SANDWELL

MEDEA

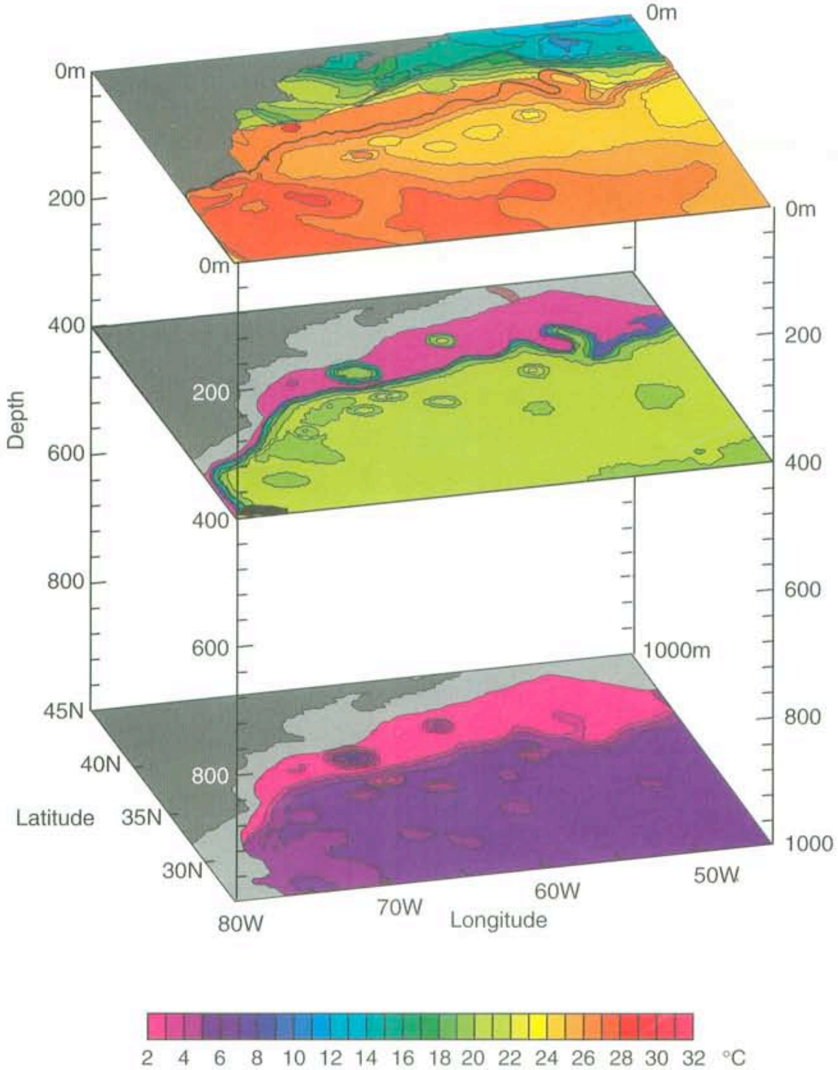
Scientific Utility of Naval Environmental Data

A MEDEA Special Task Force Report

June 1995

MEDEA

Representation of Ocean Thermal Structure in the Western Atlantic



FOREWORD

June 1995

This report from a MEDEA Special Task Force is provided in response to a request from the Navy Meteorology and Oceanography Command to examine its oceanographic data holdings and determine their potential scientific utility. The conclusions reported here represent the result of a remarkable collaboration between civilian scientists and members of the Navy's oceanographic community. The results of this collaboration have led to the identification of numerous databases which, if made available to the civilian community, would greatly advance the ocean sciences and our knowledge of the ocean environment.

We clearly recognize that serving the needs of national security through oceanographic support to naval operations remains the primary responsibility of the Naval Meteorology and Oceanography Command, the primary custodian of the data examined in this study. However, because of the resources and time involved, the data collected by the Navy for this purpose are truly unique and could never be duplicated in the civilian sector. Release of these data in an appropriate way would advance the state of ocean science by many years and result in an important public benefit from the Navy's previous investments.

The release of these data would also facilitate a closer working relationship between civilian and Navy ocean science communities, to the benefit of both. It is my firm belief that such collaboration would strengthen the Navy's overall capabilities to understand and utilize the oceans in addressing its national security responsibilities.

It is my hope that the scientific conclusions reported here, when viewed by others in the light of post-cold-war evolution in our national security needs, will lead to appropriate ways to make these important data publicly available.

Gordon J. MacDonald

Dr. Gordon J. MacDonald
Chairman, MEDEA

PREFACE

At the request of RADM Paul G. Gaffney, Commander, Navy Meteorology and Oceanography Command (NAVMETOCCOM), an assessment was conducted of the potential scientific utility of the capabilities and classified data holdings of NAVMETOCCOM. The present report describes the results of that assessment as those data and capabilities were observed during the spring of 1995.

The study was performed by a subset of MEDEA scientists representing a broad spectrum of ocean science disciplines. The scientific judgments and conclusions reflected in this report are those of the following individuals:

Dr. Mark R. Abbott	Oregon State University
Dr. Ralph N. Baker	Amoco Production Company
Dr. Otis B. Brown, Chair	University of Miami
Dr. Warren W. Denner	EOS Research Associates
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Dr. Wilford F. Weeks	University of Alaska

The coordinator of the study and editor of this volume was Dr. Kenneth E. Hawker, Jr., The MITRE Corporation.

ACKNOWLEDGMENTS

This study was accomplished with the assistance and guidance of both RADM Paul Gaffney, Commander, and Dr. Donald Durham, Technical Director, of the Navy Meteorology and Oceanography Command (NAVMETOCCOM). In addition, the technical support and advice of Landry Bernard and Dr. William Jobst, Naval Oceanographic Office (NAVOCEANO), CAPT Larry Warrenfeltz, Commanding Officer, National Ice Center (NIC), and Dr. Paul Moersdorf, Fleet Numerical Meteorology and Oceanography Center (FNMOC), are greatly appreciated and contributed significantly to this study. Their enthusiastic cooperation and support ensured that the MEDEA Task Force was fully briefed on all of the relevant databases, capabilities, and products.

It would be difficult to overstate the value of the efforts put forth by the many individuals in these organizations who assisted with this study, particularly in the face of the demands of their existing duties and commitments. In this regard, the assistance of NAVOCEANO in providing many of the figures appearing in this report is particularly noted.

In addition, meetings were held with representatives of the Arctic Submarine Laboratory and the Applied Physics Laboratory of the University of Washington, whose contributions greatly improved the treatment of an important topic addressed here.

As with its various predecessor studies, this MEDEA effort was made possible by the foresight, planning, and dedication of Dr. Linda Zall, Central Intelligence Agency (CIA).

A number of individuals associated with MEDEA have contributed ideas and energy to the process and their efforts must be acknowledged. These especially include several MEDEA scientists who were involved intermittently in meetings and discussions, and who provided review comments on this report. In addition, CDR Steve Smolinski, U.S. Navy, and Dr. Murray McDonald, Environmental Research Institute of Michigan (ERIM), were very helpful during the process of defining the study and collecting information, and their efforts are gratefully acknowledged.

The MITRE Corporation provided technical and administrative assistance to the study and produced this report. The dedicated efforts of Philip Rost and Laura Hinton, who were involved with this study from its inception, were particularly instrumental. The efforts of Dennis Violett in producing the many illustrations appearing here, David Przewlocki in production and layout of this report and the security assistance provided by Robbin Bradley are also gratefully noted.

The full and enthusiastic cooperation of all of these individuals and organizations was instrumental to any success that may be achieved and is warmly acknowledged.

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Executive Summary

GENESIS OF THIS MEDEA STUDY

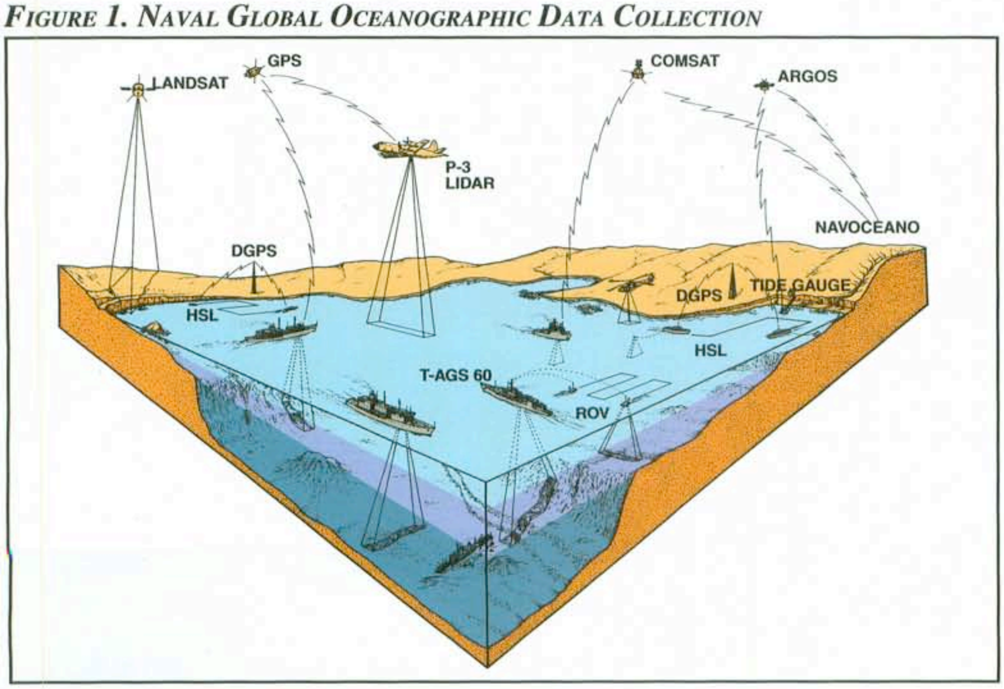
There is a growing public understanding that changes in Earth's environment, both natural and manmade, can significantly affect important dimensions of the nation's vitality, including aspects of the economy, quality of life, international relations, and national security. An enhanced scientific understanding of the key physical processes (such as global transport of heat and carbon dioxide via ocean circulation) is key to developing appropriate and responsive public policies. A major limitation to achieving this understanding is the lack of historical observations and adequate ongoing measurements of these environmental processes. In addition, the interests of U.S. national security are increasingly concerned with ensuring environmental security on global, regional, and national scales. In order to develop public policies based on a quantitative scientific understanding of the environment in the face of limited resources available for new programs, it will be necessary to exploit fully the environmental data resources already collected by the Navy (indeed of all of the Department of Defense [DoD] and the intelligence community) during the course of the cold war.

In response to a request from Vice President (then Senator) Gore, an Environmental Task Force (ETF) was established in 1992 by the Director of Central Intelligence (DCI), including involvement by DoD and other agencies. The primary emphasis of the ETF study was on space-based systems and capabilities, including the National Technical Means (NTM). Some attention was paid to a variety of Navy systems and databases; however, that study did not encompass an in-depth examination of the full variety of the Navy's oceanographic data sets and capabilities.

There was an opportunity to address those omissions with the formation of the MEDEA follow-on to the original ETF. Therefore, at the Navy's request, the present study was undertaken to examine the various classified databases, products, and capabilities of the Naval Meteorology and Oceanography Command (NAVMETOCCOM).

The intention of this study was to determine the potential for unique and important environmental research arising from the use of existing classified Navy databases, and to prioritize these data for subsequent Navy declassification efforts. In addition, this study was to identify opportunities for collaboration between the civilian and Navy ocean science communities that could benefit both, and to suggest ways to obtain increased national benefit from previous public investments in global data collection and modeling by the Navy.

FIGURE 1. NAVAL GLOBAL OCEANOGRAPHIC DATA COLLECTION



Over many years, and with increasing technical sophistication, the Navy has conducted systematic survey and measurement operations covering most of the world's oceans. Over the decades of the cold war, these operations, involving several dedicated ships, amassed results from about 100 ship-years of data collection.

Data collected include measurements of the marine gravitational and magnetic fields, seafloor bathymetry and sediment properties, and such physical properties as salinity and temperature vertical profile sections. Various other naval platforms, such as aircraft and unattended buoys, have been used extensively in this measurement program.

RECOMMENDATIONS

The major product of this study is a set of recommendations encompassing three dimensions:

- An identification of the potential for the Navy's oceanographic databases to support important scientific research, should public release become possible;

- A determination of how scientific benefit, consistent with national priorities in science and technology, can be obtained from those data that national security concerns have thus far prevented from being publicly available; and,

- A specification of means whereby closer ties between the naval and civilian oceanography communities could be achieved that would be a significant benefit to both parties.

Table 1 contains the top-level recommendations of this study. In combination, these recommendations, if adopted, would result in greater exploitation and societal benefit of the considerable public investment in the unique environmental databases and modeling capabilities developed by the Navy during the decades of the cold war. In addition, through improved ties to its basic research underpinnings, the applied science of naval oceanography would be strengthened.

It would be beyond the purview of this study to become enmeshed in issues related to the possible implementation of the recommendations to follow. However, it is very clear that resources will be required, including some level of manpower, perhaps some investment in hardware and software for processing and data exploitation, and, of course, time and funding. Here we can only recognize the need to examine the resource question without quantifying its magnitude.

TABLE 1. TOP-LEVEL RECOMMENDATIONS

- ***Payoff from Declassification***

  The Navy should consider prompt declassification of the high priority environmental data sets identified within this report. The uniqueness of much of the Navy's oceanographic data; the near impossibility of civilian replication; and the high value to scientific research, especially global change, combine to argue that this course is in the broad national interest. If entire data sets are found to be not declassifiable, the Navy should continue to work in an iterative fashion with MEDEA to find ways of releasing subsets of data, possibly through decimating, segmenting, or developing derived products.

- ***Priorities of Scientific Payoff***

  When reevaluation of classification for these unique holdings is undertaken through a systematic classification review, the priorities recommended here for the scientific value of these environmental data should be explicitly included on the benefit side of the ledger against national security needs (as provided for in Executive Order 12958, Sec. 3, April 1995).

- ***Scientific Exploitation of Classified Oceanographic Data***

  The Navy should consider implementing mechanisms to facilitate broader access to the oceanographic and geophysical data that must yet remain classified. One such mechanism should be an oceanographic data exploitation center located at the Stennis Space Center (SSC).

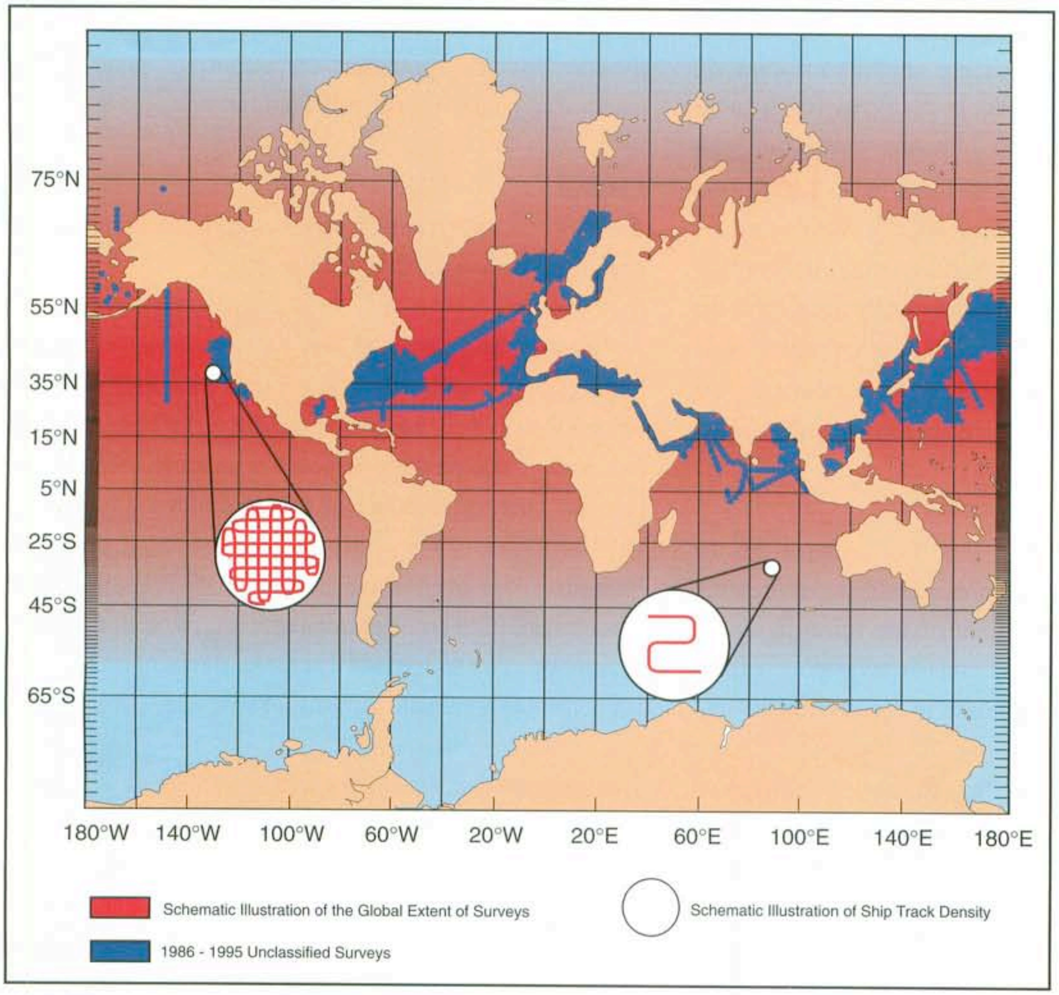
- ***Scientific Exploitation of NTM Ocean Fiducial Data***

  The National Technical Means (NTM) ocean fiducial observations should be archived at the Stennis Space Center (SSC). Scientific exploitation will require simultaneous use of these observations with correlative oceanographic data currently resident only at the Naval Oceanographic Office (NAVOCEANO). This combination will facilitate prompt exploitation of the NTM data, whereas waiting until the correlative data are available at the central United States government fiducial archive site would postpone effective use of the ocean fiducial data and jeopardize the very rationale for their collection.

- ***The National Interest and Ocean Science***

  It is in the national interest for the United States government to work to improve interactions between the Navy and the broad ocean science community. There are clear and immediate opportunities for "bridge building" between elements of naval oceanography and the civilian ocean science community. Such "bridges" will significantly benefit both parties.

FIGURE 2. WORLDWIDE SURVEY OPERATIONS



The red shaded area illustrates the global scope of the Navy's oceanographic survey and measurement program. As the tapered shading suggests, there has been a greater concentration of resources in the Northern Hemisphere than the Southern Hemisphere.

Also shown schematically are inset illustrations of how different the densities of ship tracks might be in different ocean areas. Tracks of naval oceanographic surveys (blue) from just the unclassified cruises covering the years from 1986 to 1995 show the worldwide nature of the sources of data.

Examination of all survey ship tracks from the entire cold war history of naval survey operations would show both a global breadth of coverage and a scientifically well founded spatial sampling of ocean processes.

SCIENTIFIC UTILITY

Discussion

During the past 30 years, the Navy's ocean surveys have systematically collected bathymetry, gravity, magnetics, and salinity/temperature data on a global basis. In particular, these surveys encompass almost all of the Northern Hemisphere (Figure 2). Altogether more than 100 ship-years of data acquisition have been devoted to this effort, making this the most comprehensive ocean surveying activity ever undertaken. **It is highly unlikely that such an effort will ever be repeated, and it is certain that civilian environmental scientific resources could not aspire to an ocean survey program of this magnitude during the next 20 years.**

The scientific value of this data set and other data examined, such as acoustic ice thickness data collected from submarine upward-looking sonars (ULS), is extraordinary. The unclassified release of these data would almost certainly result in significant advances in many fields of ocean and geophysical science. Release of currently classified data and improved access to classified data by researchers would stimulate the civil/academic scientific community to produce new knowledge and data products that would, in turn, be useful to the Navy. Such a process would be highly cost-effective, gaining leverage from the large public investment already made by the Navy in collecting the data sets.

A past example of scientific benefit from the declassification of oceanographic data involved Geosat. Geosat Altimetry data south of 30° S were declassified, which resulted in a significant advance in our understanding of the tectonics of the southern ocean and the identification of previously unknown seamounts. (Results from a limited analysis of these data have been published by scientists having access to the classified data.) Another historical example, though remote from oceanography, involves data from the VELA satellites, originally flown to detect atmospheric nuclear tests. Events having considerable astrophysical significance today, gamma ray bursts, were first observed and then monitored by these satellites for some six years prior to their declassification in the 1970s. On a larger scale, the entire civilian, space-based remote sensing program owes its origins to earlier successes and technology of the classified satellite reconnaissance programs. We can expect that interesting, but unexplained features in the Arabian Sea, observable in synthetic aperture radar (SAR) imagery at the NASA Space Radar Laboratory, should be interpretable using much needed ground truth data, such as the temperature and salinity data in NAVOCEANO's ocean thermal and salinity-profile databases.

The major specific findings of this study, supporting the top-level recommendations, are divided into two categories: (1) identification and prioritization of the scientific utility of the various data sets examined, and (2) developing ways to improve the community's capabilities in ocean science.

Through a series of briefings and discussions, we were exposed to a great many of the Navy's environmental data sets and capabilities, and we have identified a subset of significant importance. Furthermore, to support the Navy declassification review that we expect to follow, the data sets have been prioritized in two categories of "potential importance." The prioritization reflects our view of the uniqueness of the data, and it represents the potential for important results to be obtained, if public release were possible.

Findings

The major findings related to various specific data sets that were examined are summarized in Table 2.

