are fuel, crew salaries and benefits, and maintenance expenses. The five-ship total annual cost for each of these items is shown in Figure 52. Since 2000, each of these drivers has steadily risen for the Global ships.

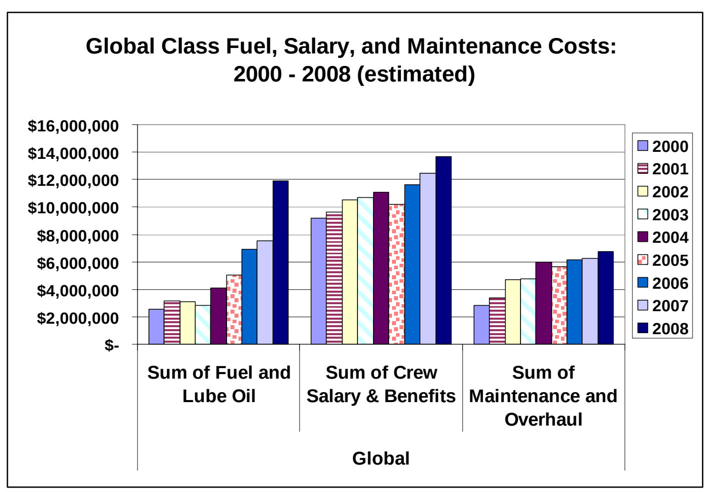


Figure 52. Global Class - Fuel, Salary, and Maintenance Costs

Over the course of nine years, the rate of increase of fuel, salary and benefits, and maintenance costs have greatly exceeded national inflation rates (Figure 53). Using the 2000 operation values as a basis, the costs based on inflation rate were calculated for 2008 using the Consumer Price Index [58]. The total cost of fuel for the five Global ships in 2000 was about \$2.5M. In 2008, based on the rate of inflation, the total fuel cost should have been \$3.2M. Instead, actual fuel costs in 2008 are estimated at \$11.9M, more than 3.5 times the inflation rate. 2008 Salary and benefit costs exceeded inflation by about \$1.9M and maintenance costs exceeded inflation by about \$3.2M.

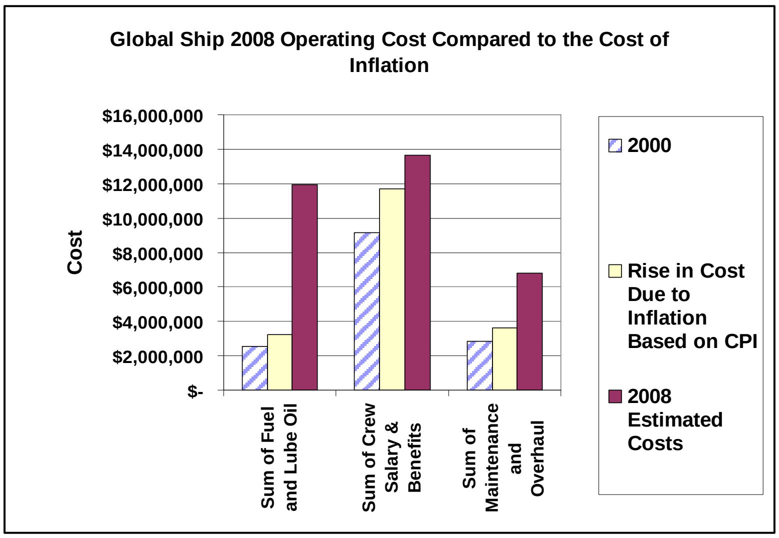


Figure 53. Global Ship Operating Costs Compared to Inflation

The impact of escalating fuel has significantly impacted the other ship classes in addition to the Global ships. The cost of fuel as a percentage of a ship's total operating cost has gone up dramatically in recent years. Fuel costs for the Global, Ocean, Intermediate, and Regional ships were examined to determine how much the increasing fuel costs were influencing total ship operating costs. In 2000, fuel costs represented on average 11% of a Global ship's total operating cost, while in 2008 the fuel cost percentage jumped to 26% of total cost (Figure 54). Similar trends are evident with the other classes. In 2000 the Regional and Intermediate ship fuel costs each represented 7% of a total ship's operating cost, but by 2008 the Intermediate ship fuel cost percentage had jumped to 18% and the Regional ship fuel cost had jumped to 16%. The Ocean Class ship, which began operations in 2002, saw an increase in the fuel cost percentage from 10% to 22% in 2008.

Federal budget constraints impact not only the operating budgets for fleet operations, but they are also influencing the designs of new ships in terms of size and capability. As acquisition plans for the ARRV, Regional and Ocean Class have moved forward, construction cost estimates have dramatically increased. Steel prices in the U.S. are high. The economic boom that shipyards are experiencing has resulted in a market that makes research ship construction unaffordable within the available federal budgets. To move forward with vessel acquisition, prioritization of ship design requirements has been necessary and tradeoff decisions will be needed.

The budget constraints that have resulted in the reduced number of funded ship days since 2006 have in turn resulted in excess ship day capacity on many of the UNOLS vessels. There are consequences of not operating a fully funded fleet. The additional funds needed to maintain the fleet capacity (lay-up costs) is money that is unavailable to support science. Instability in operations presented by ship lay-up situations has had a negative effect in terms of hiring and retention of skilled crew and marine technicians, who can often find higher paying positions within the commercial sector. Maintaining fleet expertise is critical.

Excess fleet capacity also presents serious challenges for efforts to move forward with fleet renewal initiatives. The question often arises, "Why are new ships needed when the existing vessels are not fully employed?" As this question is asked, it is important to recognize that:

- Aging vessels are less capable and will require high maintenance costs for continued safe operations.
- A modern, highly-capable, diverse, geographically dispersed fleet of vessels is essential to maintain our nation's access to the world's ocean.
- Demand for ship time remains high.

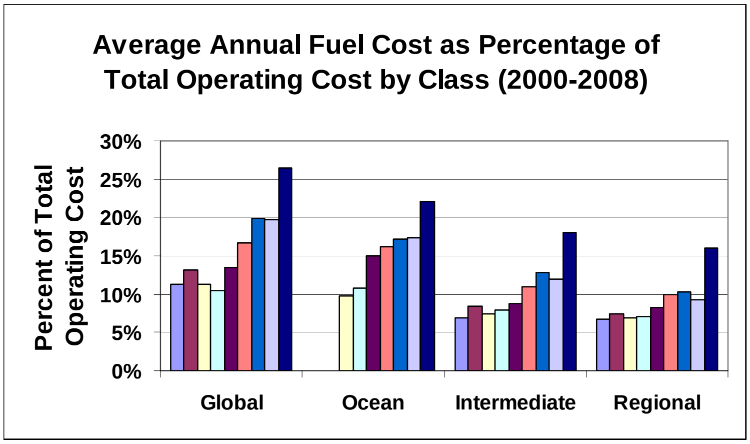


Figure 54. Average Annual Ship Fuel Cost as Percent of Total Ship Operating Cost

Along with the challenges brought on by excess ship capacity, there may also be opportunities. Increased educational uses of the ships could be explored that might encourage national and state education groups to become more engaged in oceanography. Collaborations and partnerships with other science users, both nationally and internationally, should also be explored. The excess ship capacity could potentially offer the U.S. oceanographic community an event-response capability; provided the facilities are maintained in a condition that will allow rapid deployment and the assets are located in the geographic region where events are more likely to occur.

In this challenging budget climate, it is important to examine and identify potential cost-saving strategies. Over the years, the UNOLS fleet operating model has been studied to determine if it is efficient and cost effective. The UNOLS model has also been compared to other operating models used by foreign countries, the Navy, and NOAA research vessel operators. An NSF review of the Academic Research Fleet recommended that the UNOLS system should be retained [59]. No apparent economies in consolidating the UNOLS fleet have been identified.

3. An Aging Fleet

Many of the current vessels in the UNOLS fleet are quickly approaching the 30-year age mark when service life is expected to end. In 2008, the median age of the fleet is 23 years. Over the next five years, the median age of the fleet will continue to climb before peaking at 27 years (Figure 53). Supporting the continued operations of an aging fleet can be at a high cost. Ship equipment and system failures can expect to increase with ship age. Downtime for repairs can impact scheduled science programs. As equipment becomes obsolete obtaining replacement parts can be challenging or impossible, again impacting operations. Many of the current ships cannot meet the science mission requirements that develop from science initiatives. As the ships become older, their performance is likely to degrade and they risk mission obsolescence.

After 2013, there will be a period of about five years when the median fleet age will sharply decline to a low of 15 years. This is the period in which the new vessels called out in the current fleet renewal plans will enter service. After 2017, renewal plans will be complete and again the fleet median age will again rise and will reach a median age of about 21.5 years by 2025.

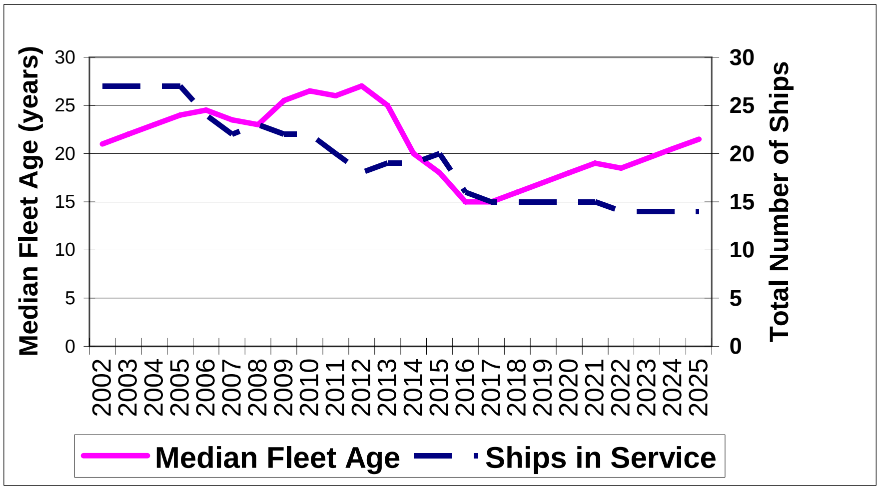


Figure 55. Median Age of the UNOLS Fleet

D. Options and Considerations for Meeting Ship Time Demand

The previous chapters of this document have highlighted that there will continue to be traditional demands for ships to accommodate basic research and education activities as well as changing demands introduced by new initiatives such as the ocean observatories. Future fleet capacity must be carefully examined to ensure that as older ships reach the end of their projected service life and are removed from service, there will still be adequate ship days available to meet future science demand.

1. Service Life Extension Programs

The timeline for fleet renewal has slipped and the number of ships to be built has been scoped down from original plans. Installation of the ocean observatory systems is scheduled to begin just as some of the vessels located near observatory sites will reach the projected end of their service life, yet before the new ships come into service. Some of the existing UNOLS vessels might be required to remain in service in order to meet ship time demand. Recognizing that there might be a gap between when aging ships are removed from UNOLS service and the time when new ships will enter the fleet, information was collected from UNOLS ship operators regarding the feasibility of extending ship lifetimes by carrying out Service Life Extension Programs (SLEPs). Additionally, since the current vessels would be expected to carry out future science missions requiring more advanced capabilities, ship operators were asked to provide information about how their respective vessel(s) compare to the Regional and Ocean Class Science Mission Requirements (SMRs) [51] [50].

There are nine UNOLS vessels in the Global, Intermediate, and Regional Classes that will reach the end of their projected service life prior to 2020 and are potential candidates for SLEPs. Ship operators have indicated that most of these ships can have their lifetimes extended five and possibly ten years for an estimated cost of $0.75M-$5M per ship (cost is based on a 5-year life extension) [60]. The operators of smaller Regional/Coastal and Local vessels in most instances do not recommend extending their respective ship projected end of service life dates.

The SLEP estimates focus on maintaining the ship in an operational condition without enhancing the scientific capabilities of the platform. The existing Intermediate Class vessels do not meet most of the Ocean Class SMRs nor do they meet several of the Regional Class SMRs. The Regional Class ships currently in operation fall short of the Regional Class SMRs in many areas. See Appendix II for SMR comparison tables. Additionally, conducting SLEPs without significant upgrade or replacement of systems may translate into future degradation of capability. Ship machinery and major shipboard science equipment of aging vessels can become obsolete. Replacement components or entire units may no longer be manufactured or available in stock.

The SLEP estimates do not include any additional accrual of future funds to deal with what will almost certainly be an increased incidence of maintenance and breakdown problems associated with aging vessels. The SLEPs do not account for unseen failures with propulsion systems, ship equipment and machinery, and science instrumentation, some of which may be catastrophic and result in lengthy disruptions in operations.

Maintaining vessels of the current UNOLS fleet beyond their designed service life will significantly impede the advance of ocean science relative to that possible with new ships that meet the SMR specifications. UNOLS considers the SLEP approach as an option that should only be considered if ship demand cannot be met, fleet renewal timelines slip, and/or funds for new construction are unavailable.

2. Use of Commercial Vessels

Over the years, as the UNOLS fleet has become more and more capable to support the increasingly sophisticated nature of oceanographic research, the gap between what UNOLS ships and commercial vessels can provide has widened [59]. There are few commercial vessels available that are configured and have the full suite of scientific outfitting needed to support diverse academic oceanographic research operations. The cost of providing additional outfitting required to support science missions aboard commercial vessels would likely be prohibitive.

Contracting of commercial ships has proven to be effective for some of the special-purpose missions (ocean drilling program) or long-term deployments to remote regions (Antarctic Ocean research). However, in both instances specific modifications to the vessel under contract were required to make the vessels suitable for their respective science missions. Future science initiatives that are sufficiently unique in terms of mission or operating area should be considered as candidates for the use of commercial platforms. An example of this is the Ocean Observing Initiative which has included commercial vessel support for cable laying in their installation plans.

One of the strengths of UNOLS is the ability of its vessel operators to provide dedicated, well-trained crews and skilled technical support groups to carry out the diverse science missions scheduled aboard its ships. The UNOLS vessel operators have a genuine interest in the science carried out aboard their ships and demonstrate institutional pride in their support of research field programs. It would be difficult for commercial operators to duplicate the level of expertise and dedication that is offered by the UNOLS vessel operators.

3. Plan Now for Future Ship Capacity Requirements

The projections included in this section identify potential ship time capacity shortfalls within the next decade. Past experience has repeatedly revealed that it takes in excess of ten years to plan, design, and construct new vessels. The fleet renewal efforts that are currently underway should be completed as soon as feasible so that the capabilities of the new vessels can be evaluated to determine how they will match future ship demands. Concurrently, planning and budgeting for new, additional ships that meet UNOLS SMRs and ship demand projections should begin now.

V. Findings and Recommendations

Future oceanographic research and education initiatives require a capable academic research fleet with sufficient capacity to address the critical environmental and societal problems of a blue planet. The vessels in this fleet need to be wisely designed to conduct wide-ranging, cutting-edge research efficiently and safely at sea. The fleet should consist of vessels that can operate in the local, coastal waters of the U.S., as well as vessels that can operate virtually anywhere in world's oceans, including ice-covered regions. The fleet's Global and Ocean Class ships must be able to carry large numbers of scientists, technicians, students, and equipment to sea in order to collect samples, conduct experiments and surveys, and observe ocean processes. The design of the ships must provide flexibility in the use of exterior and interior spaces to accommodate the deployment of a vast assortment of oceanographic equipment and to accommodate specialized atmospheric samplers. The ships' labs must be able to be easily reconfigured to meet diverse, multidisciplinary science needs on a leg-by-leg basis. Technologically advanced and specialized equipment and operations increasingly require large amounts of clean power and high data bandwidths. There is also an increasing need for 24/7 high bandwidth two-way communications to the shore.

The timely ordered replacement of the academic research fleet is vital to oceanographic research and education in the United States. As the ships age, they become more expensive to operate and less capable in supporting the evolving US scientific mission. The Fleet Improvement Committee has over the past few years presented to the community compelling data showing that systematic replacement of major portions of the fleet must begin now. If not, we will be using old and increasingly unreliable ships that do not have the required capabilities to support the science mission. Scheduled operations are also more likely to be interrupted by mechanical breakdowns and unplanned maintenance due to aging equipment.

Renewal of the Academic fleet faces two major issues today. On the short-term time scale, there is a mismatch of fleet funding, demand, and capacity as shown in the figures of Chapter III. On the longer-term time scale, the fleet is aging and there is a need for the replacement of vessels in all size classes.

Planning and acquisition of new ships generally takes about ten years or more; thus, care must be exercised on making short-term decisions that could have effects over a longer time. In this chapter, we present the findings based on the analysis of the data presented in the earlier chapters and provide some recommendations based on these findings.

Findings

There is an increasing national need for access to the sea, as articulated in several recent studies by the National Academies, the Pew Oceans Commission, the U.S. Commission on Ocean Policy, the Administration's Ocean Action Plan, and others. The science and societal drivers for research and education at sea are at an all time high. Some of these scientific topics were presented in Chapter II.

To maintain our nation's competitiveness in the ocean sciences we must invest in the infrastructure that is necessary to support ocean-going research and education. Increased knowledge of the seas will better enable our nation to understand the ocean's role in climate and to preserve the oceans' natural resources and sustain the economic benefits they offer, including food production, energy and mineral resource development, shipping, recreation and tourism, and medicinal discoveries. The research products resulting from investment in ocean infrastructure are especially needed by policy-makers and stakeholders to help inform and guide decision-making relative to important issues of our time, such as global climate change.

The current fleet is aging and facing severe budget constraints and escalating costs. Federal budgets have either been flat or increasing below the inflation rate. The percentage of federal research funds allocated for ocean sciences has decreased from 7 percent of the total research funds allocation 25 years ago to just 3.5 percent by 2004 [5]. Fuel and manning costs have been rising faster than general inflation. Additionally, there are new costs associated with security requirements and Safety Of Life At Sea (SOLAS) regulations. As the ships age, there are higher maintenance costs and difficulties in maintaining worn, inefficient systems. The fleet also faces challenges with hiring and retention of crew and marine technicians due to increasing job instability in the research sector and competition from the higher paying commercial sector.

By the year 2025 there will be fewer ships in the UNOLS fleet and fewer ship days available if only the ships included in the Interagency Working Group on Facilities (IWG-F) Fleet Status Report [2] are added (Chapter IV, Table 5). The number of vessels in the UNOLS fleet is projected to decrease from 23 ships in 2008 to 14 ships in 2025, and the number of ship days available from 5085 to 3270. By 2017, all of the Intermediate size ships and all but three of the Regional/Coastal and Local Class ships will reach the end of their projected service life. There are no formal plans currently in place for replacement of the Coastal and Local Class ships, so access to local geographic regions and platforms for support of teaching cruises could be lost. By 2025, we will have a significantly reduced capacity to support global-ranging programs that require large, general-purpose Global class ships, with only three Global ships available. R/Vs *Revelle* and *Atlantis* are both designed to support general-purpose research operations. Additionally, *Atlantis* has the added capability to support submersible operations*.* R/V *Langseth* is optimized for seismic operations, but can support general-purpose research if needed. R/V *Atlantis* and *Langseth* will still be required for support of submersible and seismic operations respectively; however, there will be an increased need for support of general-purpose ship time demand left orphaned by the ships reaching the end of their projected service lives; R/Vs *Knorr*, *Melville,* and *Thompson.* The three Global ships operating in 2025 will all be close to the end of their projected service lives.

In 2007, about 4,000 ship days were funded and the fleet had an excess capacity of about 785 ship days. (Excess capacity is primarily driven by limitations in funding for science rather than ship user demand, and is not distributed evenly over the year.) As ships are reach the end of their projected service life and are removed from UNOLS service and fewer ships replace them, by 2016 the fleet's ship day capacity will fall below the 2007 day usage and by 2025 only 3,270 ship days will be available. Thus, we will be increasingly unable to meet science user demands during peak periods in spring and summer. We will lose the required flexibility in fleet scheduling that allows for multi-ship operations and for science expeditions in remote areas.

There is a recognized trade-off between the cost effectiveness of a fully utilized fleet and the fleet flexibility that is required to meet science requirements. While a fleet with all ships fully scheduled may be more cost effective, a fully scheduled fleet will be unable to accommodate weather-related delays, easily respond to short-notice urgent requests for ship support (such as retrieval of broken moorings), or respond to important episodic events (e.g. earthquakes, volcanic eruptions, tsunamis, harmful algae blooms) without negatively impacting previously scheduled work. A fleet that is fully scheduled also lacks the needed flexibility to accommodate seasonal and occasional surge demands for ship time.

New and emerging technologies, such as autonomous underwater vehicles, gliders, and ocean observatories, will not obviate the need for ocean-going research vessels, but will in many cases change the nature of the research expedition. Whereas in the past the ship itself was the primary platform for data collection, these newer technologies will greatly increase the spatial and temporal footprint of information gathering far beyond what was previously achievable with a ship alone. The role of the ship will be to deploy and service these more mobile or enduring assets, and act as a nexus for the information aggregation. The ship will complement the simpler robots by executing the more complex tasks and experiments. Thus the ship of the future will require the utmost in maneuverability, high-bandwidth communications, and the ability to deploy heavy payloads over the side safely.

Innovative advancements in green technologies and practices are being developed that have potential applications in ship construction, operations, and recycling. While many green practices could very well be implemented to both the current and future fleet, some of the green technologies are more suited for implementation during vessel design and construction. Many of the vessels in the UNOLS fleet were likely built before green technologies were available and post-construction implementation might be difficult or not feasible. Consideration of green technologies during vessel design will allow optimal opportunities for incorporation of green features.