No attempt was made to evaluate the national security implications of possible public release of these data sets, this being a topic outside our purview. That is, we have accounted for *neither* any possible impact on national security from potential public release, *nor* of how favorably the Navy might view the release of any particular data set. Further, no cost has been attached to any possible future effort to declassify, bundle, or reformat data or create automated access by cleared scientists in as much as we understand that the existence of such costs do not constitute legitimate grounds for continued classification.

We recognize that, even in the face of a judicious weighing of national security risks on the one hand, and public benefits of declassification on the other, declassification of entire data sets may, in some cases, prove to be imprudent. In such cases, it may very well be possible to declassify geographic subsets of the

Table 2. Findings Related to Specific Data Sets

- ***Scientific Utility***

  We have singled out 10 data sets whose potential for supporting important science is so significant that our first recommendation to the Navy is to "...consider prompt declassification of the high priority environmental data sets identified here." Four of these data sets are in the domain of geology and geophysics (Marine Gravity, Geomagnetics, Geosat Altimetry, and Seafloor Sediment Properties), two are concerned with sea ice (Ice Keel Depth Acoustic Data and Historical Ice Morphology), and four are concerned with the volume and boundary properties of the ocean (Marine Bathymetry, Realtime Salinity and Temperature Fields [GOODS], Archival Salinity and Temperature Fields [MOODS], and Ocean Optics and Bioluminescence).

- ***Prioritization of Data Sets***

  The listing below shows a twofold prioritization of the probable scientific importance and uniqueness of the data, should they be made publicly available.

  First Tier
  - Marine Gravity
  - Geomagnetics
  - Ice Keel Depth Acoustic Data
  - Marine Bathymetry
  - Geosat Altimetry

  Second Tier
  - Historical Ice Morphology
  - Seafloor Sediment Properties
  - Realtime Salinity and Temperature Fields (GOODS)
  - Archival Salinity and Temperature Fields (MOODS)
  - Ocean Optics and Bioluminescence

data, decimated or smoothed data, or in particularly sensitive instances, only derived products. This report does not attempt to give guidance bearing directly on the details of such a compromise position on declassification, nor do the priorities in Table 2 account for this dimension. Therefore, in anticipation of the Navy eventually facing the necessity to understand declassification payoffs vs. national security risks, it is our view that **a declassification review of these environmental data should include MEDEA involvement (in a scientific advisory capacity) in order that the necessary compromises elicit the most scientifically useful data.**

IMPROVING CAPABILITIES IN OCEAN SCIENCE

Discussion

The Navy has developed truly unique capabilities to synthesize oceanographic products from diverse and heterogeneous data and to display the results in useful graphical forms. Beyond the more traditional forms of product generation involving large-scale ocean thermal, salinity, and density fields, this synthesis now includes the development of small-scale regional models in selected ocean areas of naval interest and the exploitation of imagery, including classified NTM imagery. This product synthesis capability, if it were opened to civilian use, could lead to an expanded national benefit. There has been a considerable investment of public funds in these capabilities, and scientific access would pave the way for ocean science to move more rapidly into small-scale oceanography.

The intelligence community, with congressional support, has established a program to collect and archive classified NTM imagery data collected from a set of reference sites that will be regularly surveyed over time periods ranging from years to decades. Currently, in excess of 200 sites are being considered for data collection. This Global Fiducial Data Program is intended to archive data to be used in scientific studies of the global environment, albeit requiring classified access. Some of these measurement sites are ocean areas, and one important result of the present MEDEA study has been the realization that scientific exploitation of the ocean fiducial data must involve analytical use of correlative NAVOCEANO oceanographic data. These "correlative data" are in many cases the same as that discussed in Chapter II: ocean thermal and salinity structure, high-resolution bathymetry, etc. The proper scientific exploitation of the ocean fiducial data is, therefore, closely tied to ensuring access to NAVOCEANO's databases and modeling capabilities.

On the other hand, there are few regular and effective mechanisms for the flow of information to naval oceanography from academia. It is our conviction that such a flow of information, involving modest collections of irregularly sampled "shoe box" measurements or recent progress in dynamic ocean models, for example, would be of considerable benefit to naval oceanography and to the accuracy of fleet products.

Several institutional mechanisms would have to be put in place to facilitate access to classified information if scientists are to realize full benefits from the environmental data holdings of the national security community. The establishment of a consistent, long-term environmental record of digital data could benefit from the participation of cleared members of the environmental science community in the collection requirements process (as is being done in the Global Fiducial Data Program).

The environmental science community might also participate in the development of policies to ensure that archival products are of maximum utility to the environmental community. For example, these policies could provide guidance to the national security community as to which data to index, abstract, declassify, and transmit outside their facilities. Environmental scientists could also benefit from the establishment of processes and systems for requesting data and transforming material for distribution. Finally, the development of new concepts of operations that support the complementary use of classified and civilian sensors could also be investigated. These could include processes to implement sensor cross-cueing, develop composite products, and perform calibration and validation.

FINDINGS

The bridge building path with institutional mechanisms and links between the civilian and Navy oceanography communities has many of the same features as the road toward scientific exploitation of oceanographic data that must yet remain classified. The findings covering these dimensions are summarized in Table 3.

TABLE 3. FINDINGS RELATED TO IMPROVING OCEAN SCIENCE CAPABILITIES

- ***Exploitation Center***
  An exploitation center, installed at the Stennis Space Center, supported by a high-data-rate local area network would allow access to essentially all NAVOCEANO databases, models, and product synthesis capabilities by appropriately cleared and United States government-sponsored civilian scientists, thus facilitating scientific use of these data and generating feedback to the Navy.

- ***NTM Global Fiducial Data***
  This exploitation center should also be the repository for the National Technical Means (NTM) ocean fiducial data, thus offering both access to oceanographic capabilities for their intrinsic value and facilitating scientific exploitation of the NTM data.

- ***Regional Model Fields***
  Building on Navy interest in littoral ocean areas, the Navy should expand its current efforts to build regional ocean models to include areas in proximity to the United States, possibly beginning with the Gulf of Mexico, which includes nearly all littoral types. The relatively dense observations available in the Gulf area would help develop and validate regional models.

- ***Access to NAVOCEANO Capabilities***
  Facilitating the civilian use of databases and models through permitting access to the Integrated Database Management System (IDBMS) being developed by NAVOCEANO would be a significant positive step. Remote access to the classified version of IDBMS, with local exploitation through the exploitation center or via an encrypted link, should be arranged. On-line connectivity should be provided to databases approved for public release, thus vastly accelerating civilian use and generating feedback to the Navy.

- ***Interagency Collaboration***
  The entire oceanography community, Navy and civilian alike, would greatly benefit from a much stronger partnership among the United States government ocean science agencies: the Navy's Office of Naval Research (ONR), National Oceanic and Atmospheric Administration (NOAA), National Aeronautics and Space Administration (NASA), Department of Energy (DoE), and the National Science Foundation (NSF).

- ***Visiting Scientist Positions***
  Provision should be made for one or more visiting senior scientist positions at NAVOCEANO and civilian scientific participation in ocean surveys.

I. Introduction

A. PURPOSE

The primary purpose of this study is to examine the various classified ocean databases, products, and capabilities of the Naval Meteorology and Oceanography Command (NAVMETOCCOM) and determine their potential value for supporting civilian scientific research, should public release become possible. In addition, the study is to determine if there might be important opportunities for synergistic collaboration between civilian and military ocean technical communities that could benefit both parties and so derive increased benefit from the considerable public investment in global ocean data collection and modeling previously undertaken by the Navy.

Although aside from the primary purposes of this study, we understand that the Navy also values this review because it is a comprehensive and independent look by outside experts at the quality of Navy data and data management processes. On this point, feedback was provided informally to the Navy during the actual process of the study. We were greatly impressed not only with the unique environmental data sets, but also with the general scientific quality of the work and the processes of data collection, analysis, and product generation.

B. GENESIS OF THIS MEDEA STUDY

There is a growing public understanding that changes in our physical and biological environment, both natural and manmade, can significantly affect the national economy, our quality of life, and even the national security. For example, natural disasters (*e.g.*, earthquakes, volcanoes, floods, hurricanes, forest fires) can cause substantial loss of life and material damage, changes in climate can adversely affect our environment (*e.g.*, global sea levels, agricultural fertility, habitats of endangered species), and environmental pollution can degrade the vitality of populations and ecosystems. To deal with the potential effects of environmental change, an enhanced scientific understanding of the key processes is needed. A major limitation to achieving this understanding is the lack of historical environmental observations and continuing scientific measurements of these processes.

In recognition of this need, in 1992 Vice President (then Senator) Gore called for the creation of a panel of cleared environmental scientists who would evaluate assets of the national security community that could help resolve critical environmental issues. In response to this request, an Environmental Task Force (ETF) was established by the Director of Central Intelligence (DCI) and endorsed and participated in by the Departments of Defense (DoD), Commerce (DoC), Interior (DoI), and Energy (DoE), and, as well as by NASA and other agencies.

Throughout 1993, the ETF scientists were briefed on a wide variety of classified systems and data/archives from many segments of the national security community to allow them to assess the applicability of these resources to environmental concerns. A final report was then issued by the ETF containing an assessment of the potential scientific utility of the classified data should public release later become possible. The ETF also dealt with other opportunities for gaining scientific payoff from these data and capabilities, including introducing the concept of derived products (primarily graphical) in order to facilitate declassification of limited specific information.

The concept of global "fiducial" data collection by classified sensor systems in support of scientific research and environmental monitoring was also introduced. The regular sampling of a preselected set of fiducial sites was seen as complementary to data collected by civilian sensors and would be a means of beginning a long-term archive of well-sampled data on a set of scientifically significant sites.

While the primary emphasis in the 1993 ETF final report involved space based systems, including the National Technical Means, some attention was also paid to a variety of Navy systems and databases. This included brief mention of databases such as high resolution bathymetry, submarine acoustic ice keel drafts, and Geosat altimetry, as well as a substantial look at the Integrated Undersea Surveillance Systems. However, constraints of time and U.S. government priority prevented an in-depth examination of the full range of oceanographic, polar ice, and meteorological databases and capabilities which were developed by the Navy during the decades of the cold war.

Subsequently, with the formation of MEDEA, there was an opportunity to rectify these omissions. MEDEA consists of a group of about 50 cleared scientists drawn from academia, government, and industry. Disciplines and interest areas include geology and geophysics, oceanography, atmospheric science, polar science, urban growth, land cover and land use, climatology, remote sensing, environmental remediation, and others. There is considerable commonalty in MEDEA with the original ETF group. MEDEA has been sponsored by the intelligence community, with direct involvement of the DoD and the Services, in particular from the offices of the Oceanographer of the Navy and the Commander, Naval Meteorology and Oceanography Command.

The present study was undertaken by a subset of MEDEA as a logical extension of the original ETF work as a result of a request from Naval Meteorology and Oceanography Command. The intention was to determine the unique potential of these data for important use in scientific research, if public release of currently classified oceanographic data were to become possible. This study was also to identify opportunities for collaboration between the civilian ocean science and Navy communities that could benefit both. In addition, it was to suggest ways to obtain increased national payoff from previous public investments in global data collection and modeling made by the Navy. Finally, the intention was to determine if there were means whereby limited scientific benefit of currently classified data could be obtained in cases where public release would not yet be possible (*i.e.*, "derived products").

C. NAVAL OCEANOGRAPHY BACKGROUND

In the 1800s during the early days of the Depot of Charts and Instruments, the objective of Navy oceanography was to provide mariners with the information they needed for safe and efficient navigation. Since World War I, when submarines came into widespread use, submarine and anti-submarine warfare have evolved rapidly to the point where today both have a deep and fundamental reliance on exploiting detailed physical properties of the oceans. Once sonar became a valuable tool to submarines and surface ships during World War II, its effective use required another dimension in understanding of the ocean environment, namely acoustical oceanography. With the advent of naval aviation, and particularly with aircraft operating off carriers, came the need for accurate maritime weather forecasts.

Evolution of computer and communications technology, along with advances in meteorology and global weather data collection, allowed forecasts of many environmental parameters to be made and transmitted to naval units operating around the world. Thus, ship and aircraft routing became important parts of the NAVMETOCCOM's mission. More recently, the long ranges of modern weapons systems, and their precise targeting requirements, forced global predictions of synoptic physical parameters from the depths of the ocean to outer levels of the atmosphere with standards of precision not previously achievable.

The NAVMETOCCOM consists of the Naval Oceanographic Office (NAVOCEANO), Fleet Numerical Meteorology and Oceanography Center (FNMOC), several Fleet Support Centers, and numerous operational units around the world. This worldwide organization comprises about 3,000 officer, enlisted, and civilian personnel; two master computer centers; a number of theater centers; and the ships and aircraft used in conducting oceanographic surveys.

FIGURE 3. OCEANOGRAPHIC SURVEY CHALLENGES

The scale of the Navy's ocean survey and measurement program has been immense. This has been the result of its global mission responsibilities, and of the priorities given during the cold war to anti-submarine warfare (ASW) and other Navy operations requiring technical support in oceanography and meteorology.

Dedicated ship services have collected data in all seasons across the breadth of the Northern Hemisphere as well as over much of the Southern Hemisphere.

The Command's mission is to collect, interpret, and apply global environmental data and information for safety at sea and for weapons system design, development, and deployment. The Command also provides meteorological, oceanographic, mapping, charting, and geodetic surveys to U.S. military forces for use in operational missions. Three major components of this command are described below:

- The Naval Oceanographic Office (NAVOCEANO) is the largest single element of the Command and one of its two master computer centers. Its primary mission is to conduct oceanographic multidisciplinary surveys of the world's oceans. The office collects hydrographic, magnetic, geodetic, chemical, navigation, and acoustic data using ships, aircraft, spacecraft, and other platforms.

- The Fleet Numerical Meteorology and Oceanography Center (FNMOC) operates the other master computer center, and produces global- and regional-scale meteorological and oceanographic prediction products, including analyses, forecasts, and tactical decision aids. These products are tailored for direct operational use by Navy ships and aircraft.

- The National Ice Center (NIC), formerly known as the Navy/NOAA Joint Ice Center, has as its primary mission providing realtime, quantitative operational support concerning the state of the polar oceans, and in particular the ice covers of these oceans, to agencies of the U.S. government. Although NIC does not provide direct project support to non-governmental organizations, its primary unclassified product, the bi-weekly global sea ice assessments, are available to the general public via computer files.

The components of this Command have been an integral part of the development of meteorology, oceanography, and other areas of geophysics in the U.S. The earliest part of the organization was the Depot of Charts and Instruments (1860), under Matthew Fontaine Maury, and the Naval Aerological Service (1919). From 1842 to 1861 the organization was referred to as the Observatory and Naval Hydrographic Office. Later this office became the Naval Hydrographic Office (1866), responsible for charting and maintaining other vital data in support of the Navy's needs. The Naval Oceanographic Office was established in 1962 and was moved in 1978 from Washington, D.C., to the Stennis Space Center (SSC), Bay St. Louis, Mississippi, where it resides today. Also located at the SSC is its parent command, the Naval Meteorology and Oceanography Command that reports to the Chief of Naval Operations (CNO) through the Oceanographer of the Navy.

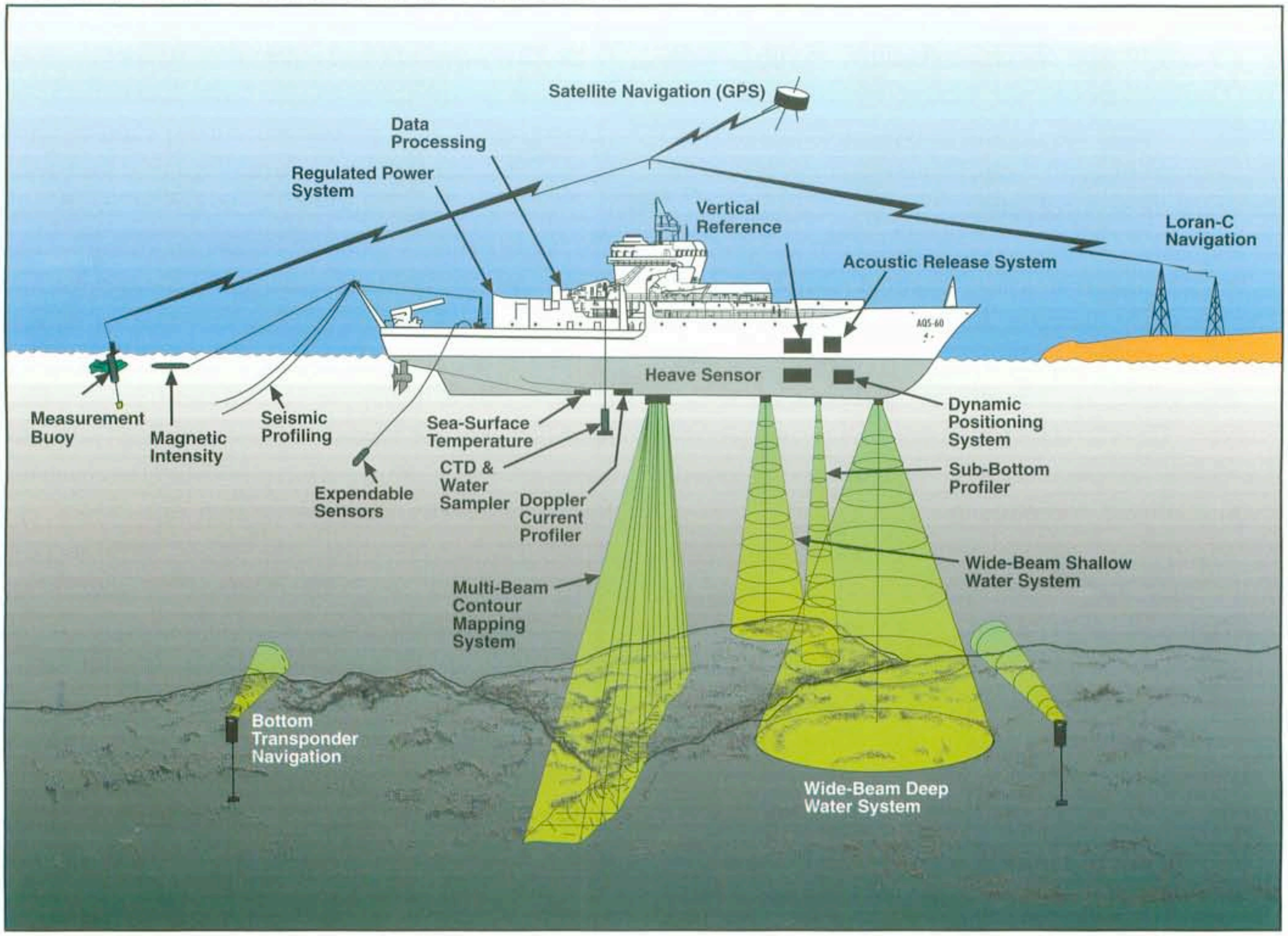
The Naval Aerological Service became the Naval Weather Service in 1956. The Weather Bureau-Navy-Air Force Joint Meteorological Weather Prediction Unit was activated in Suitland, Maryland, in 1954, and moved to Monterey, California, in 1959 to become the Naval Weather Service's Fleet Numerical Weather Central. Its first operational computer center appeared in 1961. It was renamed the Fleet Numerical Meteorology and Oceanography Center in 1993.

Today, the end result of an immense revolution in technology combined with a growing understanding of ocean physics over the past 100 years and changes in the conduct of naval warfare is a Navy increasingly reliant on exploiting detailed physical and acoustical data on the Earth's oceans. Consequently, the Navy has invested in global ocean surveys and other large-scale measurement programs, as well as supported the development of sophisticated predictive models.

During the decades of the cold war, and continuing today with a shift in emphasis toward shallower, littoral waters rather than deep waters, the U.S. Navy has come to be the world's leader in global ocean data and ocean-modeling capabilities. A particularly telling and relevant indicator of the magnitude of the U.S. Navy's investment in oceanography are the at-sea surveys encompassing magnetic, gravity, and bathymetric surveys involving about 100 ship-years of data collection.

There is no other dimension of the global environment where so much of our current scientific understanding and so many of the fundamental measurements have been rooted in the efforts of one of the military services. It is clear from the outset then that the resources the Navy has devoted to oceanography and ocean surveys have resulted in unique, extensive, and detailed databases with no civilian counterpart. As we will see in this report, this expectation was indeed realized over the course of the study.

Figure 4. Naval Ocean Survey Ship Capabilities



This illustration of NAVOCEANO's newest class of survey ships, TAGS-60, shows many of the measurement capabilities necessary to collect the types of environmental data examined in this study.

The depths of the open ocean can only be sampled satisfactorily with specialized survey ships capable of operating in heavy seas, handling heavy equipment, and providing extensive equipment spaces and berthing facilities for large scientific parties.

NAVOCEANO has routinely employed dedicated ships having a variety of deep ocean survey equipment. Historically there have been four to six of these ships operating at any given time.

D. IMPLICATIONS OF SECURITY CLASSIFICATION

The integrity and success of scientific research depend in a fundamental way on the scientific method and the peer review process. Central to these is the concept of independent reproducibility and testability of research results, and these in turn require open public access to all relevant data and information. While it is true that various scientific journals do differ somewhat in their degree of tolerance for omitted experimental details, there is no doubt that the standard in scientific research is that the bulk of material must be open to all.

Fundamental scientific insights on controversial subjects, global warming for example, will itself generate significant pressure for declassification. The scientific community at large is self-regulating through the use of refereed publications where experimental details and results need to be candidly displayed under the light of a constant peer review process. On topics subject to controversy, less than open discussion is, at best, counter productive and usually leads to acrimony and confusion.