The US Commission on Ocean Policy's vision and strategy for the 21st century and beyond articulates strong support for ocean research, including ample access to modern, well-equipped research vessels [5]. This vision can not be realized by the fleet renewal scenario outlined in the IWG-F Status Report, but will require increased support for ocean infrastructure in addition to research and education programs.

Recommendations

First, we strongly recommend that the Federal agencies implement the fleet renewal activities that are currently underway (the Alaska Region Research Vessel [ARRV], the three Regional Class ships, and the two Ocean Class ships), under the timeline shown in the 2007 IWG-F Fleet Status Report ([2]). These ships represent the absolute minimum level of renewal that is necessary to maintain needed vessel capability. This level of renewal omits two Ocean Class ships from that were previously recommended in the 2001 *Long-Range Plan for Renewal* [7].

Planning and acquisition of new ships generally takes at least ten years. Therefore it is crucial to begin the process now for other ships that will be needed in 2017 and beyond. Two of the existing general-purpose Global Class vessels (R/V *Knorr* and R/V *Melville*) are will reach the end of their service lives by 2017, so replacement planning needs to start now. A minimum of one and preferably two new general-purpose Global Class vessel(s) should be planned for, funded, and constructed by 2018. Because the new, smaller Ocean Class vessels have both design and scheduling limitations that restrict their suitability for many of the large, global-ranging expeditionary science missions envisioned in the future, the replacement Global Class vessels need to meet or exceed the specification standards of the current Global Class ships.

The ARRV, Regional, and Ocean Class ships will not enter service until several years from now. There have been delays in the timelines for delivering the new ARRV and Regional Class ships into the fleet. Some of the current ships nearing the end of the projected service life should have their service life extended so that they can be maintained at an adequate operational level to meet near term science requirements until the new ships come on line. However, UNOLS considers the service life extension approach as an option that should only be considered if there is a demonstrated need for ship days and funds for new construction are unavailable or delayed. The optimal course is to initiate the planning, budgeting, and construction of new vessels that meet the science mission requirements now rather than later.

OOI will place new and increased demands on Global, Ocean, and Intermediate vessels of the UNOLS fleet. As the observatory systems are installed, the projected service life end dates and geographic locations of these ships should be carefully considered to ensure that OOI ship demands can be met.

If budget projections remain at the current low level, the least capable ships near the end of their service lives should be considered for removal from UNOLS service. Any decisions on permanent removal from the UNOLS fleet versus lay-ups should be made based on multi-year projections of ship time demand rather than single year figures of fleet utilization.

To realize the vision of the U.S. Commission on Ocean Policy for strong support for ocean research, including ample access to modern research vessels, the UNOLS fleet must increase beyond the current projected levels detailed in the IWG-F Status Report. This will not only require increased funding for support of ocean science research and education but also increased funding for facility construction, maintenance, and operation from both public and private sectors.

Partnerships with the non-federal entities for support of facility construction should be explored. Facility access and scheduling considerations as new partnerships are formed must be carefully evaluated.

The Federal fleet renewal plan only considers vessels greater than 40 meters (131 ft). The smaller ships of the UNOLS fleet serve a crucial role in supporting science in our nation's coastal zone where the human impacts of development and resource use are greatest. The *Ocean Research Priorities Plan* recognizes that coastal ecosystems are subject to a variety of extreme events, natural processes, and human influences. The Plan identifies "Forecasting the Response of Coastal Ecosystems to Persistent Forcing and Extreme Events" as a near term priority [61]. Smaller UNOLS vessels are normally constructed with state or institutional funding. To continue to meet current requirements for the entire academic oceanographic community, UNOLS should encourage the timely replacement of Local vessels and Coastal/Regional vessels by institutions, state governments, and regional partnerships.

New state-of-the-art ships with technically sophisticated equipment will require more highly-trained and specialized personnel to provide technical support. Personnel strategies must be developed to improve the staffing and retention of experienced technical support personnel and crew.

We recommend that UNOLS, the federal agencies, and individual operators consider how to make the present and future fleet more environmentally sustainable. New and existing technologies and practices should be used in the construction, operation, and recycling of research vessels and UNOLS should take a leadership role in promoting a green U.S. research fleet, as we move forward in developing the academic fleet.

Federal agencies that operate their own research vessels are encouraged to examine their respective fleet capacities and capabilities to ensure that the Federal fleet as a whole is optimally utilized. Ship capacity that could be used to support academic research ship demand should be identified. Issues of access, facility scheduling, and financial support of an integrated Federal fleet of vessels should be addressed as a coordinated effort between UNOLS and the Interagency Working Group on Facilities.

This Fleet Improvement Plan does not advocate a direct replacement of the vessels that currently make up the UNOLS fleet. Instead, it recommends a fleet size and composition that can efficiently and effectively carry out the science that is envisioned into the next decades. If some of the required capabilities can be provided by Federally-owned vessels that are not in the UNOLS fleet, they should be evaluated.

Although this Fleet Improvement Plan has focused on ships, a capable National Deep Submergence Facility (NDSF) that includes a suite of deep submergence vehicles is also required for continued support of science on the seafloors and on the mid ocean ridge systems. OOI will place increased demand on ROVs for operations and maintenance at their observatory sites. We recommend that planning and acquisition of submergence assets to meet new and continuing science demands continue.

In conclusion, the U.S. research fleet is an extremely vital component of the national maritime enterprise. The U.S. ocean science research and education programs have benefited by broad access to the best possible mix of modern, capable, efficiently run, and well-operated research vessels, aircraft, submersibles, and other major shared-use facilities. Timely implementation of the recommendations presented in this Fleet Improvement Plan will ensure that the oceanographic community will continue to have access to a capable fleet of vessels to support the open ocean and coastal science initiatives that are important to the nation over the next 20 years.

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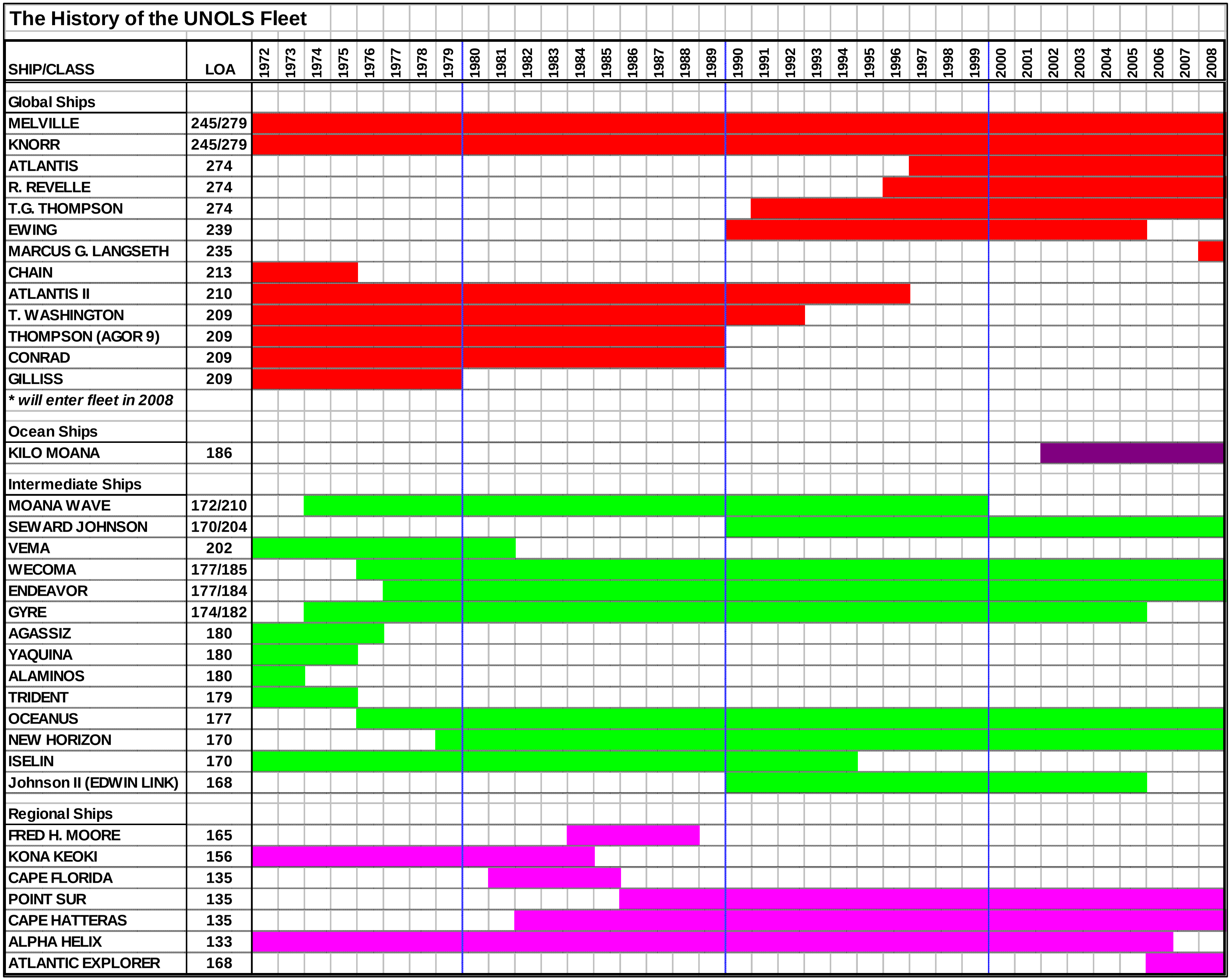
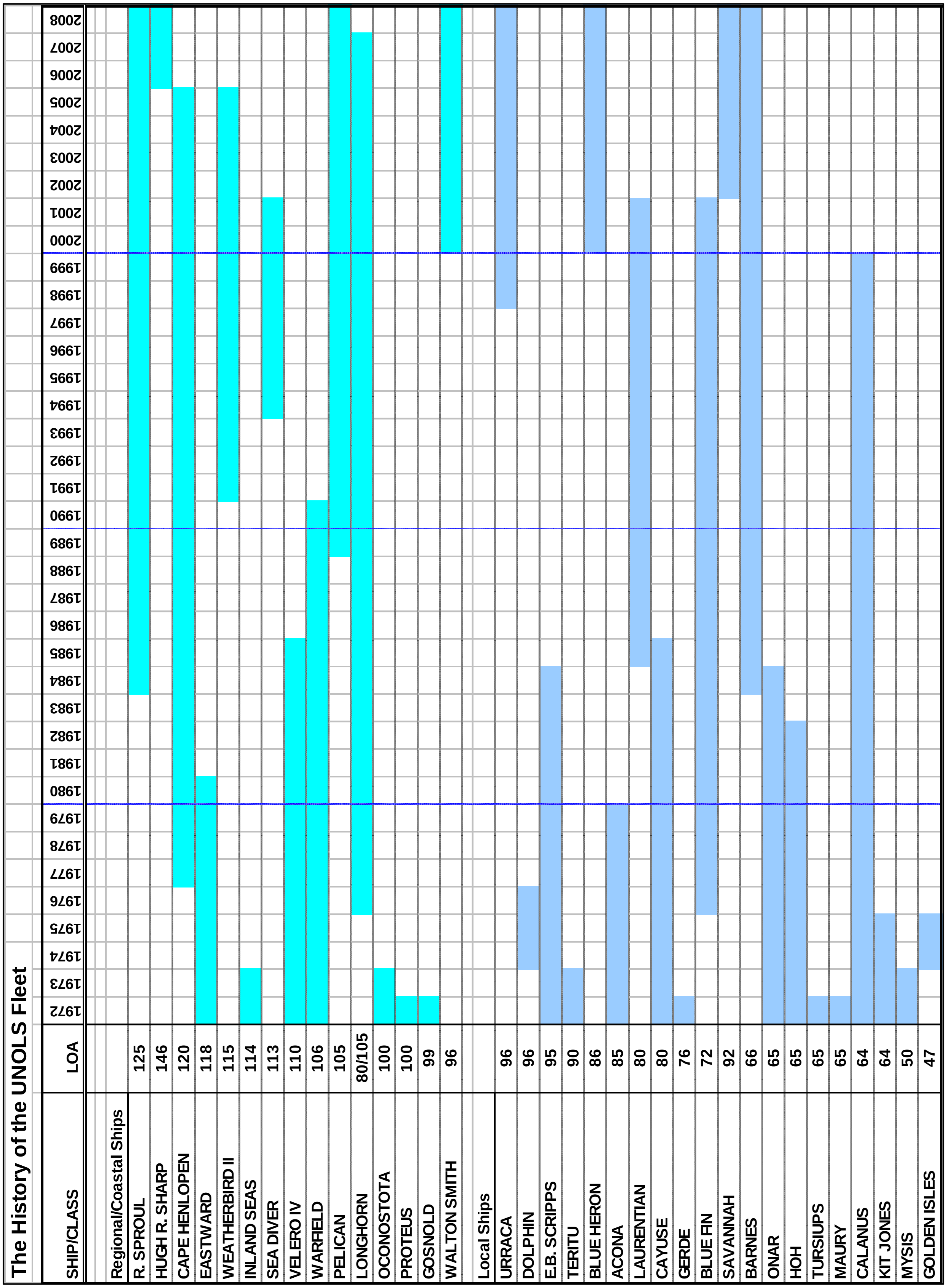
APPENDIX I