We understand that, despite the ending of the cold war and the emergence of a new national security paradigm, there remain legitimate needs for the continued protection through classification of some dimensions of the Navy's ocean data. It is essential, though, to be clear about what can and cannot be done, if classification policies remain as they stand today. A significant change in these policies may be necessary, if we are to realize the full scientific promise across the breadth of ocean and Earth sciences foreseen here.

The Executive Order (EO) that provides the basic legal authority for national security classification within the defense and intelligence communities has recently been extensively revised. EO 12958 of April 20, 1995, signed by President Clinton, with an effective date of October 14, 1995, replaces its predecessor EO 12356. While this new EO introduces significant changes to many dimensions of security classification, for present purposes it is only important to note that it **specifically authorizes balancing of the public interest in order to declassify information that continues to meet the standards for classification.** It also requires both automatic declassification of information at least 25 years old (with very narrowly drawn exceptions) and calls for both systematic and mandatory declassification reviews.

In addition, we understand that there are efforts in progress within the DoD concerning the declassification of several of the databases examined by this study. At a minimum these include

- An effort directed by the Office of the Secretary of Defense (OSD) to develop a response to the recommendations made by the ETF, including naval dimensions that partially overlap with those of the present study;
- Discussions within the OSD and the Services concerning the advisability of declassifying Geosat data and making available precision Global Positioning System (GPS) capabilities;
- Efforts by the Oceanographer of the Navy and the Commander, Naval Meteorology and Oceanography Command to declassify selected data such as high-resolution bathymetry;
- New classification guidelines have been developed that may result in declassifying some of the submarine acoustic ice keel draft data to be discussed here.

The dynamics created by these and other efforts, with the heated debates that the subject of declassification always provokes, cannot be resolved, or even understood, in a brief study such as this (nor would it be appropriate for us to attempt this). We have, therefore, chosen to set aside consideration of all of these declassification efforts and concentrate solely on identifying the scientific utility of the various data. If one or more declassification efforts result in release of any data set identified here, it will constitute a significant step forward toward achieving greater public benefit from previous investments and is to be applauded.

We believe that, with one exception, there has been no post-cold-war security classification assessment that has taken into account scientific payoff to the national interest on the benefit side of the ledger. The single exception was the Classification Review Task Force (CRTF) undertaken by the DCI and the Secretary of Defense (SECDEF) regarding the classification policies of space-based imagery. The CRTF built its case for the "benefits of declassification" on the ETF study. It is our hope that an assessment comparable to the CRTF will be undertaken of the Navy's oceanography databases, and that the open-mindedness of that assessment will be taken as a model.

We recognize that, even with a careful weighing of national security risks on the one hand, and public benefits on the other, it may prove to be imprudent to declassify some entire data sets. In seeking a compromise position then, it may be possible to declassify geographic subsets of the data (*e.g.*, a set of predefined "postage stamps") or some form of decimated or smoothed data. A second alternative to a perhaps unattainable, complete declassification of entire data sets would be the development of a set of specific derived products. If this were done with a view toward both national security sensitivities and scientific utility, these derived products might balance the "equities" in a mutually agreeable fashion.

It is our view that the Navy should conduct a systematic high-level declassification review of the environmental data considered here. Moreover, this review should include some form of MEDEA involvement. We assume that this would be in an advisory capacity only and would serve to ensure that the necessary compromises proceed so as to elicit the most scientifically useful data.

If, despite searching for compromises to release subsets of data, or derived products, the most important data still cannot be released in unclassified form, some value can yet be obtained by providing classified data access by cleared environmental scientists. Using these data, scientists might then conduct experiments from which scientific insights and products could be derived that shed light on key environmental processes. These experiments would serve to clarify the unique complementary contribution that these data can make to environmental science and to influence the strategy governing the creation of long-term archives.

E. STUDY APPROACH

1. OCEAN SCIENCE CONTEXT

For most missions, civilian and military alike, and for scientific research, the processes of observing and monitoring the oceans involve phenomena having two characteristics in common. First, the interesting problems usually involve large areas and long time periods. Second, many of the phenomena are often difficult to observe with remote sensing (*i.e.,* space-based) systems because of the lack of consistently detectable or "good" observables. Many of the ocean phenomena of interest to both civilian and military communities can be measured only with *in situ* sensors because of the need to sample at depth (*e.g.,* salinity and temperature profiles, water quality, and bathymetry). As a result of the necessary reliance on *in situ* sensors for many types of measurement, and the necessary use of ships and aircraft, the costs of ocean measurement programs, to say nothing of a well-sampled global data set, are very high and increasingly unaffordable.

As a result, oceanography and marine geophysics have always been data-starved disciplines, primarily because of the difficulty and expense of making measurements having the requisite spatial granularity over large ocean areas and for long periods of time sufficient to detect the important trends. This difficulty in dealing with the spatial and temporal granularity of the ocean processes over vast areas is one which frequently leads to either undersampling or to the high costs of well-sampled, ship-based *in situ* measurement programs. To the extent that the relevant phenomena have observables amenable to space-based observation this situation has improved dramatically in the last two decades. A few of many examples include large-scale sea surface temperature, the long wavelength gravity field, and soon with the SeaWiFS satellite, ocean color (related to phytoplankton densities).

We can expect that much of unique value that might be offered to scientific research by naval ocean databases and modeling capabilities would arise because of their unusual spatial and/or temporal coverage relative to their civilian counterparts. We will see that while the classified world has generally the same sensor types as the civilian, the global coverage and, in some cases, the extended time periods over which classified data were taken are their unique distinguishing characteristics.

2. PROCESS

This study was conducted by a group of 11 MEDEA scientists drawn from the oceans, polar ice, geology and geophysics, and atmospheric sciences, augmented by technical and administrative support. Several organizations in the U.S. government, including the Central Intelligence Agency and the Navy, have had the opportunity to review drafts of this report and comment on its technical accuracy, thereby improving the result. However, the judgments reflected in the findings reported here solely reflect the thinking and opinions of the MEDEA Navy Study Group.

The NAVMETOCCOM was instrumental in ensuring that the study group was briefed on all of the relevant databases, capabilities, and products and, moreover, provided most of the figures included in this report. These briefings offered a comprehensive and insightful window into naval meteorology and oceanography. The study group benefited from detailed meetings with NAVOCEANO, NIC, and FNMOC, along with extensive discussions with the Commander and staff of Naval Meteorology and Oceanography Command, and interactions with the Office of the Oceanographer of the Navy. In addition, we met with representatives of the Arctic Submarine Laboratory and the Applied Physics Laboratory of the University of Washington. The full and enthusiastic cooperation of all of these organizations with this study was instrumental to any success that may be achieved and is greatly appreciated.

II. Scientific Utility of Specific Data

A. OVERVIEW

This chapter will assess the potential for important scientific applications of the various data sets and capabilities described to us by the Navy. The Navy data that were reviewed, evaluated, and found to be the most promising are identified in Table 4. We have tried to include enough detail relating to each data set to support a reasoned judgment of individual importance. Each section in this chapter deals with one data set: (1) data description, (2) accessibility, (3) potential scientific utility, and (4) a summary of our findings.

Additional consideration was given to

- Generalized Digital Environmental Model (GDEM)
- Arctic Buoy Program
- Comprehensive Environmental Assessment System (CEAS)
- Acoustic Data and Acoustic Sensing of the Ocean

and a discussion of each of these is contained in Section E of this chapter.

Release of the Navy's classified oceanographic data will lead to the greatest scientific rewards if environmental scientists have access to the original measurements, as with normal scientific practice. However, the Navy has processed many of these data into many different and very useful forms, for example, compiling measured data into ocean provinces or gridded databases that essentially constitute a form of derived product. Many of these "derived forms" have potential scientific utility nearly as great as the original data. A good example of such an instance concerns bathymetry. While it is possible to envision scientific applications that would require the original data (i.e., acoustic soundings from a multibeam profiler) we conclude that a derived product (the gridded databases developed by the Navy) will generally be the most widely useful form and will be the basis of our finding related to bathymetry.

Since all 10 of the data sets listed in Table 4 are restricted or classified, in whole or in part, we have described our understanding of the "accessibility" of each data type. Use of some data is restricted because of the process used to obtain it, or because the data were obtained through an international bilateral agreement. Other data are classified because they have more direct ties to U.S. Navy forces and their operations.

This MEDEA study has only tried to clarify how these Navy data sets, obtained for use by operational forces, might be used for scientific purposes. We did not try to make any judgment about data classification, and we are not attempting to assess the utility of these data for their originally intended purposes—support of Navy operations.

Table 4. Categorization of Data Sets Examined

GEOLOGY AND GEOPHYSICS	SEA ICE	OCEAN VOLUME AND BOUNDARY PROPERTIES
Marine Gravity	Historical Ice Morphology	Realtime Salinity and Temperature Fields (GOODS)
Geomagnetics	Ice Keel Depth Acoustic Data	Archival Salinity and Temperature Fields (MOODS)
Geosat Altimetry		Ocean Optics and Bioluminescence
Seafloor Sediment Properties		Marine Bathymetry

B. GEOLOGY AND GEOPHYSICS

1. MARINE GRAVITY

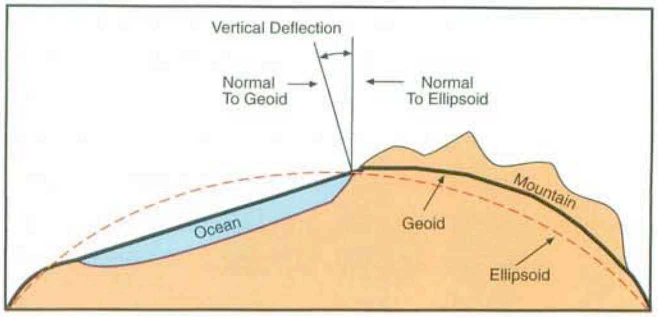
a. Data Description

Gravity is the force that attracts bodies to Earth.[1] In fact the acceleration of gravity over the surface of the Earth is not a constant from location to location. Rotation flattens the Earth's shape near the poles to approximately that of an oblate spheroid, thus reducing surface gravity at the equator. Over the past 30 years, as the need for precision in the positioning and navigation of space vehicles and other platforms increased, it became increasingly important to account for the slightest gravity variations. Thus, not only the general overall shape of the Earth (oblate spheroid) was needed to drive the gravity field, but ever smaller topographic features and geographic structures (which can cause gravity changes sufficient to affect critical instrumentation) had to be mapped.

The Earth's shape has been measured with increasing accuracy ever since the development of earth-orbiting artificial satellites. In the 1980s the Navy measured the equipotential surface of the oceans, the *geoid,* very accurately using a satellite altimeter aboard Geosat (Section II.B.3). The geoid differs significantly from the reference ellipsoid. Not surprisingly, it is possible to derive the gravity field from the geoid; in particular, the product of the gravity field and the geoid anomaly in meters (*i.e.,* the difference between the geoid and the reference ellipsoid) is equal to the anomaly in the gravitational potential. The Navy's accurate measurement of the geoid thus allows a global inference of the associated gravity field.

In dedicated Navy surveys, gravity measurements were made at sea with oceanographic ships tracing closely spaced tracks sufficient to provide scientific quality measurements. Lacoste and Romberg Air-Sea Meters were used from 1966 to 1983, and in 1969 Bell Aerospace BGM-3 and BGM-5 gravimeters were introduced. In addition to collecting the data, scientists measured gravity variations and conducted vertical deflection studies (the difference between the vertical, as indicated by the plumb line of the instrument, and the theoretical perpendicular to the Earth) to obtain true positions. This concept is illustrated in Figure 5. They also computed gravity anomalies (the difference between observed and theoretical values) that can help geologists locate mineral and oil deposits and can be applied to geophysical studies of the Earth.

Figure 5. Gravity Variations and Vertical



The geoid differs significantly from the reference ellipsoid. Not surprisingly, it is possible to derive the Earth's gravity field from a precise knowledge of the geoid.

Depicted schematically here are the reference ellipsoid and the perturbed shape of the geoid due to the masses of oceans and mountains. As shown, the different shapes of these two surfaces result in the normal directions being different.

The product of the gravity field and the geoid anomaly in meters (i.e., the difference between the geoid and the reference ellipsoid) is equal to the anomaly in the gravitational potential.

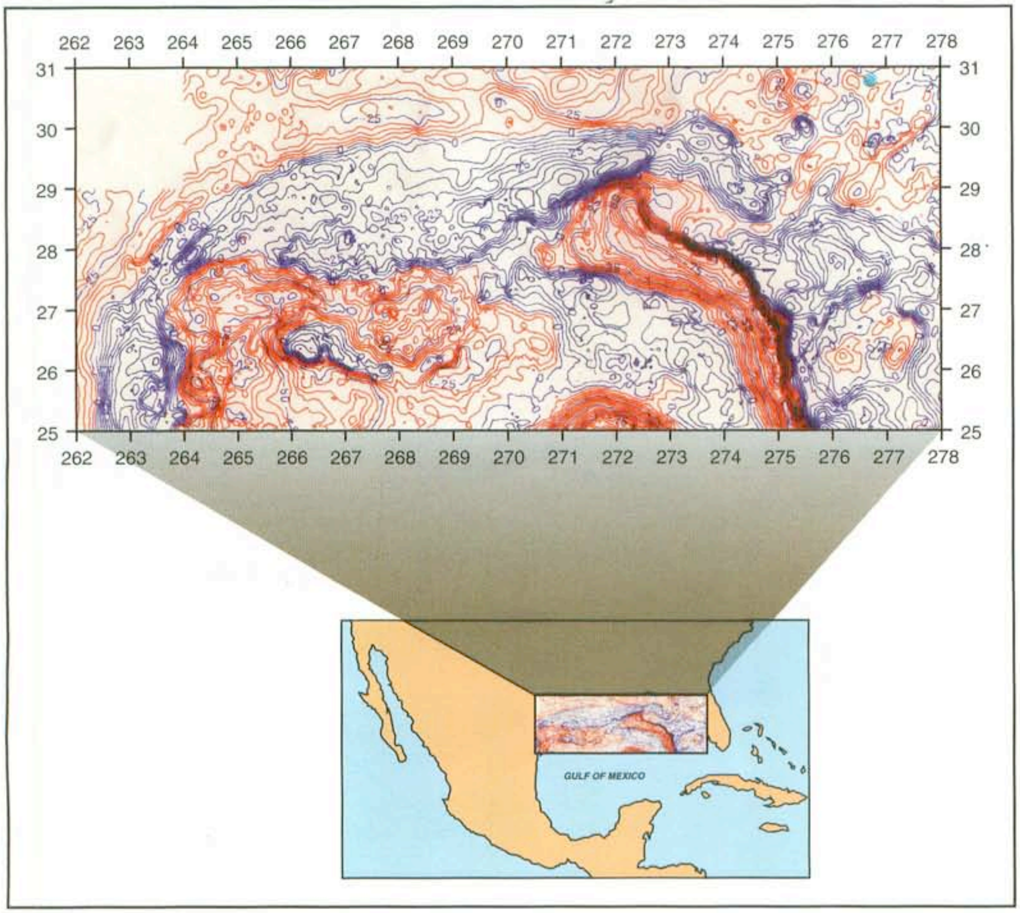
Survey data are digitized at one minute (of time) intervals and indexed by geographic position. These digitized data are called "point data." Representing gravity at one minute (of position) intervals in a survey area is considered the best estimate of gravity at an indexed point. These computed data are called "point-average gravity anomalies." NAVOCEANO collects gravity data in support of required fleet activities, which are usually classified. Figure 6 depicts an example of high-resolution gravity data from the Gulf of Mexico.[2] A study of the data in the Gulf of Mexico provided an opportunity to construct an unclassified one minute point-average gridded data set which is illustrative of the classified data covering much of the world's oceans.

From these at-sea measurements the point observations of gravity were processed and organized into a relational database. This Navy Point Gravity Database consists of a table of marine

[1] The gravity field results in an acceleration near the surface of ≈9.81 m/s^2 so that a mass of 1 kg weighs one Newton (N). A gravitational unit, the gal, was named in honor of Galileo, who first systematically measured the acceleration of gravity (gal = 10^{-2} m/s^2).

[2] The gravity data shown in Figure 6 as extending over land were taken from an earlier land-based survey and integrated with the NAVOCEANO shipboard measurements to form a single field.

Figure 6. Free Air Gravity Contour Data in the Gulf of Mexico



This figure shows a contour plot of the gravity field of a section of the Gulf of Mexico at a resolution of one arc minute.

The area shown includes in the right a section of the thickly sedimented Mississippi fan, and in the left center the broken area of the Sigsbee Escarpment (both viewed through the "lens" of the gravity field).

The gridded data used for constructing this plot over water were derived from measurements along ship tracks spaced to sample the gravity high properly.

The entire Gulf of Mexico survey required 34,638 miles of ship track and produced 162,836 original data points. Considerable processing was necessary to ensure data uniformity and to eliminate errors, and then to produce a uniformly sampled gridded data set.

Gravity data over the land area were acquired from other sources.

gravity point observations with the latitude, longitude, observation time, free air anomaly, and gravity value, supported with over a dozen tables containing survey, data processing, and statistical information. The observations table consists of over 38 x 10^6 rows of data which can be sorted by cruise and date-time group or geographic coordinates.

Information is retrieved from the database by both interactive and batch processing. There are Navy plans to replace this database with a relational database and then load the data into the Integrated Database Management System (Section III.C) as the Gravity Core Database.

b. Accessibility

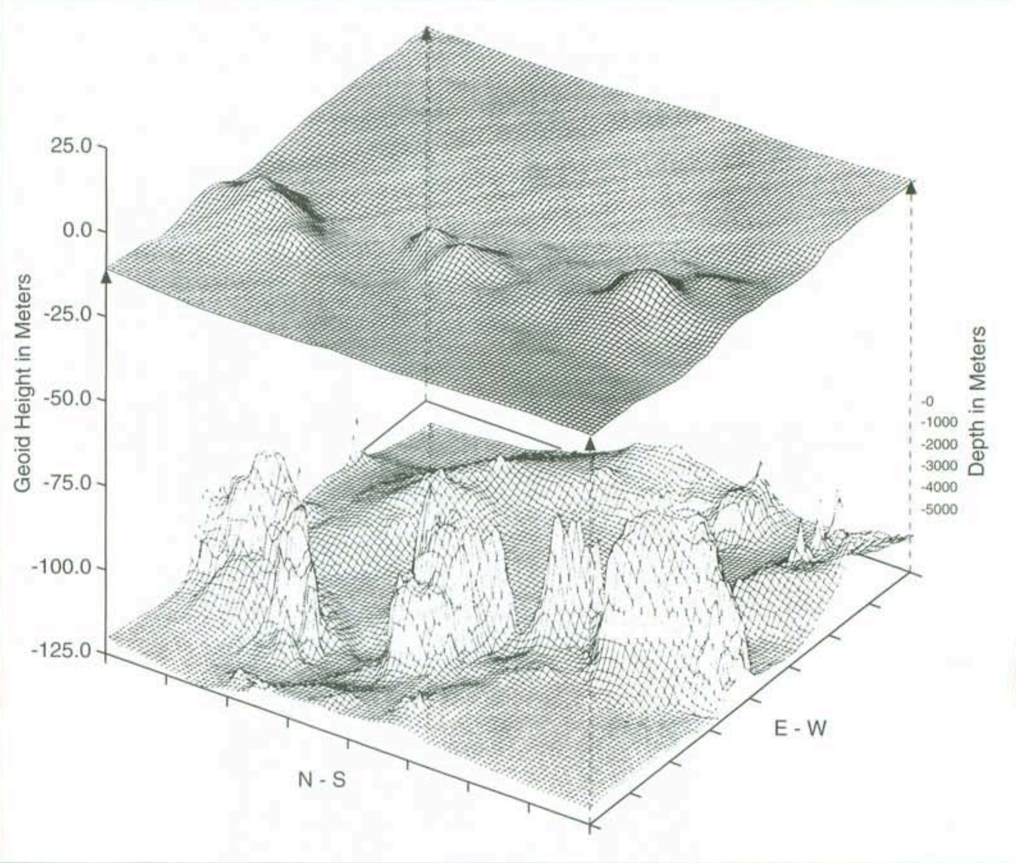
The Navy's ship board gravity data are normally classified because they reveal locations and dates of the ship tracks that might inadvertently release information about operational interests.

c. Scientific Utility

In the presence of a seamount the enhanced gravitational attraction of the seamount will cause the water overhead to pile up above the seamount, resulting in an anomaly in the geoid. A satellite altimeter can thus be used to map the seafloor from space in the same way a shipborne gravimeter can be used to construct a map of the underlying topography (Figure 7).

Unfortunately, the actual situation is not quite as simple as the foregoing would make it seem. Since late last century it has been known that mountains often have light "roots" that allow the mountain to be buoyed up in the fluid mantle in much the same way as an iceberg's keel supports the portion of the body rising above water (Archimedes' Principle). Viewed from far away, the dense mountain is compensated by the light root and the overall gravity anomaly is zero. Because a gravimeter on the ocean's surface is relatively close to the seamount, the

FIGURE 7. RELATIONSHIP BETWEEN GEOID AND SEAFLOOR TOPOGRAPHY



With satellites, the ocean surface's relative heights can be measured. The sea surface height has been shown to correlate with subsurface bottom structure.

This figure shows two very different data sets depicting different views of a small section of ocean.

At the bottom is a high-resolution shipboard measurement of bathymetry, with depths in meters, showing several prominent seamounts. Above this is the geoid of the same area, clearly showing manifestations of the same seamounts on Earth's gravity field. This effect is illustrated schematically in Figure 5.

gravitational attraction, which varies as the inverse square of the distance, is greater than the compensating attraction of the root, which lies deeper in the mantle, and a positive anomaly will be recorded.

This problem is further complicated by the strength of the lithosphere that overlies a more fluid mantle. When a small seamount is constructed by volcanism atop the lithosphere, the seamount is supported largely by the strength of the rigid lithosphere, and Archimedes' Principle never comes into play. The anomaly associated with such a seamount is quite large. However, as the seamount grows in size (or the lithosphere's strength decreases because of heating, for example), the seamount and surrounding lithosphere must obey Archimedes' Principle. Thus, the relationship between seafloor topography and gravity (or the geoid) becomes (spatial) wavelength dependent. Thus, the inference of gravity from topography or vice versa becomes ambiguous in the absence of other information. For example, as the seafloor ages and becomes sedimented and flat, it becomes impossible to infer gravity from seafloor bathymetry. In addition, the spatial relationships between topography and gravity near a volcanic ridge crest, where the lithosphere is very thin, are quite different than the corresponding relationship on more mature, thicker lithosphere.

We have identified three research topics where accessibility of the Navy's currently classified gravity data would lead to important scientific research.

i) Spatial Variations in Gravity at Mid-Ocean Ridges

Recently gravity data have been exploited in a bid to understand basic geophysical processes at mid-ocean ridges. Morphologically, mid-ocean ridges can be broken into at least two fundamentally different classes corresponding to fast-spreading and slow-spreading environments. Slow-spreading ridges are generally characterized by rugged topography and a spreading center bounded by steep mountains. Fast-spreading ridges, on the other hand, are recognized by muted topography and the absence of significant flanking mountain ranges. Detailed geophysical surveys at several locations have been used to propose that mantle upwelling, responsible for delivering melt to the seafloor, is focused at discrete points or plumes at slow-spreading ridges. Mantle flow at fast-spreading ridges, on the other hand, is often associated with proposed two-dimensional or *sheet* upwelling in the mantle. While gravity data inferred from Geosat and ERS-1 data have been used to address this problem in broad brush, sufficiently high-resolution data covering a large extent of the mid-ocean ridge simply have not been available. The release of the Navy's gravity data would greatly facilitate this fundamental research into the genesis of the bulk of the Earth's surface.

ii) Mapping of Crustal Thickness

The composition of the oceanic crust and its density variation with depth are remarkably constant throughout the oceans. Given this generally simple behavior and the significant differential in density between the crust and underlying mantle, gravity data can be used to infer the thickness of the crust and, hence, the depth of the mantle throughout the oceans. While allowing for the eventuality that variations in crustal density do occur, a detailed gravity data set can be used to discover regions of major variations in crustal thickness. For example, the availability of Geosat data south of 30° S clearly outlined an anomalous region of oceanic lithosphere south of Australia which is now called the Australia-Antarctic Discordance. The availability of more detailed gravity data throughout the Northern Hemisphere would provide an unprecedented opportunity for understanding variations in crustal thickness or variations in density that might masquerade as variations in thickness.

iii) The Structure of Fracture Zones

Transform faults are found at mid-ocean ridges where older and young lithosphere slide past each other and are frequently accompanied by earthquakes. The disrupted topography is known as a "fracture zone." The bottom topography and the differential in age across fracture zones in these regions lead to the introduction of loading effects and consequent flexure of the lithosphere. Gravity data collected across such fracture zones and parallel to the original direction of mid-ocean ridges provide important information on the long-term evolution and strength of the lithosphere. Again, the data sets currently available for studying this phenomenon are quite limited. The gravity data would provide the data needed for detailed studies of these processes in the Northern Hemisphere.

d. Findings

The findings relative to marine gravity are:

- The release of the Navy's high-resolution gravity data would greatly facilitate fundamental research into the genesis of the bulk of Earth's surface because of their unparalleled coverage, detail, and accuracy.

- Availability of detailed gravity data throughout the Northern Hemisphere would provide an opportunity for understanding variations in crustal thickness or variations in density that masquerade as variations in thickness.

- These gravity data would also provide the information needed for detailed studies of lithosphere processes in the Northern Hemisphere.

2. GEOMAGNETICS

a. Data Description

Geomagnetics is the science that deals with Earth's magnetism. Magnetic data that can be used to depict the geomagnetic field for any time and location can be used to improve the navigational safety of ships and aircraft of all nations. Because Earth's magnetic field is constantly changing, knowledge of magnetic compass corrections essential to steer a true course are necessary for safe navigation. Early sailors made these corrections by comparing the compass with the direction of the North Star. Today, ships and aircraft are guided by magnetic charts and improved geomagnetic data supplied by NAVOCEANO.

In addition, and for our purposes more importantly, geomagnetic data can be used in scientific studies of the evolution of the Earth's crust. The Earth's magnetic field results from flow in the planet's molten, iron core. The surface manifestation of this magnetic field is a dipole field with both a North and a South (magnetic) Pole. Furthermore, these poles have been, during much of the Earth's history, closely aligned with the spin axis of the planet; *i.e.*, the geographic North and South Poles. For geologists and geophysicists the magnetic field is interesting because the North and South magnetic poles have reversed themselves aperiodically throughout Earth's history; furthermore, rocks cooling from a molten to a solid state can record this ancient field. By mapping small anomalies in Earth's field, therefore, it is possible, by knowing the reversal history, to determine the age at which the rocks were formed through volcanic activity.

The Earth's magnetism is a vector field defined by both a magnitude and a direction. Neither the magnitude nor the direction of this field at a point remains constant in time. The Sun's solar wind causes daily, small variations in the geomagnetic field, and the field measured on the surface varies slowly over time, a phenomenon related to core flow and called "secular variation." This variation amounts to a few degrees in the position of the magnetic poles over the course of a century. Thus, the variation between the magnetic and geographic poles had to be mapped periodically in order to correct magnetic compass headings for true North. Because the magnetic field is horizontal at the magnetic equator and vertical at the poles, the angle of the field with respect to horizontal can be used to determine latitude. Historically this was particularly helpful when neither the stars nor Sun could be used because of weather conditions—a particular problem in the past two centuries for Arctic exploration.

Every few years the geomagnetic field at the surface is published in the current International Geomagnetic Reference Field (IGRF). **For the past two centuries, the U.S. Navy has been a major contributor to these important data. This historic contribution will come to an end this year.** While the advent of the Global Positioning System (GPS) has certainly lessened reliance on magnetic compasses for navigation, they have not yet been eliminated completely. Even apart from the important scientific applications of geomagnetism to be discussed below, we are, therefore, concerned that funding constraints associated with post-cold-war defense downsizing and changing mission priorities may not allow the Navy to continue this valuable public service.

At sea a magnetometer is towed sufficiently far behind a ship to avoid perturbations associated with the magnetic hull. The magnetometer measures the total field of the Earth approximately every 30 seconds.[3] When the IGRF is subtracted from the total field measured, the resultant anomalies (about 1% of the total field) reveal information about the past reversals of the field as recorded in the seafloor rocks. This information led to the geophysical discovery of seafloor spreading and the development of the theory of plate tectonics. In general, the Navy's holdings of shipboard magnetics data, largely in the Northern Hemisphere, is the most coherent, systematic, and complete of any survey ever conducted and, as such, is very important in understanding the past 200 million years of Earth history.

Figure 8 shows an example of a small section of Earth's magnetic field at relatively high resolution. The data shown in Figure 8 were measured by the Navy's Project Magnet aircraft in 1983 at an altitude of 500 feet and have an north/south track spacing of 3 nm with an along-track sampling of 0.25 nm. The magnetic data shown here depict the local field, with both the global field generated by Earth's core and the regional gradient field having been removed. The stripes on the seafloor represent reversals in the Earth's magnetic field and can be used to outline the detailed tectonic history of oceanic crust.

Although these data are from the wholly unclassified aircraft surveys of Project Magnet, they serve to illustrate the spatial complexity of such data and to suggest the quantity of geophysical information that is contained in the higher resolution classified NAVOCEANO ship surveys.

NAVOCEANO's magnetic data are currently stored in simple digital files without software to access or manipulate the data. However these data will be incorporated into the IDBMS before the end of FY 95. This database management system should provide better data accessibility for analyses. There is no existing gridded magnetics database, and constructing one would be a large effort because of the difficulty in reconciling the temporal and spatial variations. There is a plan to acquire scalar magnetic data from the Defense Meteorological Satellite Program (DMSP) S-15 satellite. These data could be used in conjunction with ship-measured scalar data to produce regional magnetic models.

b. Accessibility

Most NAVOCEANO aircraft and satellite magnetics data are in vector form and are unclassified, publicly releasable, and have been turned over to National Geophysical Data Center (NGDC) for public distribution. Virtually all of the ship-

[3] The strength of magnetic fields are today measured in SI units as Tesla (T), which is kg/amp/s^2. The Earth's magnetic field at the poles is on the order of 6 x 10^{-6} Teslas or 6 x 10^4 nanoteslas (nT). A previous measure, used prior to the adoption of SI units, is the gamma, which is equal to a nT.

FIGURE 8. MAGNETIC FIELD OF THE NORTHERN JUAN DE FUCA AND EXPLORER PLATES

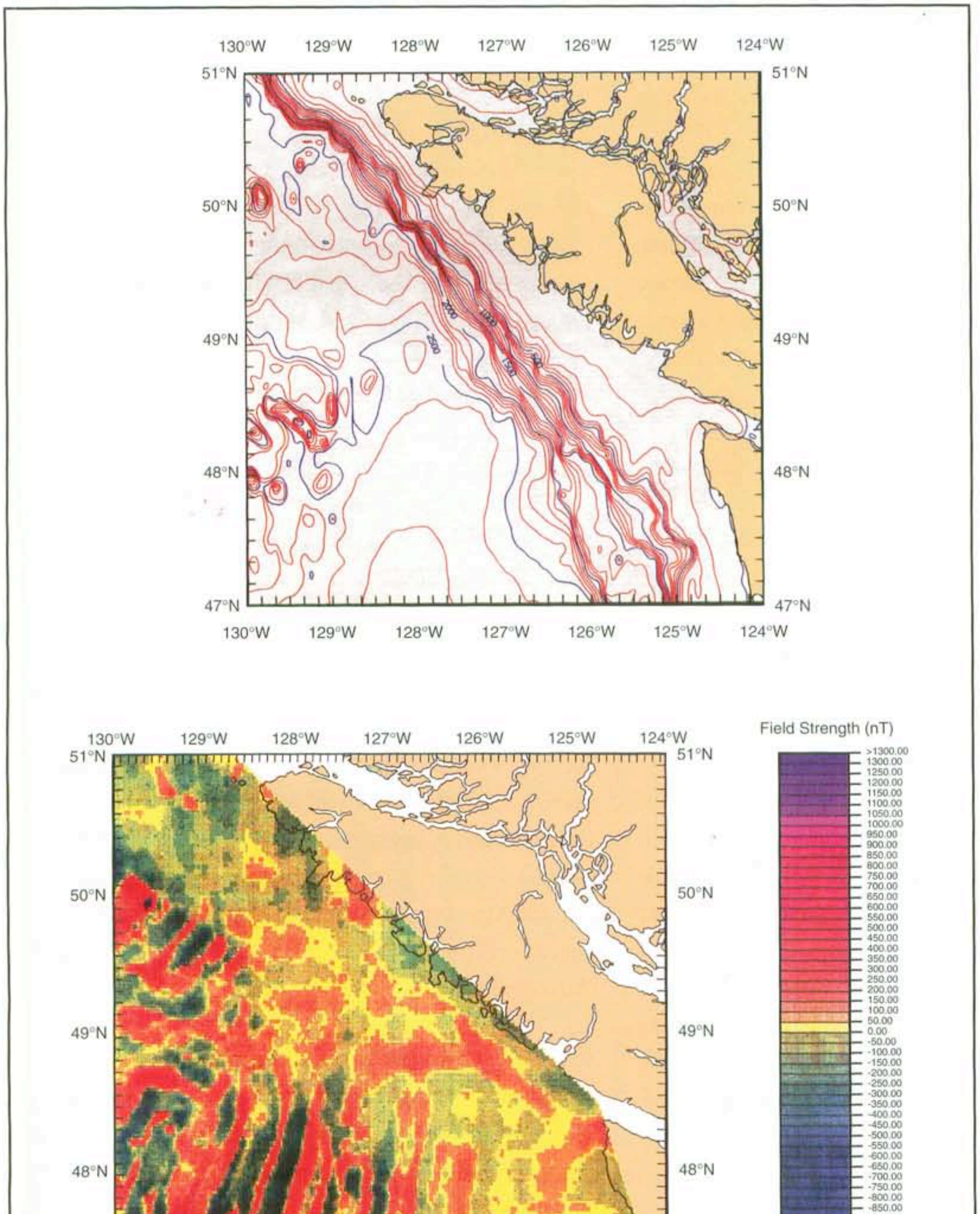


Illustration (bottom) shows the vertical component of magnetic field in the geologically complex Juan de Fuca area of the northeast Pacific (west of Seattle). The ocean area shown contains segments of both the Juan de Fuca and Explorer Tectonic Plates.

These data, from unclassified Navy aircraft surveys, illustrate the general appearance and spatial variability of high-resolution shipboard magnetic data.

The more intuitive quantity, bathymetry, is depicted (top) for reference, showing in the lower left, the northeast section of the Juan de Fuca Ridge and the north-west-southeast oriented continental slope.

collected geomagnetic data are scalar data that are classified. Because the scalar data are linked to locations and track lines, formal review is required to determine declassification policy, and very few of these data have been released.

As a result of post-cold-war changes in Navy mission priorities, the Magnetics Program will not be supported beyond FY 95 based on present fiscal plans of the Oceanographer of the Navy. To complete existing work, the Navy will finish production of the epoch 1995 World Magnetic Model (WMM), which was designed to meet DoD needs until the year 2000. Project MAGNET flights (500 hours per year) and the DoD Geomagnetic Library are funded through FY 95. However, the Navy plans to terminate its entire geomagnetic project by FY 96.

MEDEA is particularly concerned that magnetics data may be especially vulnerable to loss, and we feel it is essential that these data be protected. The collected geophysical data have many scientific purposes. Rapid release of the data to the academic community would solve the problem of continued viability. Experience shows that any database that is not regularly used is almost certain to disappear in short order. Unused data have a short shelf life because of the difficulties of adequately documenting and storing data for future use.

c. Scientific Utility

Access to dense, marine magnetic surveys would be extremely valuable to the geophysical community in several important scientific applications.

i) Improvements in the Accuracy of Plate Tectonic Reconstruction

The data-dense magnetic surveys can be used to place more accurate constraints on the age of the seafloor. Combined with the recently available satellite radar bathymetry (Geosat and ERS-1) measurements, magnetic survey data will make it possible to increase the precision of calculated plate reconstruction rotation parameters including finite rotations associated with the long-term evolution of the Pacific and Atlantic. These rotation parameters are the foundation of most plate tectonic studies.

ii) Analysis of the Jurassic and Cretaceous Quiet Zones

The origin of the magnetic quiet zones, which encompass large areas of the ocean floor, is still unknown. Analysis of dense magnetic surveys would be very helpful for evaluating various proposed models. One idea that could be tested, with fundamental implications for geomagnetism, is that the Jurassic and Cretaceous Quiet Zones have different origins. The Cretaceous Quiet Zones may represent a period of time when the field intensity was strong but the polarity was not reversing, while the Jurassic Quiet Zones may represent a period of time when the field was reversing very rapidly but the intensity was low. High-resolution magnetic surveys could test this idea.

iii) Origin of Intermediate Wavelength Crustal Anomalies

One of the most poorly understood aspects of the crustal magnetic field data is intermediate wavelength anomalies of roughly 500-3,000 wavelengths in size. Anomalies at these wavelengths have been identified in satellite magnetic fields, but their source within the crust (and even their existence) has been difficult to establish and is a matter of debate. There is currently a mismatch in the amplitude of these anomalies by about a factor of two, when sea surface observations are extrapolated for comparison with satellite observations (*e.g.,* NASA MAGSAT). It has been suggested that these differences are caused by satellite altitude errors combining to attenuate the magnitude of an average vector of component data, but they are more probably due to assumptions about interpolation implicit in the upward continuation process. The resolution of this question is important not only in determining the size of intermediate wavelength magnetic anomalies, but also in deciding what can be resolved from magnetic satellite data. Current sea surface data sets suffer from inadequate secular variation corrections because of their irregular temporal and spatial distributions, complicating comparisons between surface and satellite observations. The good temporal and spatial resolution of the Navy data could allow resolution of the source of these ambiguities.

iv) Geomagnetism and Earth's Core

The magnetics data collected by the Navy were collected over several decades while the secular (long-term, indefinite duration) variation in Earth's field changed significantly and a series of International Geomagnetic Reference Fields (IGRF) were developed to allow the study of anomalous variations in the field. The detailed, well-navigated, well-calibrated surveys conducted in three dimensions (x, y, t) should provide a database currently unequaled for understanding the details in the evolution of the main geomagnetic field. This information will, in turn, constrain estimates of the flow in the fluid core and interactions between the core and the mantle at the core-mantle boundary.

d. Findings

The findings relative to geomagnetics are:

- Data from the Navy's magnetic surveys could be used to constrain the age of the seafloor, and, combined with satellite radar altimetry measurements, make it possible to refine plate reconstruction rotation parameters, including finite rotations associated with the long-term evolution of the Pacific and Atlantic oceans.

- The availability of high resolution magnetic surveys would help scientists to evaluate various proposed models of plate tectonics.

- The good temporal and spatial resolution of the Navy surface-level magnetic data could better define the source of the ambiguities in intermediate wavelength data from satellites.

- These detailed, well-navigated, and well-calibrated three dimensional measurements should provide a unique database for understanding the details in the evolution of Earth's main magnetic field.

3. GEOSAT ALTIMETRY

a. Data Description

Over the past decade, satellite altimetry has had a considerable impact in the earth sciences. Spacecraft use pulse-limited radars, along with very accurate orbits, to measure the topography of ocean, ice, and land surfaces. Over the ocean, the radar pulse interacts over a wide footprint (3 km) effectively averaging out the surface waves so that small variations (3-5 cm) in sea surface topography can be mapped. Over rougher surfaces such as ice and land, the precision of the topography measurements degrades to several meters. These data have created new fields of research in geodesy, glaciology, marine geology, geophysics, and physical oceanography.

The small bumps and dips in the ocean surface (0.03-10 m) follow the equipotential surface of Earth's gravity field, or geoid, so satellite altimeter measurements of sea surface topography can be used to recover marine gravity anomalies. At short wavelengths (<200 km), the gravity field mimics the seafloor topography. Thus, satellite altimeter data provide important reconnaissance information over vast areas of largely uncharted seafloor, such as the Southern Ocean and Antarctic Margins.

Figure 9 shows a sample color shaded relief image (at left) of sea surface gravity anomalies over the Southwest Indian Ridge south of South Africa derived from declassified Geosat/Geodetic Mission (GM) and other altimeter data. The right-hand image in Figure 9 is a color shaded relief image of seafloor topography *predicted* from the data in the left-hand image along with available shipboard depth soundings. Both images are illuminated from the southeast.

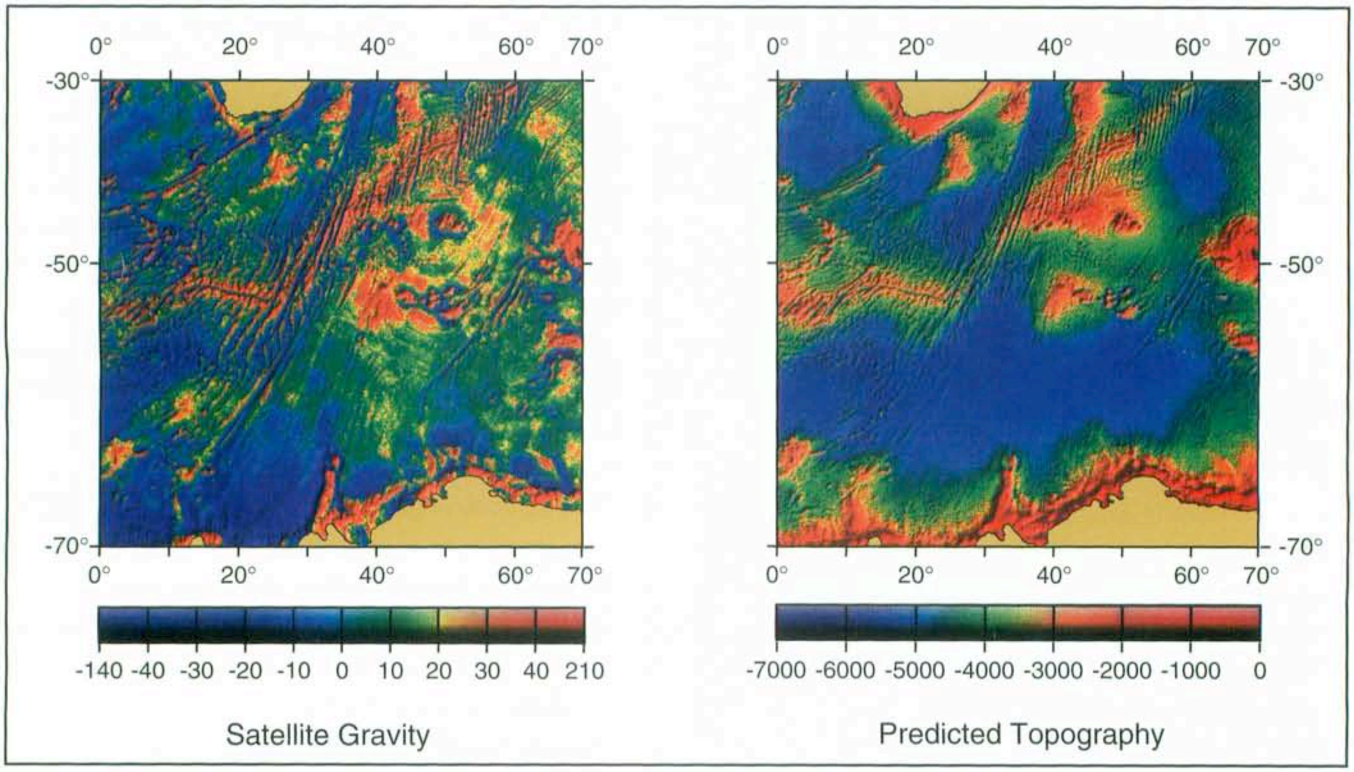
Satellite data quality (1-2 mgal on a 10-15 km wavelength) is currently considered to be better than the standard regional type of survey that was run in the previous 25 years by oceanographers and oil explorers (1 mgal of acceleration is about 10^{-6} times the pull of gravity). However, the quality is not as good as the new high-resolution data that are being collected in the oceans today, or as good as the new gradiometer data obtained from the Navy system at sea. The new high-resolution data and the unclassified gradiometer data have an accuracy of about 0.1 mgal on a 500 to 1000 meter wavelength thanks to the availability of high-quality GPS data.