The History of the UNOLS Fleet
SHIP/CLASS
LOA
1972 1973 1974 1975 1976 1977 1978 1979 1980 1981 1982 1983 1984 1985 1986 1987 1988 1989 1990 1991 1992 1993 1994 1995 1996 1997 1998 1999 2000 2001 2002 2003 2004 2005 2006 2007 2008
Global Ships
MELVILLE 245/279
KNORR 245/279
ATLANTIS 274
R. REVELLE 274
T.G. THOMPSON 274
EWING 239
MARCUS G. LANGSETH 235
CHAIN 213
ATLANTIS II 210
T. WASHINGTON 209
THOMPSON (AGOR 9) 209
CONRAD 209
GILLISS 209
* will enter fleet in 2008
Ocean Ships
KILO MOANA 186
Intermediate Ships
MOANA WAVE 172/210
SEWARD JOHNSON 170/204
VEMA 202
WECOMA 177/185
ENDEAVOR 177/184
GYRE 174/182
AGASSIZ 180
YAQUINA 180
ALAMINOS 180
TRIDENT 179
OCEANUS 177
NEW HORIZON 170
ISELIN 170
Johnson II (EDWIN LINK) 168
Regional Ships
FRED H. MOORE 165
KONA KEOKI 156
CAPE FLORIDA 135
POINT SUR 135
CAPE HATTERAS 135
ALPHA HELIX 133
ATLANTIC EXPLORER 168

APPENDIX I


The History of the UNOLS Fleet
SHIP/CLASS
LOA
1972 1973 1974 1975 1976 1977 1978 1979 1980 1981 1982 1983 1984 1985 1986 1987 1988 1989 1990 1991 1992 1993 1994 1995 1996 1997 1998 1999 2000 2001 2002 2003 2004 2005 2006 2007 2008
Regional/Coastal Ships
R. SPROUL 125
HUGH R. SHARP 146
CAPE HENLOPEN 120
EASTWARD 118
WEATHERBIRD II 115
INLAND SEAS 114
SEA DIVER 113
VELERO IV 110
WARFIELD 106
PELICAN 105
LONGHORN 80/105
OCONOSTOTA 100
PROTEUS 100
GOSNOLD 99
WALTON SMITH 96
Local Ships
URRACA 96
DOLPHIN 96
E.B. SCRIPPS 95
TERITU 90
BLUE HERON 86
ACONA 85
LAURENTIAN 80
CAYUSE 80
GERDE 76
BLUE FIN 72
SAVANNAH 92
BARNES 66
ONAR 65
HOH 65
TURSIUPS 65
MAURY 65
CALANUS 64
KIT JONES 64
MYSIS 50
GOLDEN ISLES 47

APPENDIX II

Comparison of UNOLS Vessel Capabilities with the Ocean and Regional Class Science Mission Requirements

UNOLS Vessel operators were asked to compare the capabilities of the ships that they operate with the UNOLS Ocean Class and Regional Class Science Mission Requirements (SMRs). These Science Mission Requirements (SMR) were developed as part of the Academic Fleet Renewal effort outlined in the Federal Oceanographic Facilities Committee (FOFC) report: *Charting the Future for the National Academic Research Fleet – A Long-Range Plan for Renewal* published in December 2001. The process used to construct new ships is many faceted, but a fundamental action is the formulation of the Science Mission Requirement: the SMR. The SMR states with as much specificity as possible what attributes the ship must have to perform the science envisioned for the future. The SMRs for each Class of UNOLS vessel are available on the UNOLS web site at <http://www.unols.org/committees/fic/smr/index.html>.

The tables contained in this Appendix provide a comparison between the existing UNOLS vessels and the SMRs. An "X" indicates that the ship meets or exceeds the SMR value. If an "X" appears in the Ocean Class SMR column, the Regional Class SMR is also met or exceeded.

- Table I: Global Ships – SMR Comparison Table
- Table II: Ocean / Intermediate Ships – SMR Comparison Table
- Table III: Regional & Local Ships – SMR Comparison Table

TABLE I: Comparison of Global Class Ship Capabilities with Regional Class and Ocean Class SMRs

SMR parameter	Non-crew personnel		Endurance		Range		Speed		Sea keeping		Station Keeping		Track-line following		Crane		Towing		Working Deck: Stern aft of all deck houses		Working Deck: Along one side		Working Deck: Total stern clear area	
	RC	OC	RC	OC	RC	OC	RC	OC	RC	OC	RC	OC	RC	OC	RC	OC	RC	OC	RC	OC	RC	OC	RC	OC
	16-20	20-25	21 days, surge to 30 (15 transit and 15 station)	40 days (20 transit and 20 station)	8,000 nm	10,800 nm	12 kts, 10 kts in SS4, 7 kts in SS5	12 kts through SS4	Work in SS 4, >50% in SS 5	Maximize ability to work in SS 5 and higher	Best available Dynamic positioning	Dynamic position in 35 kt wind, SS 5 and 2 kts current	Stay within 5 m of line with 25 kts wind, up to SS4, and 2 kts current	Heading deviation of less than 45 degrees with 30 kts wind, up to SS5, and 2kts current	Load/unload up to 8000 lb to a pier; 16000 lb is desirable	Load/unload up to 20000 lb to a pier	10000 lb at 6 kts, 20000 lb at 4 kts for several days	10000 lb at 6 kts, 25000 lb at 4 kt for several days	1000 sq ft; 1500 sq ft desirable	1500 sq ft	50' x 10' area	80' clear deck area	1300 sq ft	2000 sq ft
GLOBAL SHIPS																								
Melville		X		X		X		X		X		X		X	X			X		X		X		X
Knorr		34		60		12,000		12 kts, 14.5 kts max		X		yes, has SDP-10 which meets this SMR		Contains superb high & low speed Track Mode using SDP-10 DP system		6' / 60,000, 70'/ 8,000 ft/lbs		20,000 lbs portable A-frame		2,024		124		3,818
Atlantis		37		60		17280		12 kts, 15 kts max		X	X(1)		X(2)			10'/ 42000, 65'/ 3400 ft/lbs		X		3,045		124		3805

TABLE I: (continued **-** Comparison of Global Class Ship Capabilities with Regional Class and Ocean Class SMRs)

SMR parameter	Laboratories														Vans		Science Storage		Science load		Workboats		Real-time data acquisition system	
	Main dry lab		Wet/hydro lab		Electronics/ computer lab		Res Tech work space		High Bay		Climate controlled space		Total lab space											
	RC	OC	RC	OC	RC	OC	RC	OC	RC	OC	RC	OC	RC	OC	RC	OC	RC	OC	RC	OC	RC	OC	RC	OC
	800 sq ft	1000 sq ft	400 sq ft	400 sq ft	Separate or part of main lab	300 sq ft	Separate electronics repair shop/work space for resident technicians	Separate electronics repair shop/work space for resident technicians	High bay/ hanger space adjacent to aft main deck	High bay/ hanger space adjacent to aft main deck	100 sq ft	100 sq ft	1000 sq ft (1500 sq ft desired)	2000 sq ft	2 20'x8' deck vans, space for 1-2 smaller vans	2 20'x8' deck vans, space for 1-2 smaller vans (500 sq ft)	400-500 cubic ft	5000 cubic ft	At least 50 LT	200 LT	16' or larger	At least one 16' or larger	Multibeam, ADCP, IMET, transducer wells	Multibeam, ADCP, IMET, transducer wells
GLOBAL SHIPS																								
Melville		X	<400			X		X		X		X		X		X		X		325 LT[3]		X		X
Knorr		2,011	320			X		X		250 sq ft		240		2756		X		5,520	175 LT			X		X
Atlantis		1512		880		750		X		X		375		3,517		X		6,000	150 LT			X		X

Notes: (1) *Atlantis* needs a new DP System and there are issues with the Bow Thruster.

(2) *Atlantis* needs a new DP System with a good high speed and low speed track follow system.

(3) *Melville* science payload verified by The Glosten Assoc. and stability documents.