Individual Geosat profiles have a precision of about 6 mgal and along-track resolution of 30-50 km. The close spacing of the profiles (4 km) supports a cross-track resolution that is better than the along-track resolution. This redundancy enables one to construct a two-dimensional gravity field having equally good resolution in all directions (25 km full-wavelength).

b. Accessibility

The Geosat altimeter was launched by the U.S. Navy in March 1985 and provided data until October 1989. Its primary geodetic mission was to map the marine gravity field at a high spatial resolution on a global basis. Because of their military value at the time, most of the data collected during the first 18 months of the mission remain classified, although data from the Southern Ocean (south of 30°S) were declassified in 1992. Some limited results based on the still-classified data have been published by those having access.

FIGURE 9. GEOSAT MEASURED SEA SURFACE GRAVITY ANOMALIES AND PREDICTED SEAFLOOR TOPOGRAPHY IN THE SOUTHERN INDIAN OCEAN



Large scale features of Earth's sub-surface structure are revealed through the use of altimetry measurements from space.

The left figure illustrates Geosat geodetic repeat mission data south of 30° S that has previously been declassified. At right is a depiction of seafloor topography derived from these Geosat altimetry data. Comparison with shipboard bathymetry data would show a high degree of correlation between the directly measured (ship) and inferred (satellite) bathymetry.

c. Scientific Utility

Geodynamic applications of the satellite altimetry data include:

- Location of uncharted features for planning detailed shipboard surveys and improving bathymetric charts;
- Investigation of seafloor morphology and isostasy;
- Identification of fracture zone trends for improving plate reconstruction models;
- Determination of the global distribution and loading histories of undersea volcanoes;
- Location of marine sedimentary basins for hydrocarbon exploration;
- Constraining shallow mantle convection processes including those beneath mid-ocean ridges.

A review of the available unclassified and declassified data suggests that additional altimetry from either Geosat or European Space Agency ERS-1 coverage will lead to a major improvement in the resolution of the marine gravity field, especially in the low latitude regions.

In July 1991, the European Space Agency launched the ERS-1 spacecraft into a high inclination (98.5°) low altitude (780 km) orbit similar to the Geosat orbit. While its primary mission is to collect synthetic aperture radar (SAR) images, it also carries a pulse-limited radar altimeter that is similar in design to the altimeters aboard Seasat and Geosat. In April 1994, ERS-1 began a geodetic mapping phase along a dense 168-day repeat ground track. Two 168-day missions have been completed by ERS-1 and it is now possible to "see" any features that are "seen" in the Geosat GM data, as the measurement precision and spatial resolutions of the two data sets are similar.

If the Geosat GM data were declassified, the ERS-1 and Geosat data could be combined to improve the resolving power slightly beyond the capabilities of either data set alone. Declassification of Geosat GM data would be particularly beneficial in the equatorial regions, for several reasons. First, the ground track spacing of the orbits is largest at the equator, and hence the resolving power of the data sets is least. Second, the ERS-1 orbit is more polar than Geosat, so that at the equator ERS-1 is not expected to resolve the east component of gravity as well as the north component of gravity. Third, there are a number of important outstanding scientific problems in this area.

In addition to the value of Geosat data for inferring marine gravity fields, the Geosat GM data are important in studying global change. The GM data were acquired during an important time in the El Niño cycle. The release of the GM data would extend the range of time available for studying the seasonal and interannual sea-level changes and allow better calibration of long-range forecasting models. The release of the raw GM data would allow the calculations of sea level change between GM and ERS-1 or Topex/Poseidon.

d. Findings

The findings relative to Geosat Altimetry are:

- It is evident that there will be significant improvements in the accuracy and resolution of the marine gravity field north of 30°S if Geosat classified high-track-density data become available. Such availability would support a variety of geodynamic applications.

- The availability of the Geosat data will extend the range of time available for studying sea level changes that are possibly associated with the El Niño cycle.

4. SEAFLOOR SEDIMENT PROPERTIES

a. Data Description

The academic community does not have a complete, comprehensive, digital database of sediment thickness and sediment type. The Navy has developed such a database and has incorporated it in a sea-floor acoustic reflection loss model, Low Frequency Bottom Loss (LFBL). The global sediment properties database has been derived from a variety of classified and unclassified sources, including open ocean survey operations and seafloor measurements (cores and reflection profiling) taken in shallow waters around the world, as well as use of coring data from the Deep Sea Drilling Project (DSDP), the International Program of Ocean Drilling, and the Ocean Drilling Program. In addition, the Navy has databases containing a variety of information about sediment subsurface structures (*e.g.*, salt domes) that are also unique.

Figures 10 and 11, taken together, present both global scale (Figure 10) and regional scale (Figure 11) representations of surface sediment type and sediment thickness on the seafloor. These figures illustrate the quality and coverage of some of the data types currently available in the Navy's unique global seafloor sediment properties database.

b. Accessibility

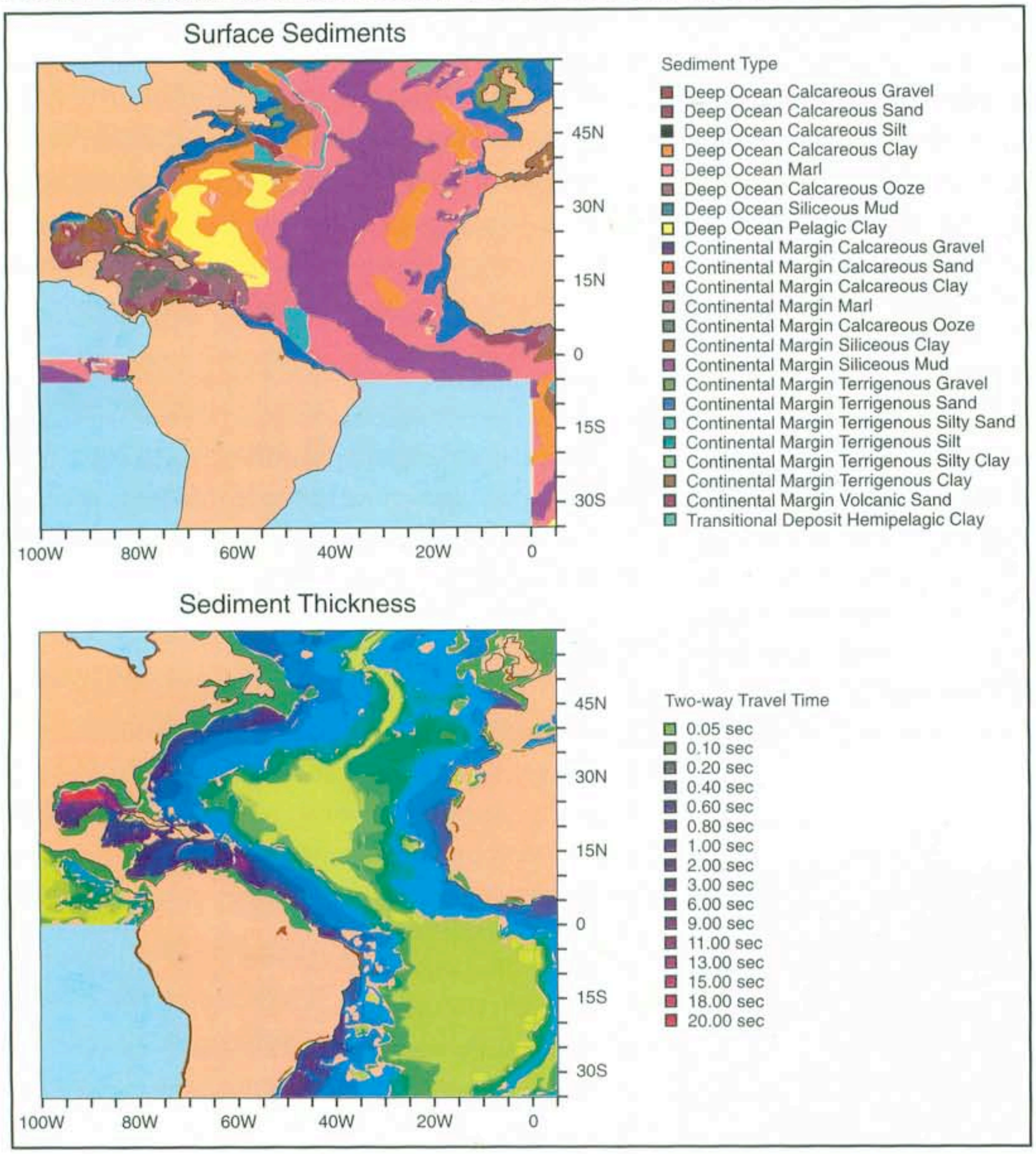
The LFBL acoustic reflection loss model, which was the Navy's rationale for developing the sediments database, is actually composed of two distinct parts: a database of geophysical and acoustic parameters over seafloor regions, and an acoustic model, which calculates acoustic bottom loss for selected frequencies across a full range of acoustic grazing angles. The data in the first LFBL construction were derived from unclassified sources. Further refinement and data additions by NAVOCEANO led to the classification of the LFBL. MEDEA's major interest is in the sediment thickness and sediment type sub-files. Although unclassified, the LFBL sediment thickness and sediment type files have not been distributed outside the Navy's oceanographic/acoustic community.

The Navy also maintains a Geological Laboratory database of site specific bottom cores and grab samples. This database has both restricted and classified content.

c. Scientific Utility

The release and unrestricted distribution of the sediment databases, including the thickness and sediment type parts of LFBL and other databases containing information about subsurface structures, would provide the academic community

FIGURE 10. EXAMPLE OF SEAFLOOR SEDIMENT TYPE AND THICKNESS DATA



The seafloor was characterized by the Navy on a global basis, primarily for use in acoustic (sonar) models.

This figure shows an example of the sediment types and sediment thickness (expressed as seconds of two-way travel time) for much of the Atlantic Ocean.

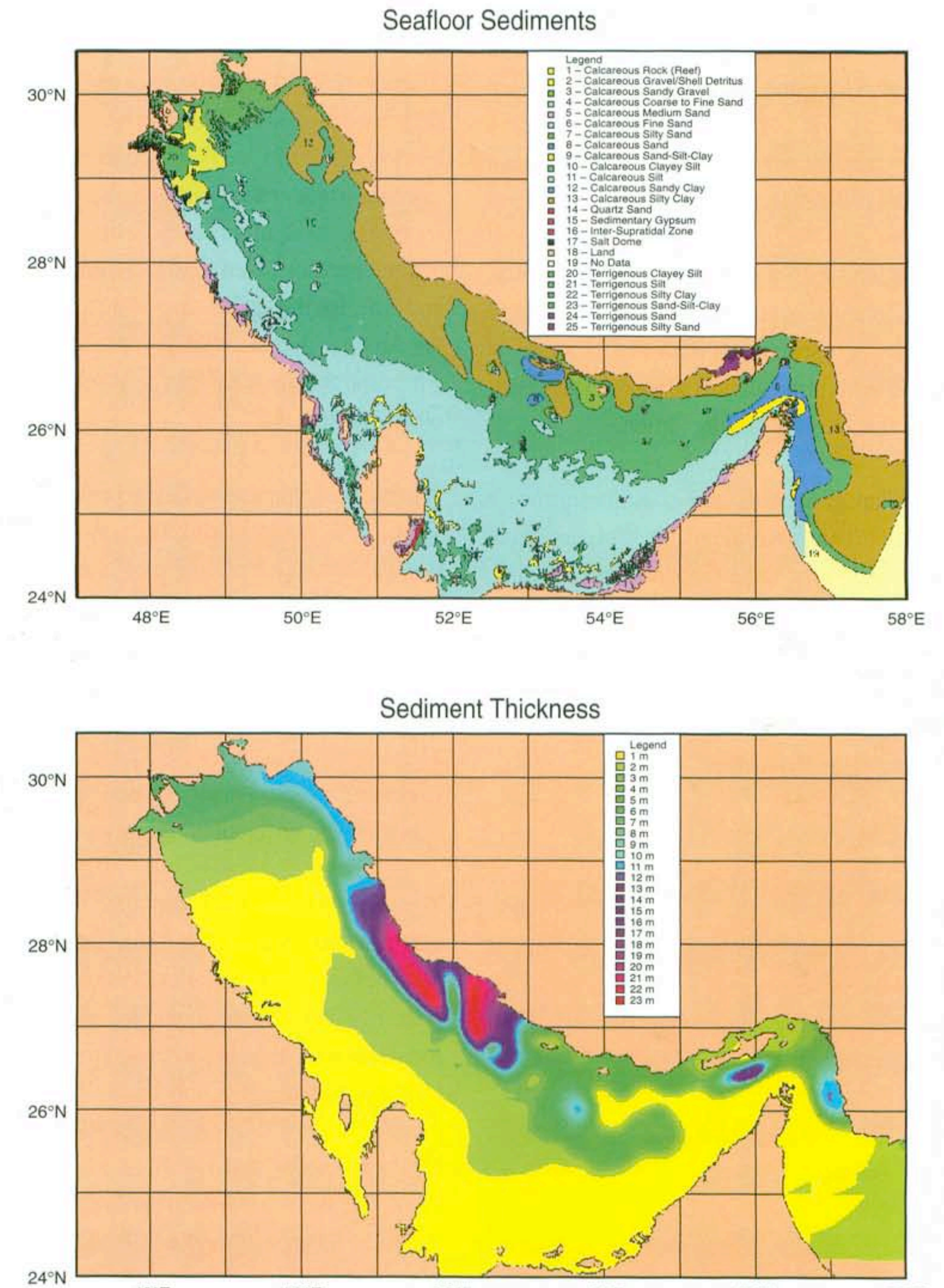
The mid-Atlantic ridge is seen in both illustrations, but most plainly in the region of very thin sediments (≤0.05 sec). Also to be noted is the small region of very thick sediments of the Mississippi Fan, a portion of which was seen through the "lens" of gravity data in Figure 6.

with its first, albeit somewhat limited, global database of sediment characteristics.

Applications of interest include the construction of much more accurate geological maps of the seafloor, providing an environmental baseline and guide to the distribution of natural resources. The descriptions of the physical composition and grain size distribution of the sediments contained in the Navy data could help to significantly improve our understanding of the occurrence of sub-bottom features such as salt domes. Distribution of sediments will also allow research scientists to study in greater detail seafloor processes such as deposition and erosion of sediments by ocean currents.

We anticipate that the quality of the data across this database to be quite variable, but the availability of this global compilation would provide a starting point and background for further refinement. Data from the Ocean Drilling Program and other coring programs were incorporated in the initial configuration. As similar data become available these data can be added and the database improved and expanded beyond its use as an acoustic model subcomponent.

Figure 11. Regional Illustration of Sediment Type and Sediment Thickness



In selected regional ocean areas, the detail of sediment data in the Navy's database is increased and there is content more specific to each area.

Shown here is the Persian Gulf. Like many ocean areas in proximity to land having low relief, the sediment in the Persian Gulf is seen to be very thin (<5m) except near the outflows of rivers, where thicknesses are ≥ 20m. In this figure unconsolidated sediment thickness is given in meters.

Given the detail depicted in this figure, it is important to remember that the civilian community has no digital database on a global or regional basis of seafloor sediment properties that approaches this level of detail.

The Navy's classified collection of bottom sediments and cores available in a relational database could augment the Ocean Drilling Program worldwide data set. Applications of interest include the construction of highly accurate geological maps to provide an extension of onshore mapping, an environmental baseline, and a guide for natural resources exploration. The descriptions of the physical composition and grain size distribution of the sediments could help commercial users locate oil-saturated sediments, locate titanium and manganese deposits, and map salt domes, which can act as petroleum traps or influence migration pathways. Composite records of the distribution of sediments (like the LFBL sediment thickness data) could assist in the study of sea bottom processes such as current activity, erosion, and deposition.

The thickness of sediment deposits near coastlines provides important constraints on the nature of the evolution of continental margins that are subject to the same thermal decay, loading, and elastic flexure as the seafloor. Seismologists observe low frequency surface waves that propagate across the ocean basins and continental margins, but do not have access to global maps of sediment thickness to use in estimating its effect on the dispersion characteristics of the modes.

d. Findings

The findings relative to seafloor sediment properties are:

- The Navy's global ocean sediment thickness database is unclassified, though it has not been generally accessible. Its value and uniqueness strongly support the conclusion that it should be publicly distributed.

- The associated seafloor sediment type database should also be made publicly available.

- The bottom sediments data can be of use to geophysicists for studies of the solid earth, including investigations of seismic wave propagation.

- Geological maps constructed with these data as well as extensions to onshore mapping can provide data for environmental business, natural resource exploration, and paleo-productivity assessments.

C. SEA ICE

1. HISTORICAL ICE MORPHOLOGY

a. Data Description

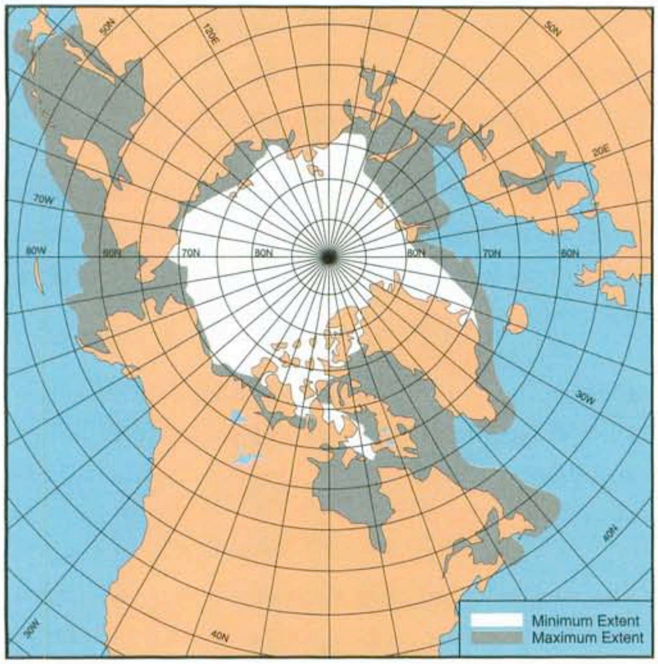
Temporal records of Arctic ice extent, ice type, ice drift, and ice draft are collected and stored in Navy classified archives. The Navy's interest in ice is related to its operations at northern latitudes where sea ice can be both a hazard and a haven. The ice provides both an optical and acoustical cover for submarines, and the operation of surface ships is constrained by ice boundaries and drift. Ice thickness is important for submarine operation in the Arctic region since under-ice safety is related to knowing where the thinner ice might be found or where deep ice keel obstructions exist.

A particularly impressive data set available at the National Ice Center (NIC) is a detailed historical analysis of sea ice conditions over the Arctic Outer Continental Shelf. This data set provides a decade of ice observations prior to the launch of LANDSAT in 1972 and is the result of an inventive compilation from a wide variety of data sources. There is an excellent chance that this data set is superior to any compiled set available elsewhere. These data exist in the form of hand drawn charts exhibiting ice edge and ice condition information compiled from a variety of classified and unclassified sources.

Figure 12 (unclassified) shows the minimum and maximum extent of ice edges. The Navy's classified Historical Ice Morphology charts cannot be shown here, but their contents are primarily depictions of the ice edge and ice conditions (concentration, type, etc.) in hand-drawn chart format with a temporal granularity of one week.

The well-known mean drift of Arctic ice is illustrated in Figure 13. Arrows represent the direction of the ice drift across the Arctic Basin, with the speed being proportional to the length of the arrow. This Arctic ice drift, combined with the seasonal effects of warming/cooling and variable snow cover, will require much more granularity for depicting ice conditions, should scientific research into topics like climate warming be initiated.

Figure 12. Maximum and Minimum Extent of Ice Edges



The extent of the Arctic ice cover undergoes a large seasonal fluctuation, between an average of about 16 million square kilometers in winter (March) to 8 million square kilometers in summer (August). Year to year variations are large in specific sectors, but averaged over all longitudes, they are only a few percent.