APPENDIX II

TABLE II: Comparison of Intermediate / Ocean Class Ship Capabilities with Regional Class and Ocean Class SMRs

SMR parameter	Non-crew personnel		Endurance		Range		Speed		Sea keeping		Station Keeping		Track-line following		Crane		Towing		Working Deck					
																			Stern aft of all deck houses		Along one side		Total stern clear area	
	RC	OC	RC	OC	RC	OC	RC	OC	RC	OC	RC	OC	RC	OC	RC	OC	RC	OC	RC	OC	RC	OC	RC	OC
	16-20	20-25	21 days, surge to 30 (15 transit and 15 station)	40 days (20 transit and 20 station)	8,000 nm	10,800 nm	12 kts, 10 kts in SS4, 7 kts in SS5	12 kts through SS4	Work in SS 4, >50% in SS 5	Maximize ability to work in SS 5	Best available Dynamic positioning	Dynamic position in 35 kt wind, SS 5 and 2 kts current	Stay within 5 m of line with 25 kts wind, up to SS4, and 2 kts current	Heading deviation of less than 45 degrees with 30 kts wind, up to SS5, and 2kts current	Load/unload up to 8000 lb to a pier; 16000 lb is desirable	Load/unload up to 20000 lb to a pier	100000 lb at 6 kts, 200000 lb at 4 kts	10000 lb at 6 kts, 25000 lb at 4 kt for several days	1000 sq ft; 1500 sq ft desirable	1500 sq ft	50' x 10' area	80' clear deck area	1300 sq ft	2000 sq ft
Intermediate / Ocean Ships																								
Endeavor	18		32		8000		X	X	X	X	no	no	X	X	X	X	X	X	~1,200		~50		~1500	
Oceanus	19		30		7000		12 kts, 14.4 kts Max		X	X	no	no	not w/DP style track line following			sea: full extension - 6890 lbs; retracted 40000 lbs. Pier: Exceeds 40000 lbs		35000 lbs SWL A-Frame	1,122			84'	1,600	
Wecoma	18		30+		~7200		X		X	X		no	Depends on directions		14,000			?	~1,200		~50		~1500	
Seward Johnson		28	35		6000			X		X		X		X		X		X		1,762	60'		1,160	
New Horizon	X			X	X				X				X						X		X	X	X	
Kilo Moana		X		X		X				X		X		X		X		X		X		X		X

APPENDIX II

TABLE II: (Continued - Comparison of Intermediate / Ocean Class Ship Capabilities with Regional Class and Ocean Class SMRs)

SMR parameter	Laboratories														Vans		Science Storage		Science load		Work-boats		Real-time data acq. system	
	Main dry lab		Wet/ hydro lab		Electronic/ computer lab		Res Tech work space		High Bay		Climate control space		Total lab space											
	RC	OC	RC	OC	RC	OC	RC	OC	RC	OC	RC	OC	RC	OC	RC	OC	RC	OC	RC	OC	RC	OC	RC	OC
	800 sq ft	1000 sq ft	400 sq ft	400 sq ft	Separate or part of main lab	300 sq ft	Separate electronics repair shop/work space for resident technicians	Separate electronics repair shop/work space for resident technicians	High bay/ hanger space adjacent to aft main deck	High bay/ hanger space adjacent to aft main deck	100 sq ft	100 sq ft	1000 sq ft (1500 sq ft desired)	2000 sq ft	2 20'x8' deck vans, space for 1-2 smaller vans	2 20'x8' deck vans, space for 1-2 smaller vans (500 sq ft)	400-500 cubic ft	5000 cubic ft	At least 50 LT	200 LT	16' or larger	At least one 16' or larger	Multibeam, ADCP, IMET, transducer wells	Multibeam, ADCP, IMET, transducer wells
Intermediate / Ocean Ships																								
Endeavor	700		390		208		X	375	no	no	no	no	1657		very small	very small	1600		50 LT		X	X	X less multi-beam	
Oceanus	595		240		X		X						1185			3			40 LT		X		X less multi-beam	
Wecoma	576		390		208		no	no	no	no			1174			3			60 LT		X	X		
Seward Johnson	468		288		288			224		NA	85					X4	1100			X		21'	X less multi-beam	
New Horizon													X			X			X					
Kilo Moana		X		X		X		X		X		X		X		X		X				X		X

TABLE III - Comparison of Regional and Local Class Ship Capabilities with Regional Class and Ocean Class SMRs

SMR parameter	Non-crew personnel		Endurance		Range		Speed		Sea keeping		Station Keeping		Track-line following		Crane		Towing		Working Deck					
																			Stern aft of all deck houses		Along one side		Total stern clear area	
	RC	OC	RC	OC	RC	OC	RC	OC	RC	OC	RC	OC	RC	OC	RC	OC	RC	OC	RC	OC	RC	OC	RC	OC
	16-20	20-25	21 days, surge to 30 (15 transit and 15 station)	40 days (20 transit and 20 station)	8,000 nm	10,800 nm	12 kts, 10 kts in SS4, 7 kts in SS5	12 kts through SS4	Work in SS 4, >50% in SS 5	Maximize ability to work in SS 5 and higher	Best available Dynamic positioning	Dynamic position in 35 kt wind, SS	Stay within 5 m of line with 25 kts	Heading deviation of less than 45 degrees with 30 kts wind, up to SS5,	Load/unload up to 8000 lb to a pier; 16000 lb is desirable	Load/unload up to 20000 lb to a pier	10000 lb at 6 kts, 20000 lb at 4 kts	10000 lb at 6 kts, 25000 lb at 4 kt for several days	1000 sq ft; 1500 sq ft desirable	1500 sq ft	50' x 10' area	80' clear deck area	1300 sq ft	2000 sq ft
Regional & Local Ships																								
Cape Hatteras			X						X						X		X							
Point Sur	12		need resup.if >21		6500				X				X		6,500		X		X					
Vessels <40m																								
Hugh R. Sharp	X		21 day max, no surge		3500		12kts, 6 kts SS4		X		X		X		X		X		~1700 w/o vans		w/o stbd van			
Pelican	X		X						X						X				X		X			
Sproul													X						X		X		X	
Walton Smith											X		X											

TABLE III - Comparison of Regional and Local Class Ship Capabilities with Regional Class and Ocean Class SMRs

SMR parameter	Laboratories														Vans		Science Storage		Science load		Work-boats		Real-time data acq. system	
	Main dry lab		Wet/ hydro lab		Electronic/ computer lab		Res Tech work space		High Bay		Climate control space		Total lab space											
	RC	OC	RC	OC	RC	OC	RC	OC	RC	OC	RC	OC	RC	OC	RC	OC	RC	OC	RC	OC	RC	OC	RC	OC
	800 sq ft	1000 sq ft	400 sq ft	400 sq ft	Separate or part of main lab	300 sq ft	Separate electronics repair shop/work space for resident technicians	Separate electronics repair shop/work space for resident technicians	High bay/ hanger space adjacent to aft main deck	High bay/ hanger space adjacent to aft main deck	100 sq ft	100 sq ft	1000 sq ft (1500 sq ft desired)	2000 sq ft	2 20'x8' deck vans, space for 1-2 smaller vans	2 20'x8' deck vans, space for 1-2 smaller vans (500 sq ft)	400-500 cubic ft	5000 cubic ft	At least 50 LT	200 LT	16' or larger	At least one 16' or larger	Multibeam, ADCP, IMET, transducer wells	Multibeam, ADCP, IMET, transducer wells
Regional & Local Ships																								
Cape Hatteras					X																X		no IMET, no multi - beam	
Point Sur	480		100		X								~660		1 20'x8', 1 10'x8'		~360 under bench		X		X		X	
Vessels <40 m																								
Hugh R. Sharp	~380		~250		X		work- shop for general use		no		buy van as need				x		no		30 LT		17'		X	
Pelican			X		X		X										X				X		X	
Sproul					X								X		X				X					
Walton Smith							X																	

OCEAN ACOUSTICS

Introduction

Acoustics in general, is the interdisciplinary study (or science) of the behavior of all forms of media under the influence of mechanical energy (or physical displacement). Ocean acoustics in particular, is the study of fluid media, which includes the fresh waters of the world; and the boundaries: the air-sea interface and the sea-floor. Ocean Acoustics research has a number of "branches", ranging from propagation in inhomogeneous media to the study of the characteristics of vector acoustic sensors. The single factor that is common to every branch of this science is its interdisciplinary nature. Whether it is teaming with a solid state physicist to discover a new transduction material/method for remotely deployed, efficient acoustic projectors, or with a physical oceanographer to interpret propagation characteristics in a dynamic internal wave dominated water column, progress in this discipline is linked to collaboration with a wide spectrum of related sciences. Due to US Navy influence, emphasis has ranged from deep oceanic basins and consequent water column behavior in the 1950-1980s to shallow water (or boundary limited) studies in the 1990-2000s; with a re-emerging interest in deep waters today.

Sound velocity is a function of the temperature, pressure and salinity of sea water, so as an acoustic signal traverses the ocean, it changes direction, and velocity, dependent on the conditions it encounters. When discussing Ocean Acoustics, there is a temptation to use "good news-bad news" terminology. Why? Acoustic energy will travel much further in the ocean medium than other forms of energy. The consequence of this; is the energy field is influenced by a potentially enormous range of differing oceanic conditions, leaving the researcher with a conundrum: either instrument the pathways the energy traveled over very thoroughly (likely not possible because of expense) or rely on ocean models (likely not spatially and temporally well enough developed) to interpret the inevitably complex character of the acoustic signal collected. An additional important property of acoustic energy to consider is the frequency dependence of loss: as the frequency (f) increases, the energy loss increases, roughly with an f squared behavior, which results in ocean acoustics not being a remote sensing panacea.

Some examples of research follow, to provide both a "snapshot" of what has been, and is ongoing in the ocean acoustics "world" and also to illustrate the time and space scales investigated (because many potential readers of this science overview will be ship operators and cruise participants, some attention has been directed to acoustic equipment sizes, weights, and other operating requirements).

Global Ocean Acoustics

Figure 1 shows some of the acoustic propagation paths of the Heard Island Experiment, conducted in 1991 (Ref 1), which emphasizes the global potential. The individual acoustic projectors for this test were of the dimensions and weight of a Volkswagon "Beetle", requiring a dedicated ship acoustic source for operations. The receiving acoustic arrays were of various types, ranging from simple one hydrophone units to bottom mounted horizontal arrays.