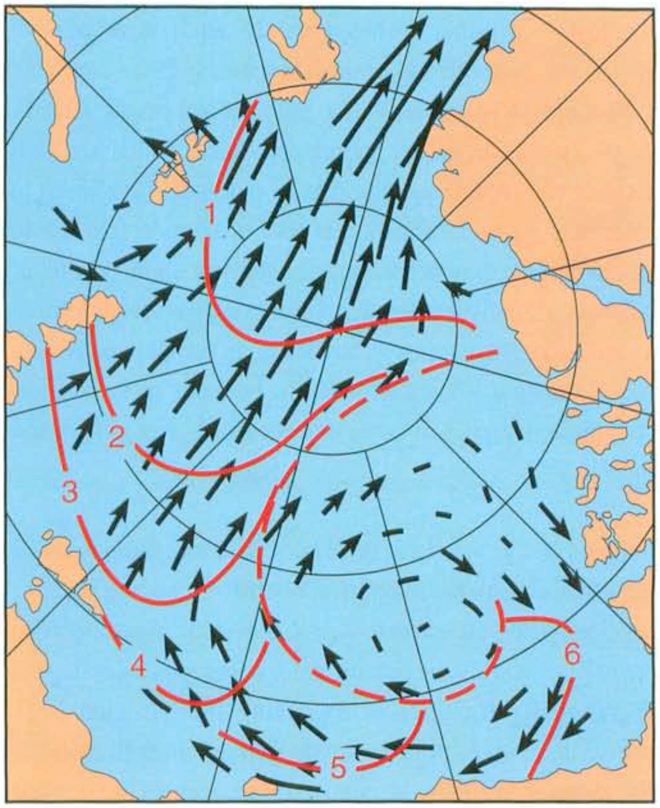
The northernmost position of the Arctic sea ice edge at each longitude is shown in white for summer and grey for winter.

The Navy's Historical Ice Morphology data are a refinement of the long term averaged view shown here, and include information about ice conditions and composition on finer spatial and temporal scales.

b. Accessibility

Most of the Navy's best historical ice morphology data for the Arctic are classified today. A closer review is needed to determine how this data set could be made more accessible. Although NIC does not provide direct project support to non-governmental organizations, the primary NIC unclassified derived product (the bi-weekly global sea ice assessment) is available to the general public via computer file transfers. NIC also indirectly supports a variety of private activities such as the sea lift resupply of communities along the North Slope of Alaska and winter fishing fleet operations in the Bering Sea.

Figure 13. Average Annual Ice Drift in the Arctic Basin



Ice drift direction and speed data are represented by vectors.

Arrows represent the direction of ice drift across the Arctic Basin; the speed is proportional to the length of the arrow. The ice movement "fronts" are shown in yearly intervals.

Solid lines labeled 1-6 indicate the likely number of years that ice will survive before it exits the Arctic Ocean through the Fram Strait (between Greenland and Spitzbergen) or melts in the warm water near the coast during summer.

c. Scientific Utility

The sea ice cover of the polar regions exhibits complex interactions and feedback that affect both local Arctic climate as well as the climate of more distant, inhabited temperate regions of the globe. Both the extent and the thickness of sea ice are believed to be particularly sensitive to subtle changes in climate, a sensitivity that is believed to be particularly important over the outer continental shelves of the Arctic. Also, model calculations for a wide range of greenhouse warming scenarios predict the poleward amplification of climate change, which should be accompanied by a reduction in the sea ice cover.

To date, the prediction of significant changes in the ice cover has not been borne out by measurements. However, this conclusion is primarily based on the analysis of passive microwave data collected by satellite sensor systems, which are limited in both spatial resolution and temporal extent. Clearly the Navy's historical ice morphology data, which are both detailed and predate satellite data by a decade, have much to offer here. This information is also of considerable use to climatologists; to scientists studying the near-shore transfer of pollutants; to individuals studying near-coastal sea ice dynamics, as well as polynya (open water "leads" in the ice) and bottom water formation. These data could also be important to modelers carrying out studies of processes occurring over continental shelves.

It should also be noted that the historical ice morphology charts are also of considerable importance both to groups interested in developing coastal sea routes across the Arctic region between the Atlantic and Pacific oceans, and to companies assessing the operational difficulties of extracting the assumed large petroleum reserves from the Arctic Shelves. In both cases the Navy data would allow an improved assessment of hazards and trends.

Finally, the Navy data should prove invaluable to individuals investigating primary production in the food chain over the Arctic Shelves. Although the Arctic region has for many years been assumed to be biologically barren, recent evidence suggests that this is particularly not true over the continental shelves. Indeed the ice edges in the Bering and Chuckchi seas are proving to be areas of intense biological activity including important fisheries. The improved data on the variability of shelf ice conditions should definitely contribute to the analysis of observed variations in biological stocks over the Arctic Shelves. For instance, in the Bering Sea research suggests that there are direct relations between ice conditions and oceanographic factors that favor the survival of juvenile stocks of important varieties of fish.

With respect to these scientific questions, it is not the current realtime products of the National Ice Center that are of prime importance. Instead it is the accumulated historical database of global sea ice information. It is important that the release of this accumulated historical database be continued through the National Snow and Ice Data Center (NSIDC).

d. Findings

The findings relative to historical ice morphology are:

- The reanalysis of the Ice Morphology data set, currently underway at the NIC, should be completed with consideration given to releasing a sanitized form of the final product as an unclassified data set.

- Classified holdings of accumulated historical sea ice information in the Arctic region, if released, would contribute significantly to the inventory of available data and facilitate climate and ocean thermal studies in a significant way.

- This information would be of considerable use because it is an "undiscovered" historical record that will fill gaps in studies of ice/water thermodynamic and hydrodynamic processes and transport.

- The pre-LANDSAT data should be digitized and a means sought for its release in an unclassified derived product.

- A separate, classified ice morphology archive at NAVMETOCCOM should be retained. This archive would contain additional high-resolution analyses obtained from classified sources.

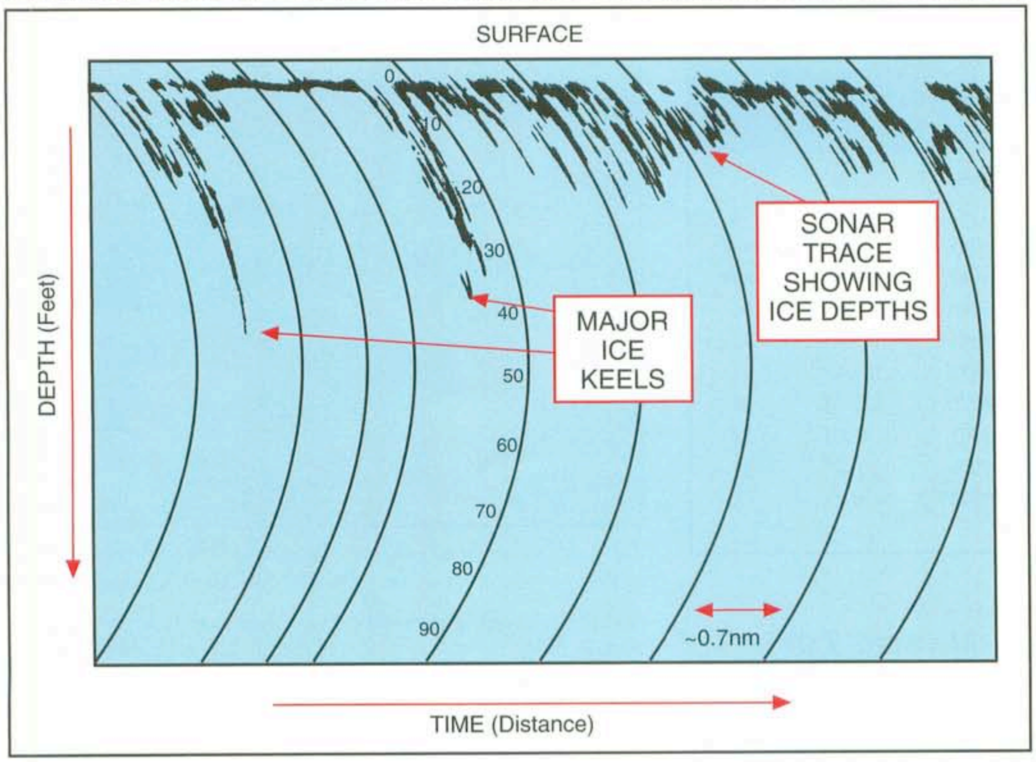
2. ICE KEEL DEPTH ACOUSTIC DATA

a. Data Description

The only reliable methods of obtaining extended profiles of ice keel drafts (depths), and by implication, ice thickness, are upward-looking, narrow-beam sonars (ULS) mounted on submarines (Lagrangian data), or mounted at the top of subsurface floats moored to the seafloor (Eulerian data). Methods to deduce ice thickness from parameters observable by satellite are in an experimental stage and will, in any case, yield regional or average thicknesses and "ice type" rather than data with the high spatial resolution of the sonar method.

Submarines have been acquiring sonar ice draft data since the first Arctic crossing by Nautilus in 1957. In assessing the

FIGURE 14. EXAMPLE OF A SUBMARINE UPWARD-LOOKING SONAR RECORD FROM SEPTEMBER 1993



Paper strip charts from analog recorders generated during an under ice experiment show the variations in ice keel depths in the central Arctic region. Several major ice keels extend about 30-40 feet below the surface.

The horizontal scale is actually time, but given the ship speed from ship's logs it also represents distance traveled under the ice. In the case shown the major horizontal division is approximately 0.7 nautical miles.

This example has been declassified by the Navy through omitting certain details that would be necessary for scientific use, including some level of detail in location and time.

scientific value of these data it should be borne in mind that their primary purpose has been to avoid obstacles (icebergs and deep pressure ridge keels) and locate thin ice for surfacing. Moored sonars have been placed entirely in the service of scientific research, but they have been in operation only during the past four years.

Between 1957 and 1975, the submarine sonar data were recorded in an analog mode. Starting in 1976, a digital recording system was added to the analog recorder on a number (but not all) of the cruises. The advantage of the digital system, which is referred to as DIPS (Digital Ice Profiling System), is that it greatly facilitates analysis of the data after the cruise has been completed. The reason that the analog system was retained was that it provided the crew with realtime information on the position of the bottom of the ice overhead. Figure 14 shows an example of these analog recordings.

There is a large inventory of analog data that has not been reduced from the original paper strip chart format (Table 5). Accompanying these data are the associated records of location, time, depth, etc. necessary to process the data into a scientifically useful series of ice keel depth data points at specified locations.

From detailed discussions with the Navy concerning these data, we have concluded that the analog records could produce mean ice draft that would be accurate to within ≈ 0.5 m; a value that would be similar to the results of the analysis of the DIPS data. In addition, since both analog and DIPS data exist on a number of cruises, a quite exact estimate can be obtained of any systematic differences between these two data sets as used on exactly the same ice. These analog results would therefore also yield valuable information on keel depths and distributions.

The current data holdings (including the DIPS data) are from slightly more than 50 deployments comprising approximately 1,800 days under the ice and 380,000 nm of ice information (Table 6). Almost all cruises up to and including the present have analog records of the sonar information while only 20 cruises have DIPS data, 4 of which had major recording problems and are not useful, and 12 of which have been preprocessed.

b. Accessibility

Except for the five earliest cruises (*e.g.,* the Nautilus cruises) all of the Navy's raw ice keel sonar data remain classified because the complete records necessarily contain submarine tracks

Table 5. Existing Analog Submarine Ice Keel Draft Acoustic Data

YEAR	TRACK MILES OF DATA	NO. PAPER RECORD ROLLS	YEAR	TRACK MILES OF DATA	NO. PAPER RECORD ROLLS
1957	0+	9	1982	9,198	71
1958	2,463	17	1983	13,916	104
1959	3,090	31	1984	19,900	Undet
1960	6,003	57	1985	12,200	Undet
1962	0+	69	1986	17,085	166
1967	1,075	7	1987	11,478	79
1969	9,551	75	1988	10,649	88
1970	6,286	94	1990	11,476	75
1973	1,806	45	1991	3,989	25
1975	0+	63	1993	0+	23
1979	9,139	65	1994	0+	16
1981	7,503	37			

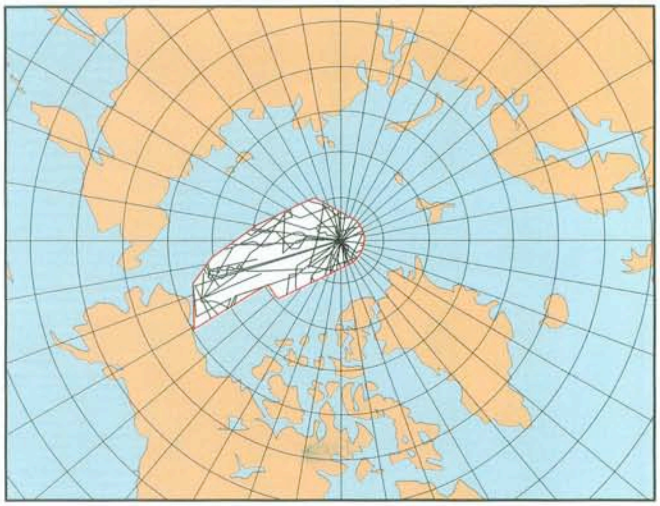
Table 6. Existing Digital (Magnetic Tape) Records of a Submarine Ice Keel Draft Acoustic Data

YEAR	NAUTICAL MILES	YEAR	NAUTICAL MILES
1976	7,641	1988	15,396
1977	11,425	1989	3,614+
1978	8,498	1990	12,063
1982	7,837	1991	14,342
1984	8,072	1992	15,231
1985	69,621	1993	11,673
1986	20,321	1994	9,098
1987	20,324		

under the Arctic ice, which have operational sensitivity. However, as these events age, the security concerns diminish and the Navy has openly discussed some Arctic cruises like that of the Nautilus, and papers have been published using such data.

Certain classified aspects of under ice data sets could be preserved while still providing the environmental community with data that retain their usefulness. Although no raw data are likely to be declassified soon, the Navy has agreed[4] to provide, in unclassified form, all existing submarine ice exercise acoustic data taken within the geographic area shown in Figure 15. This figure also shows a depiction of previously released submarine tracks through 1982.

Figure 15. Data Release Area and Historical Submarine Tracks



This figure shows the boundaries of the area approved by the Navy (CNO) in 1992 for release of environmental data from Arctic submarine exercises. Also shown for this area are the submarine tracks of Arctic ice exercises through 1982.

Present Navy policies require that in order to be released, acoustic ice data lying within the designated area shown in Figure 15 can be released only if the associated positional data have been coarse grained in time and space. We have examined this matter within context of the coarse graining parameters specified by the Navy and see it as no impediment to full scientific exploitation of the data. For future scientific Arctic cruises, data release has been approved for the slightly larger area shown in Figure 16.

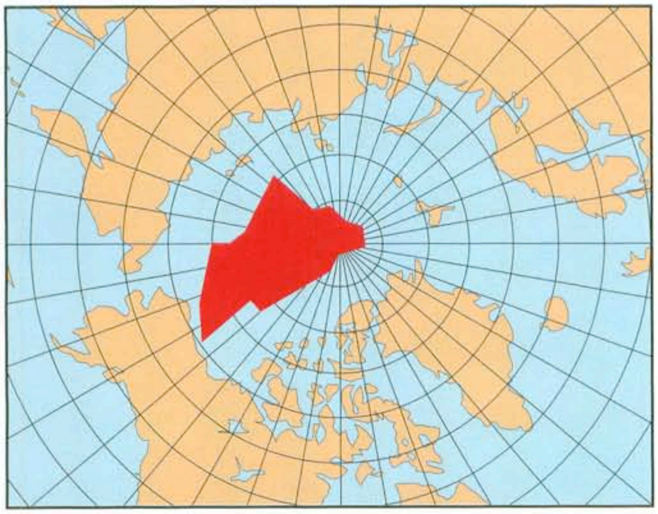
c. Scientific Utility

Since Nansen's Arctic journey, drifting ice camps of various sorts have been in operation for approximately 100 station-years. Ice thickness observations obtained by drilling holes or measuring ice freeboard have established an average ice thickness in the central Arctic region of about 3 meters, with a large variance on small spatial scales. However, from these physical, location-specific data, over the past century no discernible secular trend has been documented.

Submarine ice profiles are a valuable data source for ice draft and ice process studies. The spatial and the temporal coverage that these data supply is important for investigations studying both large- and small-scale variations and trends in the state of the ice pack. From the data that are eligible for release, one

[4] The scientific community has yet to "test" this policy with new data requests.

Figure 16. Area Approved for Release of Future Arctic Data



This figure shows the boundaries of the area approved by the Navy for release of environmental data from future Arctic submarine exercises.

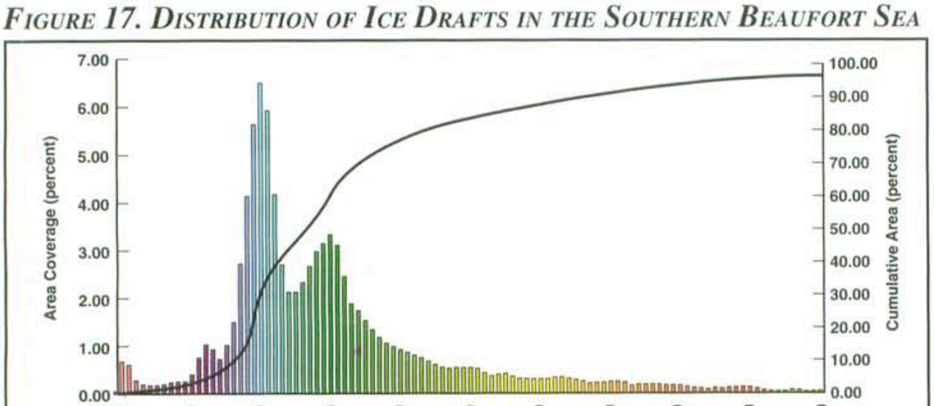
could hope to develop seasonal distributions of ice thickness extending over many years and covering important sections of the Arctic basin.

The Navy's ice draft acoustic data could also prove valuable in developing and assessing methods for estimating ice thickness and especially, ice thickness distribution, by satellite and aircraft remote sensing (*e.g.*, ERS-1 and Radarsat). For example, many synthetic aperture radar images exist over the Arctic region, especially the Beaufort Sea. Efforts to use these images to estimate sea ice thickness are hampered by the lack of calibrated surface measurements. The Navy's ice draft data could fill this gap if the track along which the data were collected could be located in the SAR image. Sufficiently precise techniques do exist to locate both SAR image pixels and the submarine track. However, since release of detailed track data may be difficult, and since few such tracks will happen to fall within existing SAR images, only a limited number of detailed submarine ice draft acoustic data with detailed locations would be needed. Use of these acoustic ice draft data would support the long-term scientific goal of creating ice thickness maps of the Arctic regions using both aircraft and satellite remote sensing.

One product that it would be possible to extract in a straightforward way from the ice draft acoustic data would be the distribution of ice thickness. An example of what one "snapshot" distribution might look like is shown in Figure 17 taken from the Southern Beaufort Sea (using data unrelated to the Navy's classified data discussed here).

During the cold season (September to May), new ice forms wherever existing ice cover splits and diverges. Subsequent motion under the influence of winds and ocean currents causes the ice to shear, converge, raft, and ridge. The result is an ice thickness distribution such as the one shown. This thickness distribution is an important indicator of mechanical forces and of heat exchange between atmosphere and ocean. Only upward-looking sonar is capable of obtaining this information efficiently and with the necessary accuracy.

Figure 17. Distribution of Ice Drafts in the Southern Beaufort Sea



The small maximum at 0m represents open water and very new ice having a thickness of only a few centimeters. The poorly defined maximum at ice thicknesses near 1 meter represents ice that has grown as a result of ice divergence during the past 1-2 months. The largest peak, near 2 meters, is first year ice that started growing during the previous autumn. The broad maximum near 3 meters represents the preponderant population of multiyear ice. The tail of the distribution toward large thicknesses (greater than 4 meters, extending to 15 meters) represents mechanically compressed ice such as ridges and rafts.

The line rising to nearly 100%, associated with the scale at the right, gives the cumulative area. Thus approximately 75% of the area measured contains ice that is 4 meters thick or less, and approximately 95% is less than 10 meters.

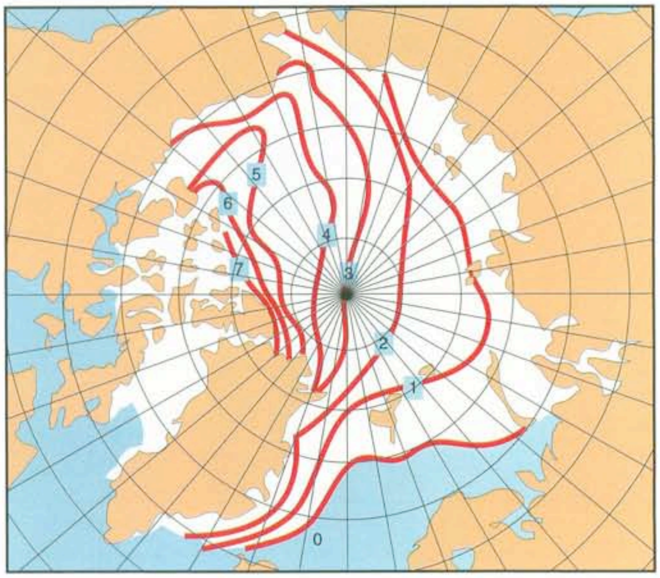
The overall picture of Arctic ice thickness has been developed by several investigators from a variety of sources. One such portrayal is shown in Figure 18, depicting the mean winter ice thickness developed from some of the early Navy data (adapted from publicly available data).