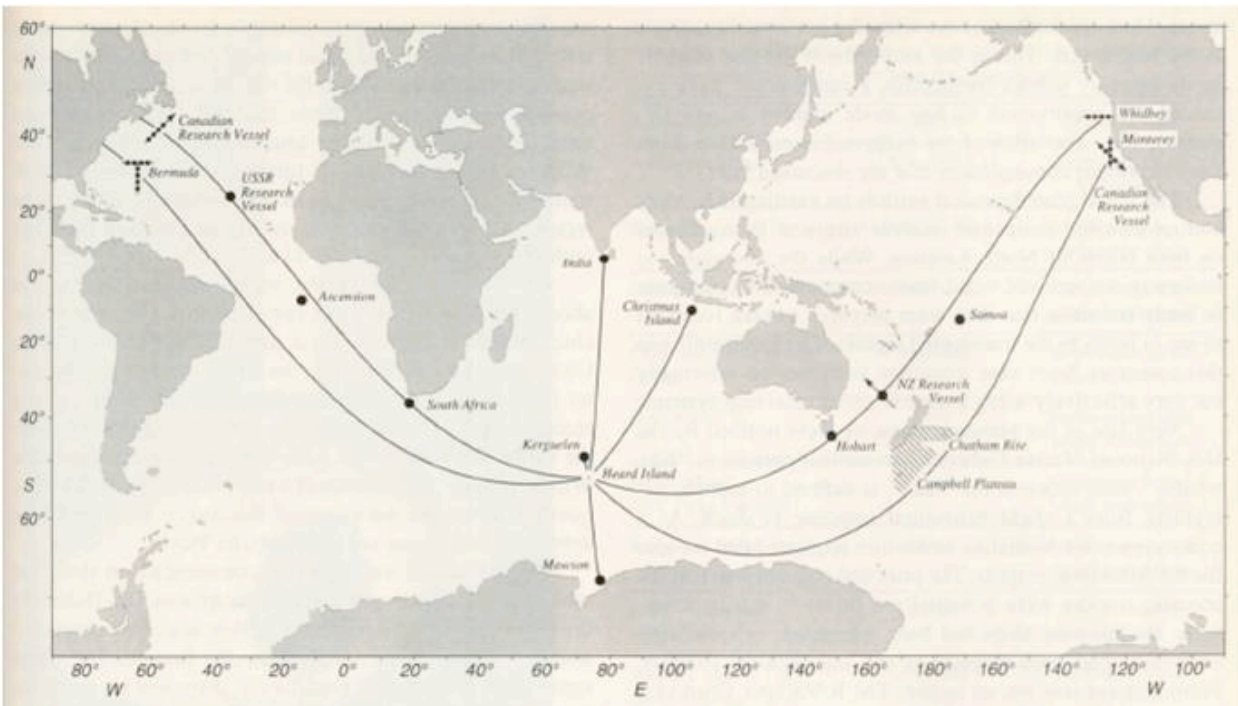


Figure 1. Ray paths from source to receiver sites are refracted geodesics, i.e., great circles corrected for Earth flattening and horizontal sound speed gradients. The source array was suspended from R/V CORY CHOUEST 50 km southeast of Heard Island. Single dots indicate sites with single receivers. Dots connected by horizontal lines designate horizontal bottom-mounted arrays, vertical lines designate vertical arrays, and slanted lines designate arrays towed in the direction of the arrow. Signals were received at all sites except for the vertical array at Bermuda (which sank) and the Japanese station off Samoa. (Ref 1)

Shelf Break Studies

Figure 2 is the instrumentation field for SHALLOW WATER 06, carried out off the New Jersey Coast (Ref 2), which is a recent attempt to thoroughly populate the acoustic pathways approaching the shelf break with ocean sensor suites. The space scales are certainly reduced, but the amount of equipment in the water is greater than for Heard Island. There was so much equipment, that participating ships made multiple trips back to ports to load additional deployed hardware, as there was not sufficient room aboard to store everything. Every mooring depicted comes with the "usual" burden: anchors; acoustic releases for recovery; cables; sensor units (including arrays); power packages; subsurface floats; in sum, several thousand pounds of gear, taking up significant space for each mooring unit.

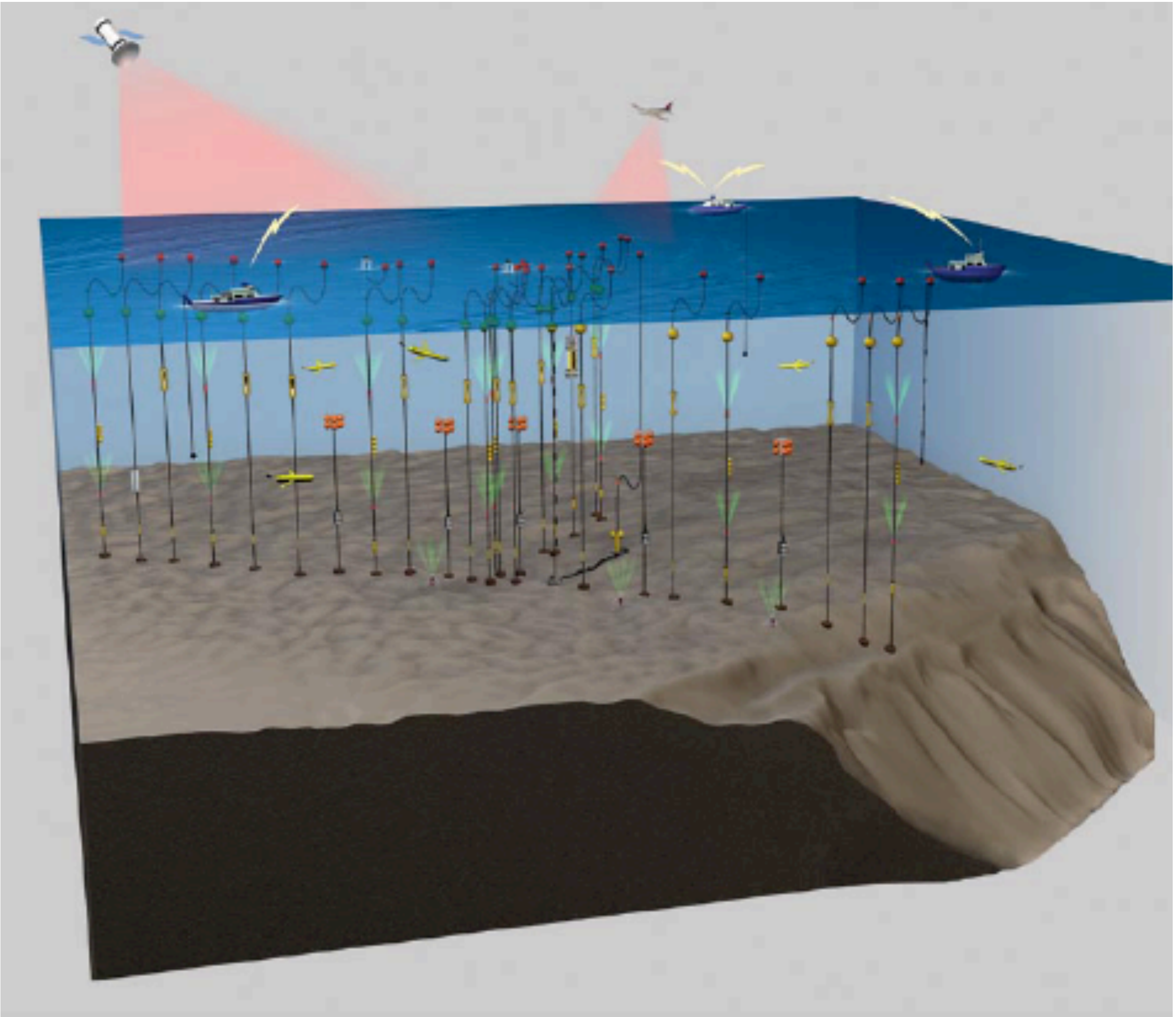


Figure 2. A graphic overview of the SW06 experiment. Moored instrumentation is deployed in lines in the along-shelf and across-shelf directions to observe shelf-break front and internal wave packets. A fully three-dimensional array at the intersection of the "T" is designed to study the wave-front length scales of nonlinear internal waves. A fleet of six gliders monitors mesoscale oceanography in the region. An "L" shaped array of hydrophones consists of a horizontal and a vertical line array, and monitors sound transmissions throughout the experiment, while moored and shipboard sources transmit signals. Ships carry out oceanographic, geologic, and acoustic research while networked to each other and to laboratories ashore to share information. Planes and satellites overhead image internal waves and other ocean processes. The bathymetry in the figure is an artist's rendition showing generally correct but not exact features. (Ref 2)

High Resolution Sonar

Figure 3 is a synthetic aperture sonar (SAS) view of a shipwreck, resolution scale ~ 1 inch up to 2-300 meter range (Ref 3). This is the other end of things: an SAS unit is of the order 100+ pounds, and dimensionally 1-2 feet in size. However, operation will require an ROV or an AUV, with their consequent weight and space needs, which include both deployment and recovery equipments. The extreme resolution requires both very accurate navigation and especially very stable deployment platforms.

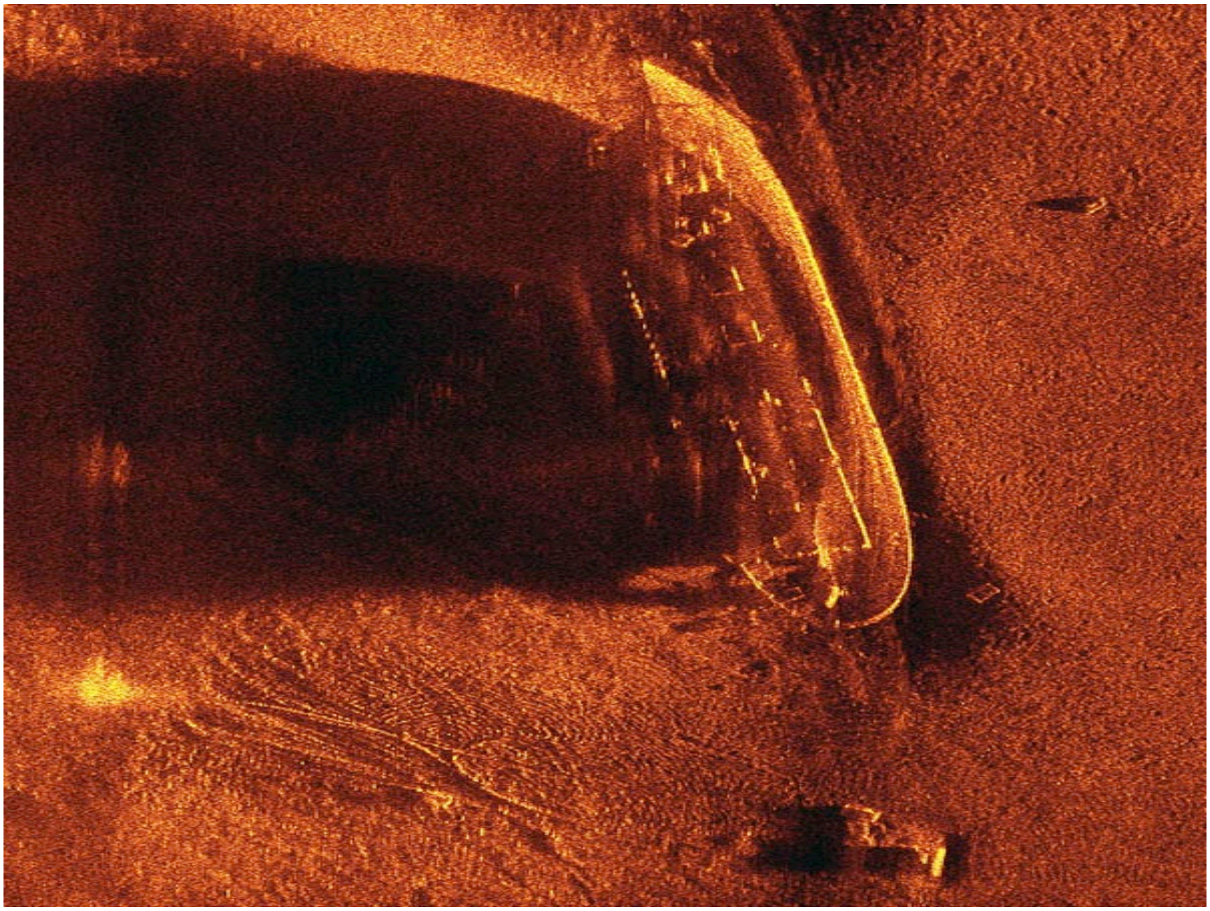


Figure 3. The SAS-12 produced this image of the Prudence Island shipwreck during AUV fest 2008. The SAS-12 synthetic aperture sonar produces images at very high resolution. Note the lines the buoy chain has left in the sand. (Ref 3)

Marine Bioacoustics

Another "recent" (the work has actually been ongoing for a number of decades, but its interest and tempo of work has accelerated in recent years) very active aspect of Ocean Acoustics is Marine Bioacoustics research. There are two major efforts ongoing; collecting vocalizations of both mammals and sea life passively and the use of active acoustics to measure sea life quantity and distribution, and when possible provide species identification. Properly so, much attention is directed to understanding and mitigating the impact of human intrusion into the world of marine life.

Research Trends, Findings and Initiatives in Ocean Acoustics

Within the ocean acoustic research community, there has been a tendency to divide the efforts into the "forward" and the "inverse" problem. The former is physics driven and the latter is focused on parameter space search (inversion) methods to correctly identify the causal physical properties.

There is also more use of "natural" power----which simply is the exploitation of naturally occurring ambient noise as an "acoustic source of opportunity", which mitigates the impact of human presence, does result in reliance on very acoustically quiet ships, AUVs or other data collection systems.

Office of Naval Research (ONR) Ocean Acoustics is focused in both shallow (or coastal) and deep water. Three major shallow water acoustics field experiments are planned between now and ~2017: 2011-2013, reverberation (scattered energy) studies off the coast of Florida; 2014-2015, Seabed acoustic characterization, location TBD; and 2016-2017, Shelf break, slopes and canyon (3-D acoustic fields) studies, also in a location TBD. For deep water, an equipment and data recovery cruise in the Philippine Sea was completed, April, 2011 (see insert); a long range acoustic communications (ducted acoustic propagation) study in 2012-2013; and a high latitude tomographic experiment in 2015-2016. While under consideration at this juncture, plans are subject to change due to funding uncertainties in the out years.

The NPAL Philippine Sea Experiments

The Philippine Sea is the source region of an intense western boundary current, the Kuroshio. The background sound-speed field is modulated by significant eddy variability moving in from the east. The internal tide field is intense. The shipping density is high. The North Pacific Acoustic Laboratory (NPAL) Group performed a series of experiments during 2009–2011 to study deep-water acoustic propagation and ambient noise in this oceanographically complex and highly dynamic region.

Figure 5. One of the 150 Hydrophone Modules that made up the 5000-m long DVLA receiver for the 2010–2011 NPAL Philippine Sea Experiment being recovered on the *R/V Revelle*. (Photo: L. Green, SIO.)

The UNOLS vessels *R/V Melville* and *R/V Kilo Moana* participated in a one-month Pilot Study/Engineering Test during spring 2009. The *R/V Roger Revelle* subsequently conducted a series of cruises for the 2010–2011 NPAL Philippine Sea Experiment, which combined measurements of acoustic propagation and ambient noise with the use of acoustic remote sensing (ocean acoustic tomography) to help characterize the 4-D ocean sound-speed field. In these experiments, moored and ship-suspended low-frequency acoustic sources transmitted to a newly developed Distributed Vertical Line Array (DVLA) receiver capable of spanning the water column in deep water. The Five Octave Research Array (FORA), acoustic Seagliders, and ocean bottom seismometers were also used to record both the acoustic transmissions and ambient noise.

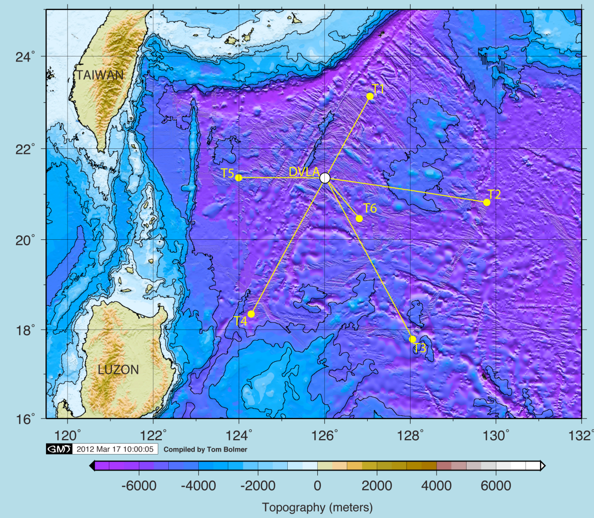
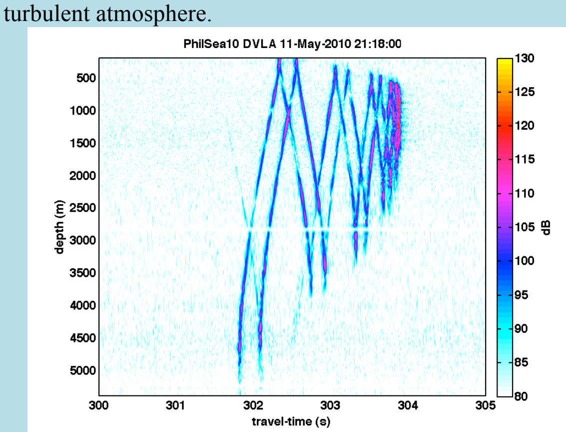


Figure 4. Overall mooring geometry of the 2010–2011 NPAL Philippine Sea Experiment, consisting of five 250-Hz acoustic transceivers arranged in a pentagon with a sixth transceiver in the center (T1, T2, … T6) and a 5000-m long Distributed Vertical Line Array (DVLA) receiver. The array radius is approximately 330 km. [Courtesy S. Thompson Bolmer, WHOI.]

Investigators from seven U.S. institutions were involved in the fieldwork for this ONR sponsored effort. Additional investigators from other U.S. institutions are involved in the analysis of the data, as well as related theoretical and numerical studies.

Figure 6. The acoustic time front recorded on the DVLA receiver for a transmission from transceiver T3 during the 2010–2011 NPAL Philippine Sea Experiment. The color indicates the intensity of the received signal. The range is 450.1 km. The complex accordion pattern seen at the receiver results from a single transmission at T3. Ocean internal waves and other small-scale oceanographic variability cause fluctuations in the intensity and travel time of the received time front, much as stars scintillate when observed through a turbulent atmosphere.



Complexity of Acoustic Inversion Techniques

The experimental program labeled Shallow Water 06 (SW06) clearly demonstrated the impact of oversimplifying the water column when attempting to recover seafloor physical properties with inversion methods: Figure 7 shows a cold water intrusion (illustrated by the deep blue color in the figure) into the lower section of the water column from offshore activity. The modification to the acoustic propagation behavior (expressed by the varying sound velocity profiles) was shown to have a significant impact on the inversion schemes employed (Ref 4).

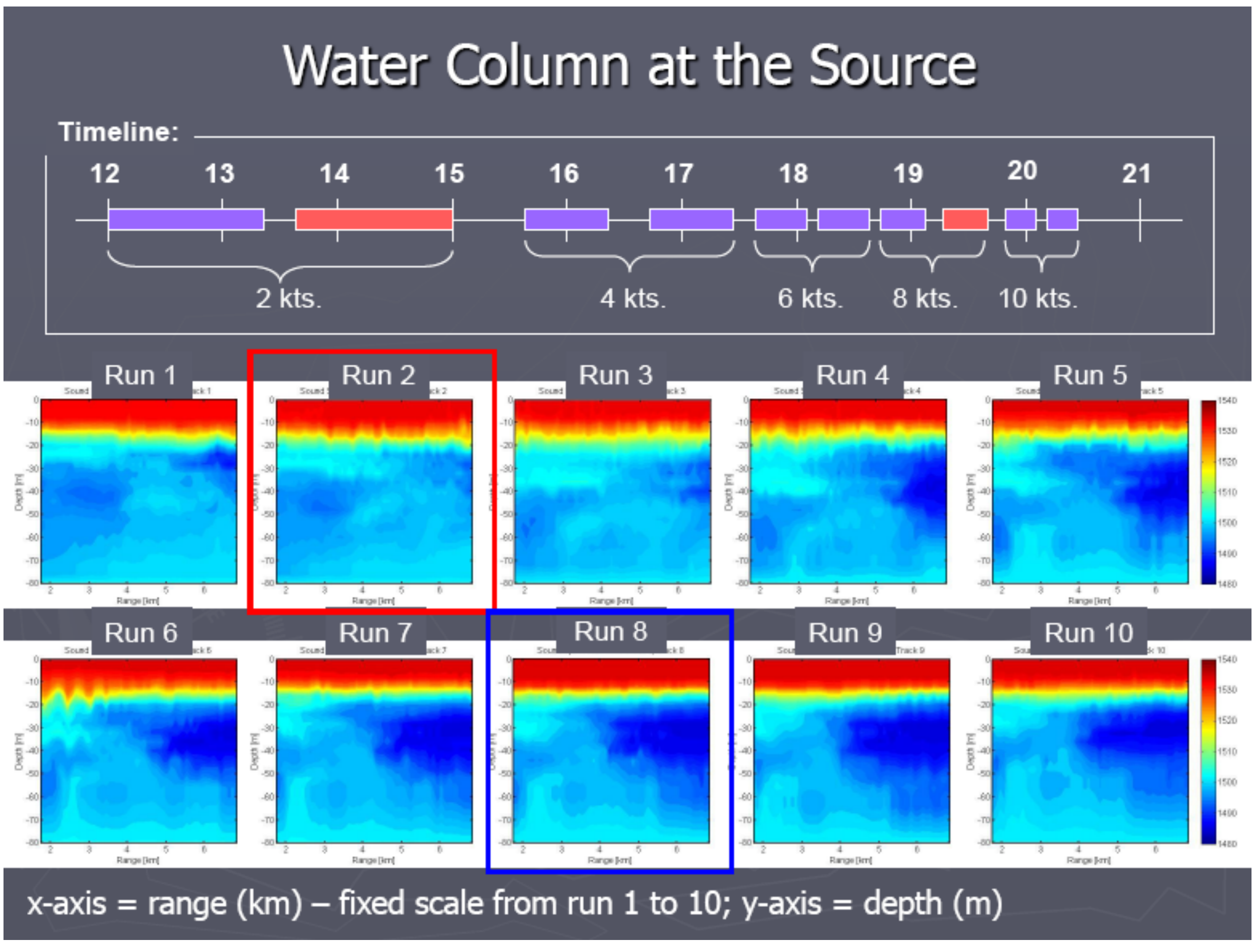


Figure 7. Sequential CDT tows, resulting in varying sound speed profiles as a function of range and depth, with a time line for the tows shown above the 10 runs illustrated.