The Navy also holds some of the acoustic ice draft data in processed forms. For its own purposes the Navy has developed classified and unclassified databases of under ice features. For instance, ice information was needed in acoustic models that were developed to predict sound propagation loss in the Arctic region. Since 1989 the Navy has analyzed the DIPS data from 14 of the 20 cruises on which the DIPS system was deployed. As a result of these analyses, 10 statistical parameters including mean ice draft, rms ice draft, and standard deviation of the mean ice draft, as well as a variety of parameters describing ridging, were calculated for each nautical mile when ice was overhead. These data are available in two different databases.

The first database remains classified because it includes position and timing details for individual cruises as well as the specific data extracted from individual cruises. In that database, results are generally binned into 60 x 60 nm regions. The values are interpolated for regions where data are not available, and a clear distinction is made between real information and interpolated values. The second unclassified database is entitled Ice Profile Database V3.1. The data upon which V3.1 is based are identical to the classified database. In addition, the 60x60 nm geographic binning is retained. However, the data are grouped into two seasons, fall and spring, and the results of all the data obtained for each 60x60 nm block are averaged. Values are interpolated for blocks where data are unavailable, and information is not provided to allow the user to distinguish real average values from interpolated values.

In its present format the Ice Profile Database V3.1 cannot be exploited by the scientific community. Because of the global averaging, it is impossible to look at temporal variations in ice conditions, potentially the most interesting aspect that could be studied. Also, the grouping of data into spring and fall does not provide adequate temporal resolution to allow sorting of changes with time (although it may not be necessary to know time and place exactly). Another problem with V3.1 is that

Figure 18. Mean Ice Draft from Various Early Submarine Cruises



Over the Arctic region, ice thickness composites have been constructed from previously released submarine acoustic and a variety of supporting data.

This figure shows one such depiction of mean winter ice thicknesses. Not surprisingly the mean is driven by the thick multiyear ice causing the peak at 3m seen in Figure 17.

Although the distribution in Figure 17 results from measurements in one part of the Beaufort sea, and Figure 18 shows a long term winter mean for the entire Arctic region, the two depictions are quite consistent.

measured data cannot be distinguished from interpolated numbers that are filling data voids.

The Profile Database could be made useful if the data were only averaged within individual cruises and within each 60 x 60 nm box (30x30 nm boxes would be preferable). Further, the box averages should be coupled with a year and a time of year. If these changes were made, scientists probably could perform more detailed analyses of ice patterns and trends.

The practical accessibility of the analog data is limited by its present format. If these data are ever to be analyzed and thereby made available for further studies, now is the time. The early charts are nearly 40 years old. Yet, all the information required for an adequate analysis still exists at the Arctic Submarine Laboratory.

With regard to the analog data, we expect that current state-of-the-art image analysis techniques could prove extremely useful in speeding the processing of the analog data. If it were decided to analyze these data, all of the data should be analyzed, even those data from areas outside of the releasable geographic region.

d. Findings

The findings relative to ice keel depth acoustic data are:

- The data from upward-looking submarine sonar measurements of ice are the only quantitative measures of under ice structure available to studies of under-ice topography and climate.

- Archival analog data from about 50 exercises still exist. These data were found to be of sufficient quality that they could be reduced and processed to create a digital database. The analog data, in classified form, should be digitized and put into a database along with the supporting information (tracks), and then reduced to a geolocated time series of ice thickness. This classified database should then be archived at NAVOCEANO pending possible declassification, prior to which it should be made accessible in its classified form to appropriately cleared scientists.

- All of the data, both analog and digital, within the area already identified by the Navy as containing releasable data for future submarine scientific cruises, should be provided to the scientific community for its use (in accord with current Navy plans).

- The unclassified Ice Profile Database V3.1 could be a useful composite reference containing ice structure if modified to contain more detailed data (less averaging).

- The Navy's ice draft acoustic data, accumulated over about 30 years, is likely to prove valuable in developing more accurate methods for measuring ice thickness by aircraft and satellite remote sensing (e.g. ERS-1 and Radarsat).

- Both unclassified and classified data should be processed and archived in such a way that temporal changes of ice thickness and thickness distributions are fully preserved. Regional averages and their changes in time can be derived as needed if the primary data are fully documented.

D. OCEAN VOLUME AND BOUNDARY PROPERTIES

1. REALTIME SALINITY AND TEMPERATURE FIELDS (GOODS)

a. Data Description

The Global Oceanographic Observation Data Set (GOODS) contains a wide variety of ocean measurements collected from drifting buoys, moorings, ships, and aircraft (primarily vertical profiles of temperature and temperature/salinity data with some observed sound speed profiles and surface temperature values, similar to MOODS). These are near realtime data that are relayed to FNMOC and NAVOCEANO and loaded into a database for access the next day. GOODS coverage is worldwide. These daily observations provide a new look into ocean processes that has previously been unavailable to most of the ocean science community.

Data are stored in an on-line accessible database for a period of approximately three months. To the panel's knowledge, the GOODS data set is the only realtime, quality-controlled, network-accessible collection of surface ocean observations available anywhere. Availability of this data set is of primary interest to ocean modelers and analysts. It would be of immense immediate interest to various researchers for validating satellite observations.

Figure 19 illustrates the global nature of one component of GOODS holdings, those in the "restricted" category. It is important to note the large number of measurements, even within this limited category, that are typically accomplished in the short period of five months.

b. Accessibility

Many of the GOODS data are obtained from unclassified sources. However, Navy ships also contribute to the databases, and the locations of these ships are usually classified while they are out of port. As a result, some individual data entries in the database are classified, and because of the regulations governing processing and storage of classified digital data, the entire GOODS database must be handled as classified.

Data are stored on-line and can be accessed electronically. Data accessed at a summary level (like sea surface temperature contours) can be used as unclassified material.

c. Scientific Utility

If researchers are afforded access to the data, the near realtime view afforded by GOODS would open important new applications to the ocean science community.

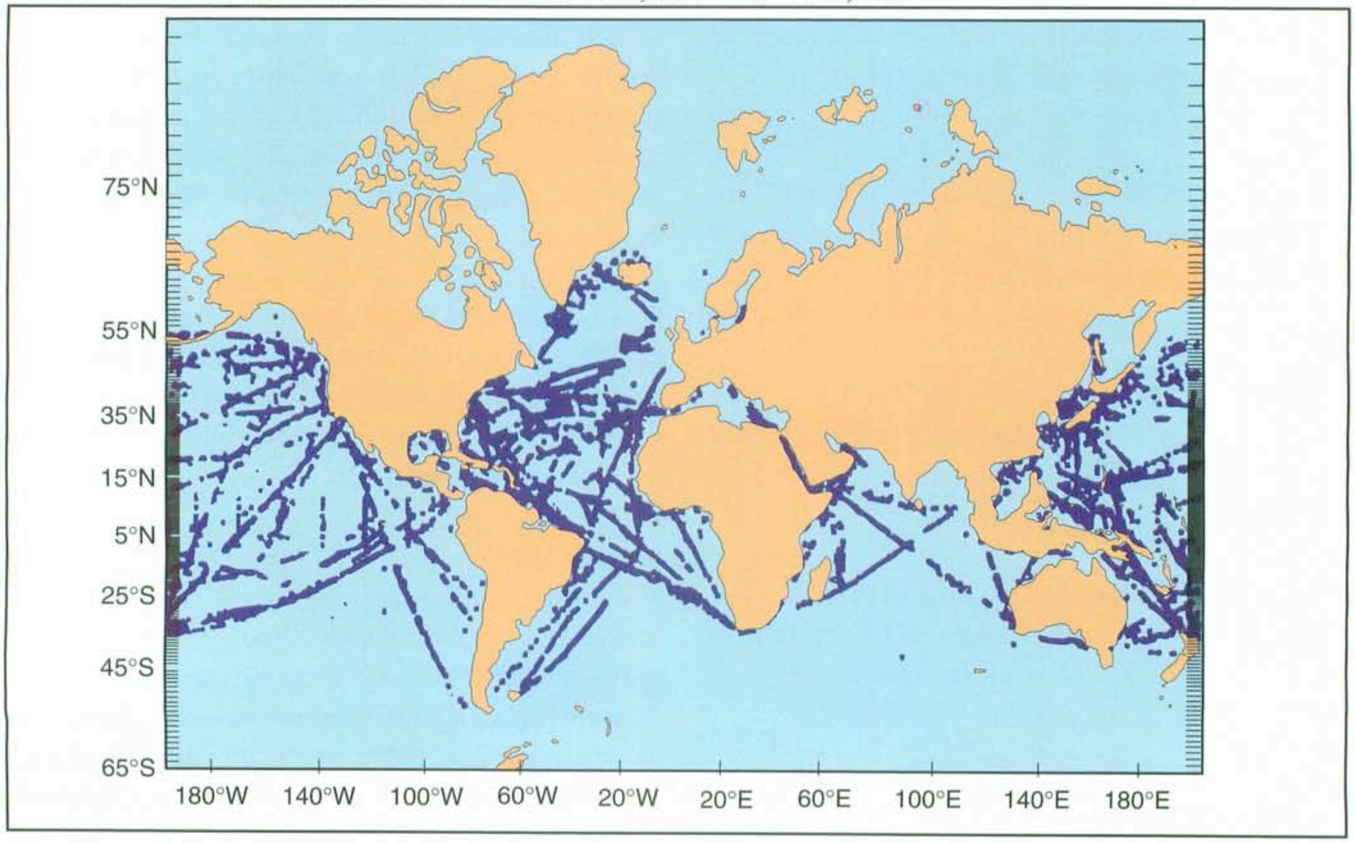
- Ship observations and other sampling schemes could be adapted to conform to the state of the ocean. Such adaptive sampling would greatly increase the efficiency of limited sampling resources, much as access to near realtime satellite imagery has done in the past decade.

- Many satellite algorithms make use of *in situ* observations for either sensor calibration or validation. Access to GOODS would allow researchers to test the performance of such algorithms and assess their quality based on comparisons between the satellite-derived observations and the data located in GOODS. Reducing the delay between the comparison of *in situ* and satellite observations would greatly improve the utility of remote sensing data.

- Numerical models of ocean processes are evolving toward the use of data assimilation techniques and *nowcasting* of the current state of the ocean. Similar to procedures used in weather forecasting, ocean models could incorporate GOODS data directly into the nowcast system.

- The techniques used in GOODS could eventually migrate into operational systems to support commercial and regulatory needs. For example, near real-time observations could be used to forecast warming events that might be critical for near shore aquaculture activities.

Figure 19. Global Data Holdings for GOODS, June–October, 1994



Shown here are the locations at which "restricted" GOODS data were collected during the period June-October in 1994.

Even over the span of a few months the GOODS data are spatially diverse and contain frequent samples. The actual data include temperature profiles and may include salinity profiles and other measurements depending on the collection platform and its instrumentation.

The total volume of GOODS data, including the public access and classified data, is significantly greater than that shown here.

Oceanography is steadily moving toward nowcasts (and eventually forecasts) of ocean circulation patterns. Access to near realtime data will be a critical element of such models. Many other activities, including ship and aircraft observations, would benefit greatly by this near realtime view. The present system focuses primarily on physical observations such as currents, temperature, and salinity. We encourage NAVOCEANO to examine new data types, such as bio-optical measurements, as a wider variety of autonomous sensors become available and are widely distributed in the oceans.

d. Findings

The findings relative to realtime salinity and temperature fields (GOODS) are:

- Although the largest part of the GOODS database is unclassified it is not generally accessible. It is recommended that steps be taken to explore access to this database via the Internet where it would get its most productive use.

- Nowcasting of the ocean circulation and temperature is the future direction of oceanography, and GOODS data would make a significant contribution.

2. ARCHIVAL SALINITY AND TEMPERATURE FIELDS (MOODS)

a. Data Description

The Master Oceanographic Observation Data Set (MOODS) is probably the largest collection of *in situ* oceanographic observations that has been synthesized into a single coherent database. The MOODS data set covers the time period from 1900 to the present. MOODS contains primarily vertical profiles of temperature and temperature/salinity data with some observed sound speed profiles and some surface temperature values. The highest depth resolution of the MOODS data is one meter. Examples of ocean thermal structure data extracted from MOODS are given in Figure 20 for two nearby but dissimilar ocean areas.

Figure 21 again shows dissimilar data from nearby ocean areas, this time in the Mediterranean Sea. Unlike Figure 20 which shows many individual temperature profiles, Figure 21 shows only the envelope of temperature and salinity profiles. Ship surveys such as the ones resulting in the data shown in Figure 21 commonly produce both temperature and salinity (and other) data, whereas aircraft surveys normally provide only temperature data as depicted in Figure 20.

To gain some understanding of the spatial sampling of MOODS data, Figure 22 illustrates the locations of *public domain* MOODS survey data for the Norwegian and Barents seas in the winter season.

b. Accessibility

Currently MOODS is only available to the Navy and the DoD community. The unclassified MOODS database contains publicly available data as well as restricted and/or sensitive but unclassified data. Disclosure of the restricted and/or sensitive data may be controlled by bilateral international data exchange agreements or other understandings. Coupled with the unclassified/restricted/sensitive data, there is also a classified MOODS database which contains data at various classification levels.

NAVOCEANO transfers unclassified data collected for MOODS to the National Oceanographic Data Center (NODC) for distribution in the public domain. In theory, this should ensure a timely progression of these data to general use.

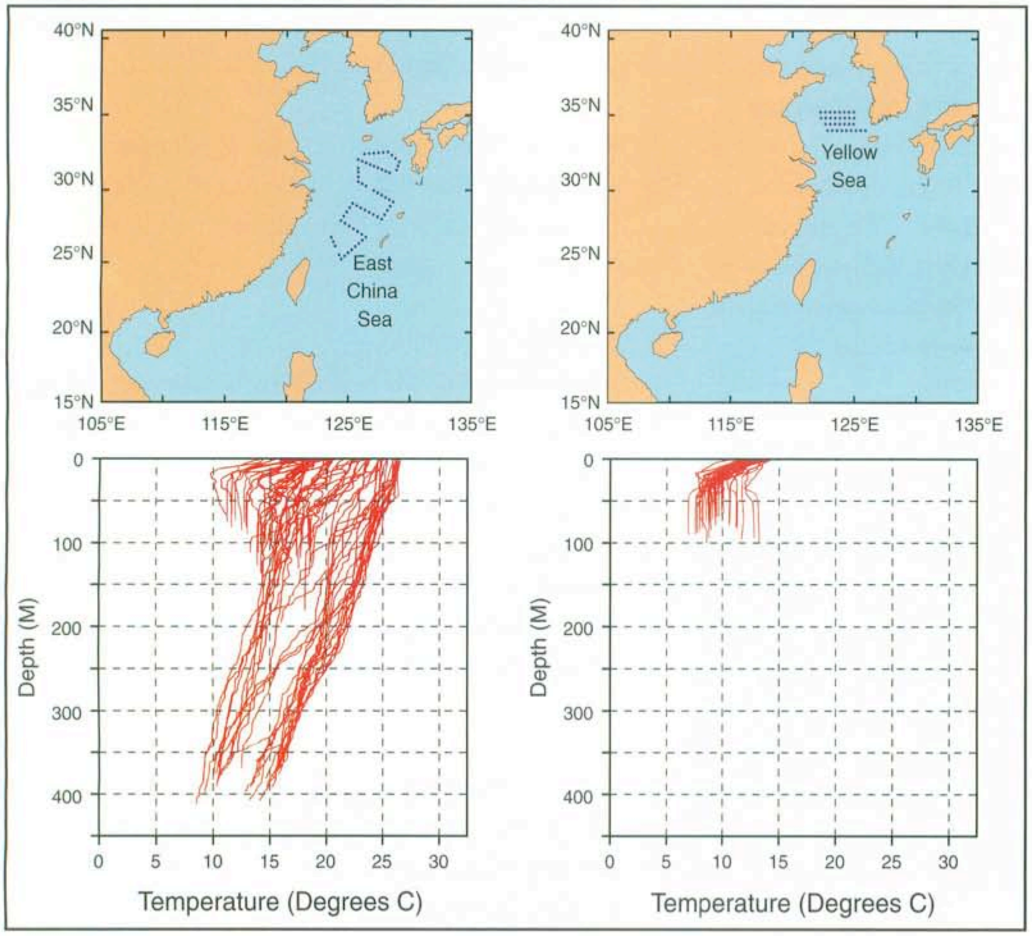
Each vertical data cast in the MOODS database contains a data classification code in the data header, including the data distribution statement and reason for restriction. A comparison of the amount of data categorized by distribution statement is illustrated in Figure 23. A representative area (the Norwegian and Barents seas) was chosen as a baseline for comparison of the different types and categories of data.

c. Scientific Utility

Improved descriptions of the oceanic density field are fundamental to our understanding of the ocean's circulation. Such descriptions provide a basis for estimates of mean circulation as well as analyses of low frequency changes in circulation, *e.g.*, decadal fluctuations in North Atlantic salinity.

General availability of the original MOODS database from NAVOCEANO to the civilian oceanographic community would significantly enhance education and research in ocean sciences. It is unclear to us whether access to either the restricted or the classified data would significantly enhance the value of current

Figure 20. Sample MOODS Aircraft Survey Data



MOODS aircraft-collected data consist of temperature measurements vs. depth (i.e., profiles) along with location and time references.

Over ocean areas the ocean structure represented by ocean temperature changes on various spatial scales. Here we see the cooler (7°C to 14 °C) waters of the shallow Yellow Sea on the right and the warmer (10° C to 26° C) waters of the deeper East China Sea on the left. In this case only temperature data were collected.

ocean data archives, since the distribution of these data with respect to the unclassified holdings has not been examined in detail. It has been determined, however, that in many cases the non-public data primarily improves the spatial sampling of the public data rather than providing data in areas or time periods having no public data.

To quantify the uniqueness of the restricted data types in MOODS, we recommend that NAVOCEANO review the MOODS holdings and develop products that address the uniqueness of these particular holdings. If the result of this process suggests that the classified holdings do not contribute significantly to the overall ocean database, we would recommend that the public domain data be released for general open distribution. On the other hand, if such a review of the data suggests that the restricted and/or sensitive data holdings provide significant insight into ocean processes, then we would recommend more general disclosure of the overall database.

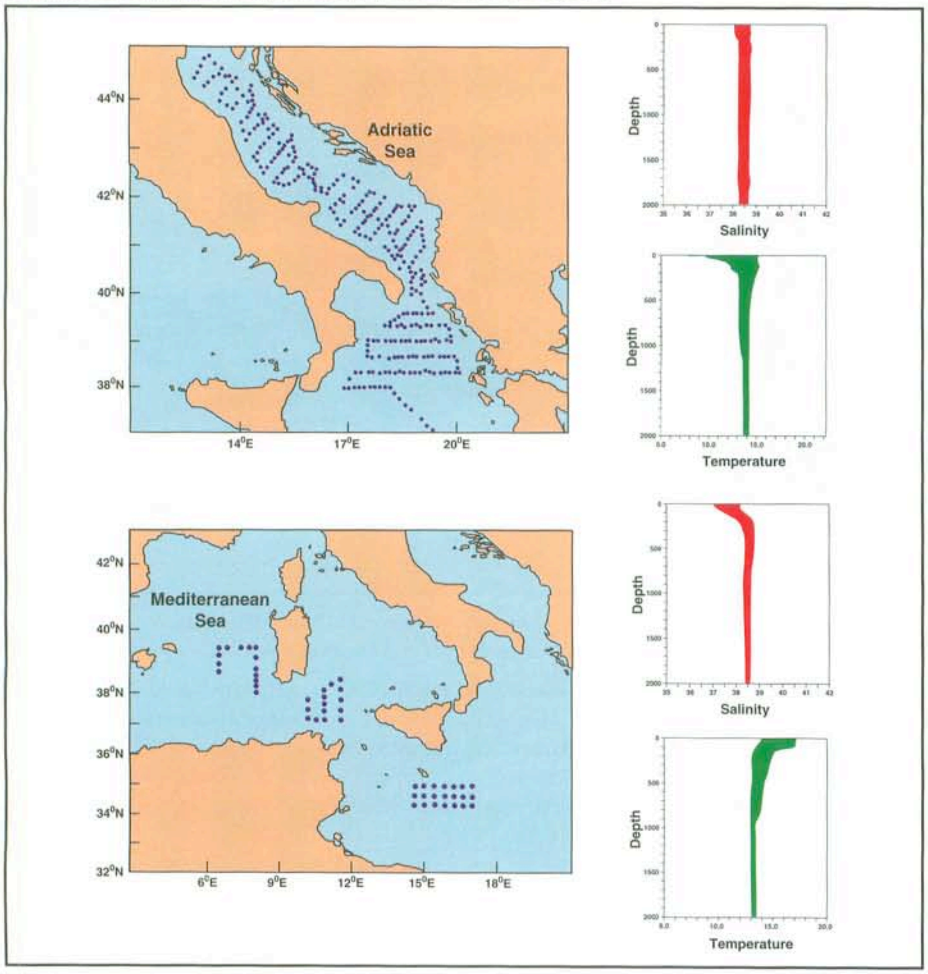
d. Findings

The findings relative to archival salinity and temperature fields (MOODS) are:

- The general availability of the original MOODS database to the civilian oceanographic community would significantly enhance the ocean climatological data inventory available for public sector education and research in ocean sciences.