Acoustic Propagation variability in a dynamic water column

Ongoing analysis of SW 06 discussed above continues to shed light on the behavior of acoustic energy (and the value for the understanding of detailed spatial and temporal water column characteristics). Figure 8 is a view of the sound speed over range and depth in a different shallow water location, but illustrates the potential of a towed CTD chain to provide the level of resolution necessary for both the forward and inverse methods. Figure 9(a) is an example of the sound intensity as a function of depth and time (Ref 6), which is an excellent example of the typical signal complexity that ocean acoustics researchers must work with. Figure 9(b) is an equally typical prediction, when limited ocean data is available for analysis.

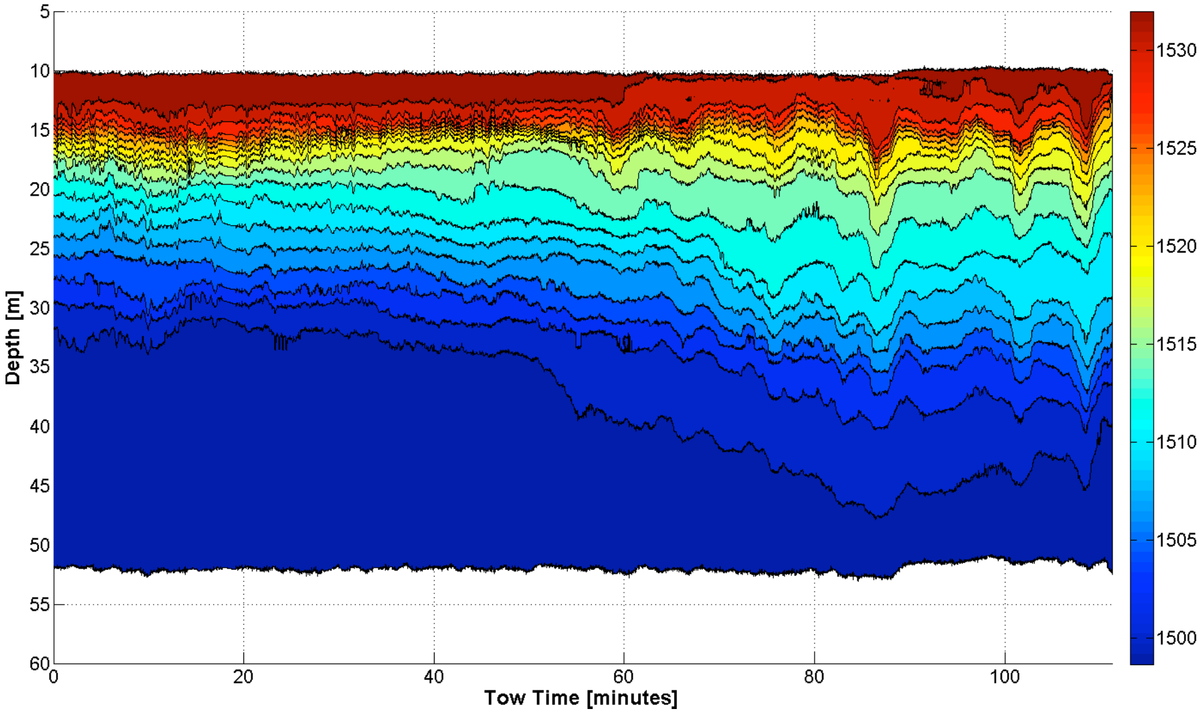


Figure 8. Sound speed field calculated from CTD tow measurements. Color scale for sound velocity in [m/s] (Ref 5).

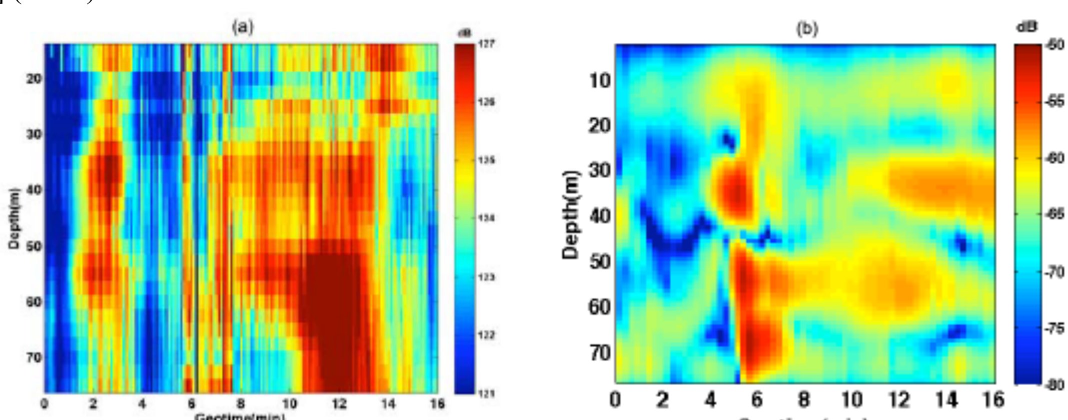


Figure 9. (a) Measured signal on WHOI Vertical Line Array (VLA) and (b) the Parabolic Equation (PE) modeling result for a transmission. The plots are acoustic Intensity in dB relative to a reference Intensity. (Ref 6)

Future Facility Needs, Advances in Methodology, and Technology that will Influence Ocean Acoustics

Equipment

In general, as both forward modeling and inversion methods get better and better, acoustic research will take advantage of and perhaps, influence development of Classic Ocean measuring devices that have extended time and space scales. A cogent example is recent extensive use of a towed CTD (Conductivity, Temperature and pressure (Depth)) chain in several experiments..

The science of ocean acoustic remote sensing is driven by time and resolution. More time on station drives the community toward moorings, AUVs and gliders to complement ships. Longer time monitoring can also be accomplished with cable-to-shore resources. Better (shorter) time resolution is reached with higher frequencies and shorter signal pulse lengths, implying more sensor systems to provide spatial coverage. Consequences of better resolution is more accurate navigation, tighter station keeping and precise tow paths.

Spatial resolution requires acoustic array receiving systems, which can be, depending on frequency, large. Typical linear towed arrays for frequencies in the low 100s of Hertz reach dimensions of kilometers. For two dimensional resolutions, "billboard" type arrays can and have approached the dimensions of ship keel/lengths. Soon to be common is the combination of an AUV and a towed acoustic array. (See figure 10)

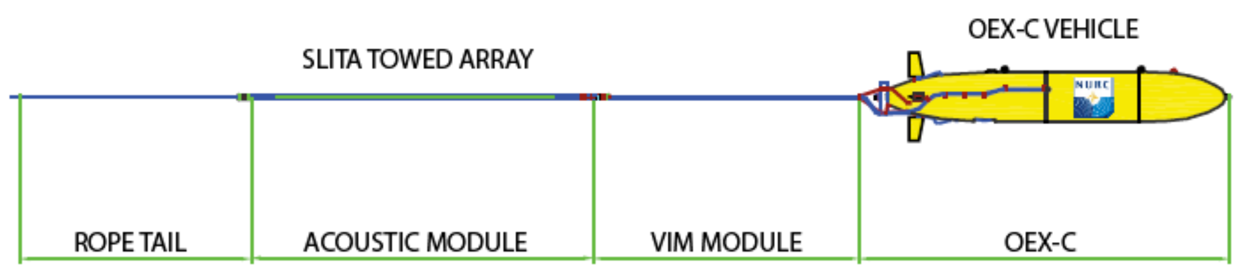


Figure 10. Schematic of the Slim Line Towed Array (SLITA) towed from the *Ocean Explorer* (OEX) AUV (Ref 8).

The deck footprints for operating or stowage of the equipments themselves or the necessary related hardware (an example would be an acoustic towed array and the level wind reel for stowage and operating; the weight is over 10 tons and the deck footprint is approximately 16 square meters) can be over whelming, as very little is amenable to below deck stowage, or movement to other locations on board, while at sea, due to size and weight. Due to the variety of research requirements and the consequent large number of acoustic-based devices developed in response, it is not possible to provide a "one size fits all" manual or operating plan for the ship crew prior to pre-sail discussions.

Hull mounted acoustic sensors (multi-beams, Acoustic Doppler Current Profilers(ADCPs), side-scans, etc) require isolation, clear "fields of view", and ship motion compensation. If sensors are deployed overboard (single hydrophones, vertical arrays, e.g.) ship radiated noise is usually an issue, as ordinary ship operations will result in unwanted and often overwhelming noise that will result in experiment failure.

The trend is toward more complex equipment, often larger in size, weight and handling complexity. At-sea operations are typically 24/7, due to ship costs, and also lead to larger scientific crew size, which in turn, results in bunk space issues.

Environmental Impact

The world-wide recognition and reaction to anthropogenic activity (especially research) impact on sea life is of major concern to Ocean Acoustics, due to its intrusive nature for active transmissions. The concern extends to ships and other platforms, and to other equipments deployed in the sea.

In particular, Marine Bioacoustics has some unique requirements: Development of devices that can be attached in an eco-friendly way to mammals, and later recovered, is in its infancy. The techniques of "target" approach and attachment require small boats, sensitivity to mammal response and extremely careful and slow maneuvering. While acoustic techniques are useful for active search of or passive listening to fish and other vocalizing marine life, they have not progressed to the stage of replacing nets, trawls, etc for quantitative analysis. Integration of traditional sampling methods with acoustic sensors is being addressed, particularly within NOAA.

Because of the concern regarding active acoustic signals' impact on sea life, and given that ship radiated noise must be added to that mix, Ocean Acoustic research has a significant effort underway toward mitigation. From a ship perspective, it will be radiated noise limitations imposed; for the researcher, the near term impact is lower projected levels transmitted, which in turn results in less volume covered, leading to more ship time required to accomplish the same task.

Ship Crew and Scientific Complement

Ocean Acoustic data collection can be, usually is, a dynamic process, requiring station keeping, ship maneuvering, continuous day-night operations and multi sensor package deployments that are stressful and complex for ship's crew and scientific complement. The data collection, real-time analysis and storage require complex computer systems, very large "byte" capacity and sizeable computer lab space.

Of critical importance to any ocean acoustic experiment are the shipboard techs that span disciplines: they must be able to operate acoustic systems and other ocean data gathering equipments, complex computer systems, understand and appreciate the importance of coincident data collection requirements----the term "tech" was used, but quite frankly it is a gross mis-statement when used to describe the capabilities of the individual(s) needed. One potential solution to this problem is to "move" the sea going technical expert from the ship complement to the scientific side, which shifts the cost center, but does have the advantage of an individual that is involved in the sea trial from planning and gearing up, through the time at sea and then back to the parent institution to work with the information collected. If those folks ever have any "down" time, they could be contracted out to other sea going expeditions. Current experience with acoustic systems has demonstrated the technical expert usually ends up "tied" to a specific system, which results in less flexibility for other sea going equipments.

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