- An investigation into the restricted/sensitive data or classified data in MOODS should be conducted to determine if these data would enhance the database enough to argue for further release of classified MOODS holdings.

FIGURE 21. SAMPLE MOODS SHIP SURVEY DATA



MOODS ship-collected data consist of both temperature and salinity versus depth profiles along with location and time references. For clarity only the envelopes of the individual temperature and salinity profiles are shown. The profile envelopes exhibit the near-isothermal and isohaline waters of the Adriatic on the top, and the waters of the central Mediterranean having an upper ocean layer with strong gradients in both parameters.

3. OCEAN OPTICS AND BIOLUMINESCENCE

a. Data Description

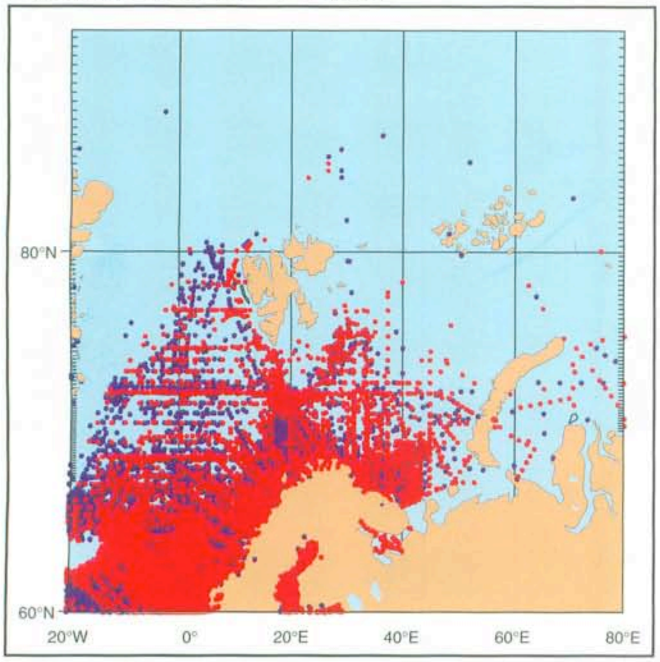
The Navy's interest in optics of the ocean derives from such issues as the potential for optical detection of underwater objects and laser bathymetry, as well as for environmental concerns, such as the detection of fuel leaks, determination of the toxicity of antifoulant coatings, detection of chemical compounds, or location of contaminated sediments. Similarly, civilian environmental measurement applications are present at both the micro and macro levels. Micro level analyses of contaminated water and macro level analyses, for example, global ocean color, are complementary methods of measuring ocean "health." Color and transmission properties help determine the presence of effluents and estimate their rates of dissipation or dispersal. Bioluminescence is tied to ocean life processes and can be a convenient measurement tool of broader ocean "health."

Figure 24 shows a measurement of bioluminescence activity in a portion of the East China Sea at a measurement depth of 3m.

Space-based techniques for the estimation of ocean color and ocean clarity are in development. Older Navy data are less voluminous both temporally and spatially than that permitted by present techniques. While remote sensing techniques are being refined, there still is the need for *in situ* and at-depth measurements that cannot be duplicated without using ships at sea. These data must also be available to provide a baseline for remote sensing techniques.

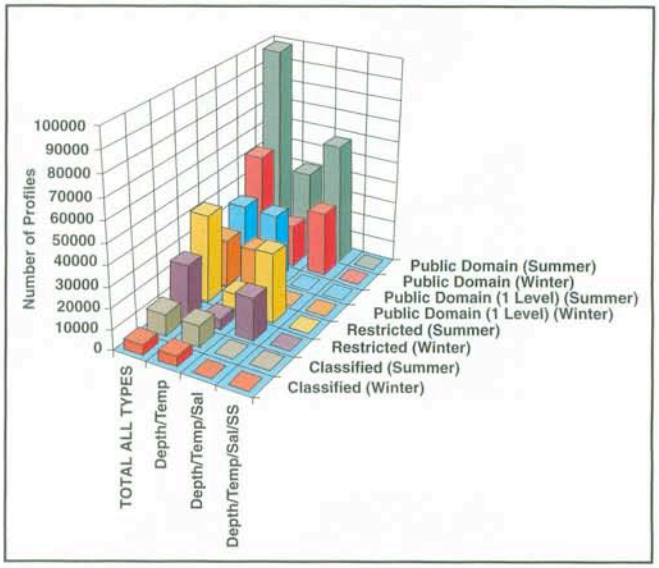
More optical data are being collected in the coastal zones of the world with the change in focus of U.S. Navy operations. These regions are especially challenging because optical properties are far more complex and regionally specific, and because the scales of variability are much smaller. Traditional sampling

FIGURE 22. MOODS SURVEY LOCATIONS IN THE NORWEGIAN AND BARENTS SEAS



Each color point represents the location of a particular oceanographic measurement and indicates the type of profile that was collected and placed into MOODS. A blue point indicates a location where a depth/ temperature profile is available. A red point denotes a combined depth/ temperature/salinity profile. The map plots all of the data points available in the public domain for the winter season.

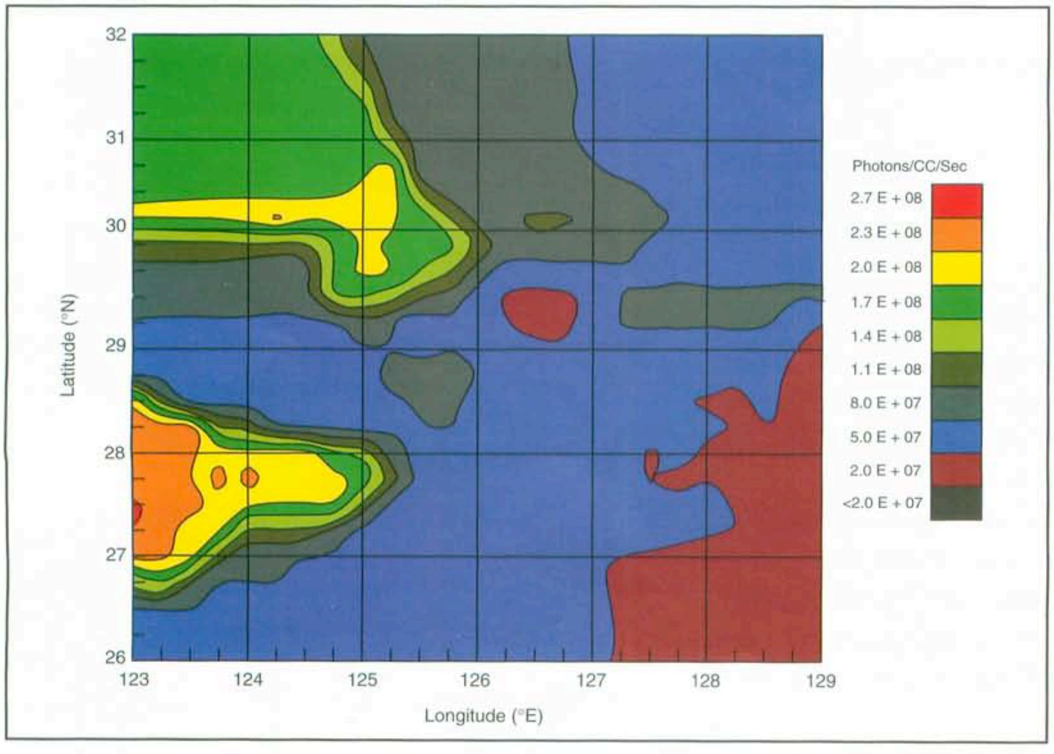
FIGURE 23. QUANTITIES OF DATA CONTAINED IN MOODS DISTRIBUTION CATEGORIES



This figure compares the numbers of MOODS profiles that are available in the various categories of accessibility.

A large amount of MOODS data are already in the public domain category. Many of the non-public domain data are not classified, but restricted (usually as a result of some bilateral international agreement). It is not necessarily the case, however, that the potential for gaining public access to currently restricted data is greater than that for currently classified data.

FIGURE 24. SHIP SURVEY BIOLUMINESCENCE DATA IN THE EAST CHINA SEA



These data show the intensity of bioluminescence at a depth of 3 meters. The maximum activity is in the southwestern part of the area and the minimum in the southeastern portion, which includes a part of the Ryukyu Island chain.

Unlike many ocean characteristics that vary by small amounts over even very large areas, these data exhibit variations greater than an order of magnitude.

These measurements were made in the same area as portions of the aircraft surveys depicted in Figure 20.

methods that rely on deployment of expensive, one-of-a-kind sensors are inadequate to meet the challenge of optical research in the coastal zone.

b. Accessibility

Generally there is no public access to these data since the majority are classified. The Naval Oceanographic Office has collected an extensive set of optical and bioluminescence measurements of the world's oceans, primarily in classified form. These ship observations include both underway and on-station measurements. Although the data are primarily located in areas of specific interest to the Navy, they represent an extensive set of unique measurements. Most of these data are available through official (classified) data reports, but they are not available electronically through a relational database.

c. Scientific Utility

Improved characterization of optical parameters in littoral access will be of immediate help to studies of ocean health, living marine resources, and basic research. Coastal studies are a prime example of how the operational and research communities would benefit by joint data sharing and research programs. For example, the next-generation satellite ocean color sensors will provide much better measurements in these complex coastal waters. Access to both civilian and operational databases of *in situ* observations would significantly improve the quality of the satellite retrievals for both communities.

A second example of utility would be in the area of *in situ* sensor design. The research community is moving toward less capable (in terms of signal-to-noise ratios, number of spectral bands, etc.) sensors that are dramatically less expensive. Such sensors are suitable for deployment in greater densities (to resolve small-scale variability) or in areas where loss of sensors is likely (such as in areas of heavy fishing activity). These sensors would benefit both the operational and research communities. We encourage NAVOCEANO to continue to foster the exchange of information on sensor development.

d. Findings

The findings relative to ocean optics and bioluminescence are:

- NAVOCEANO should continue to foster the exchange of information on optical sensor development since this drives data collection capabilities for both civilian and Navy communities.

- Coastal studies are a prime example of how the Navy operational and civilian research communities would benefit by joint research programs, thus taking advantage of the post-cold-war Navy focus on littoral regions.

4. MARINE BATHYMETRY

a. Data Description

Bathymetry is the science of measuring ocean depths to determine seafloor topography. Seafloor bathymetry, and global topography in general, represents the most fundamental of geophysical databases. Oceanographic, meteorological, and geologic studies depend upon accurate descriptions of morphology to understand the magnitude and lateral scale of variability within the earth, ocean, and atmosphere. In the past, national and international bodies have sought to incorporate as much survey data as possible to generate reliable and accurate maps of the seafloor. NAVOCEANO has assisted in this important process by making survey data available and has supported unclassified databases such as the Digital Bathymetric Database (DBDB).

The Navy has been interested in ocean depth not only because of navigation, but because of the channeling of ocean signals and noise. To support acoustic analyses, the bathymetry of the world has been digitized into databases with five arc minute grids, with some geographic areas at 2, 1, 0.5, and 0.1 arc minute resolutions. All ocean areas north of 78° S are covered, as well as depths up to the 200 m contour line near the coasts (shallower depths are interpolated values). Bathymetric values are in uncorrected meters measured acoustically and are referred to a sound speed of 1,500 meters/sec.

Figure 25 shows three dimensional representations of ocean bathymetry of a small test area of the northeast Pacific at two resolutions, high resolution (0.1 arc minute) and low resolution (1.0 arc minute). Bathymetric data having a resolution of 0.1 arc minute are normally classified by the Navy. However, this particular example was taken from a data collection in a test area used by the Navy for understanding the utility of high resolution data.

The original multibeam bathymetric sonar data are archived at NAVOCEANO and can be accessed in their original raw form. Returning to these raw sonar data could provide researchers with the highest level of detail available. These data were used in the construction of the gridded database summaries. Multibeam data from the Sonar Array Survey System (SASS) became available starting in the mid-1960s. SeaBeam data collection began in 1987. SIMRAD systems, including EM-100 (1992) and now the EM-121A and SeaBeam 2000/2012 systems (1995), are the latest bathymetric mapping equipment in use today.

b. Accessibility

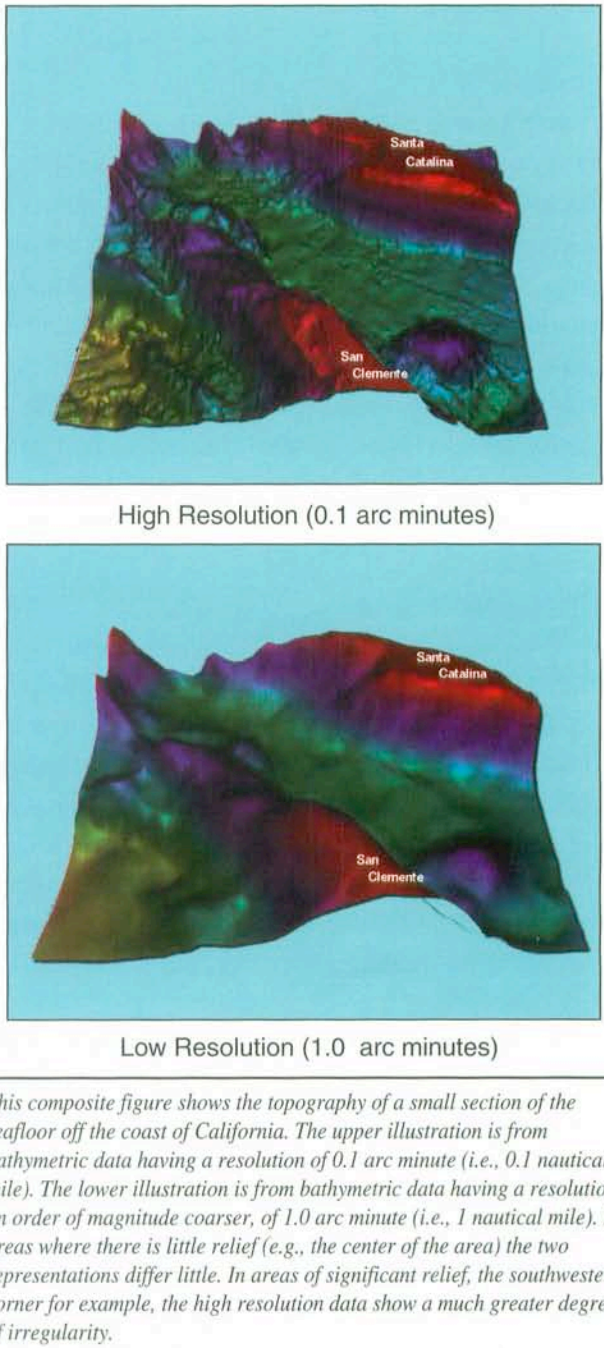
Accessibility to some of the bathymetric databases is possible at the unclassified level except for sensitive regions where the location of detailed surveys may compromise location-specific issues. Detailed gravity surveys that include bathymetry data were generally conducted at locations that are not associated with such systems and where gravity variability is high. There are also high resolution databases that are classified in their entirety. Distribution of the DBDBs to government users is through the Defense Mapping Agency with assistance from the Naval Oceanographic Office. A 5 arc minute resolution, global grid DBDB is available to the public through the National Geophysical Data Center. There is an effort underway to produce an unclassified database with variable resolution (DBDB-V) that would incorporate some 0.5 arc minute data.

Multibeam bathymetric sonar data are mostly classified or restricted. Restricted data are often the result of a cooperative data collection with a foreign government or under a bilateral agreement. The host government would have to give its approval before these data dissemination restrictions could be removed. While possible, this could be very difficult in practice.

c. Scientific Utility

The joint availability of magnetics and seafloor topography data would greatly improve plate tectonic reconstructions.

Figure 25. Sample Bathymetry Data at High and Low Resolutions



This composite figure shows the topography of a small section of the seafloor off the coast of California. The upper illustration is from bathymetric data having a resolution of 0.1 arc minute (i.e., 0.1 nautical mile). The lower illustration is from bathymetric data having a resolution, an order of magnitude coarser, of 1.0 arc minute (i.e., 1 nautical mile). In areas where there is little relief (e.g., the center of the area) the two representations differ little. In areas of significant relief, the southwestern corner for example, the high resolution data show a much greater degree of irregularity.

Detailed bathymetry data, accompanying marine magnetics data, and geoid data from Geosat/ERS-1 would allow detailed reconstructions of plate motions through time to include the oldest Jurassic and Cretaceous lithosphere.

As new oceanic lithosphere is created at mid-ocean ridges and spreads away from volcanic centers, the lithosphere cools, becomes more dense, and sinks. For some time, a square root relationship between age and depth of the seafloor has been understood as a manifestation of the diffusion process, which conducts the heat into the overlying ocean. However, the accuracy of seafloor depth data and ambiguities in the age of the topography (available from magnetics data) have resulted in numerous hypotheses of spatial and tectonic variations in the cooling process. The availability of these highly accurate and finely sampled data would allow, for the first time, a detailed study of the spatial variations in this important evolutionary process.

The oceanic lithosphere acts as an elastic plate of time-varying thickness. As lithosphere ages, volcanoes are sometimes erupted onto the plate (*e.g.,* Hawaii) and the loading causes the lithosphere to flex. Often such flexure results in *moats* around the volcanoes, and the spatial characteristics of the flexure can be used to estimate the thickness of the plate and the age of loading. Frequently the lithosphere can be reheated after cooling; previously submerged islands can again ascend above the ocean's surface. Outward of oceanic trenches, old, cold lithosphere is flexed by the forces associated with the subduction of the lithosphere to great depths. Again the spatial characteristics can be used to provide an estimate of the elastic thickness. Detailed ocean bottom topography, enhanced by geoid and gravity data, would greatly expand upon the data sets available for studying the importance of the elastic lithosphere in understanding the vertical component of tectonics in the oceans.

The North Pacific contains many linear volcanic chains that are poorly defined on current bathymetric charts. Most scientists believe that these chains formed as the Pacific plate moved over numerous hot spots. However, some chains may be caused by volcanism associated with plate deformation. High-resolution bathymetry would help address this issue by revealing the spatial relationships among the volcanoes. Moreover, high-resolution maps would reveal the detailed morphology of individual structures. The important morphological features are the flatness of the seamount or guyot, the number of rift flanks, and preferential alignment of the rift flanks perhaps related to plate-wide stress patterns. Finally, detailed bathymetry is needed for magnetic modeling of individual seamounts to establish their paleolatitude of formation, as well as magnetic reversal patterns along volcanic chains.

The Navy's bathymetry data are truly a national asset. The compilation and gridding represents an estimated 176 man-years of effort, and the survey data on which the data are based are never likely to be duplicated. Accurate and detailed measurements of the ocean depth can only be done using ships, which is both expensive and time consuming.

Raw, side-scan sonar data offer an exciting opportunity to augment relatively low-resolution surveys, which have been available for several years in limited areas (*e.g.,* GLORIA). The availability of high-resolution side-scan sonar coverage will have major implications for the oil and gas industry in mapping seafloor faults and fractures that control oil or gas seeps, produce subsea freshwater springs, and contribute to slope instability. Hazards to navigation and existing pipelines can be much more accurately located, facilitating pipeline repair or ship routing around hazards.

d. Findings

The findings relative to marine bathymetry are:

- The joint availability of magnetics and seafloor topography data, in combination, would greatly improve the accuracy of plate tectonic reconstructions and materially aid planning of at-sea experiments and a variety of ocean measurements and analyses.

- It is very important that the Navy's planned release of DBDB-V is achieved soon.

- A determination should be made concerning the level of utility afforded by DBDB-V if significant amounts of the 0.5 arc minute resolution database (DBDB-0.5) are not released and incorporated into DBDB-V.

- Provided that the release of DBDB-V occurs, there will be a smaller potential scientific benefit to the release of the remaining classified data. However, should the planned release of DBDB-V with 0.5 arc minute data not occur, we strongly believe that a review of the classification policies themselves should be undertaken with a view toward making such a declassification possible.

E. ADDITIONAL CONSIDERATIONS

1. GENERALIZED DIGITAL ENVIRONMENTAL MODEL (GDEM)

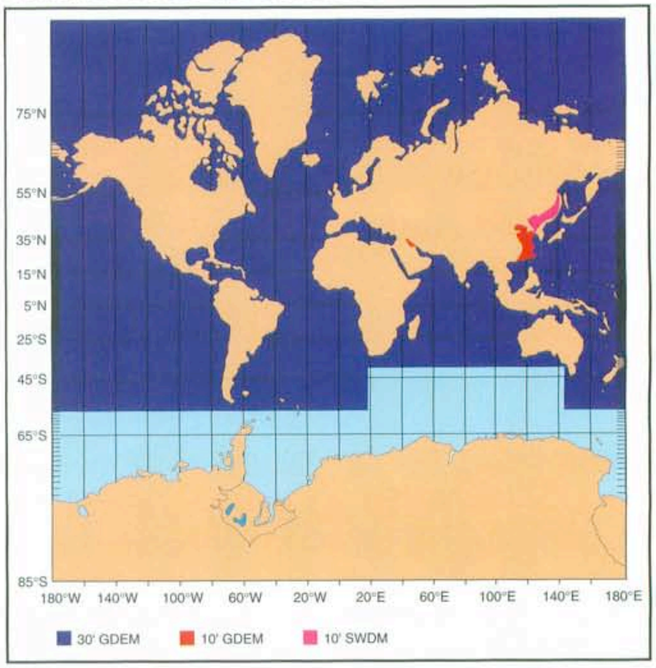
The GDEM is one of the Navy's standard climatology databases providing information on the temperature and salinity of the ocean. It is a derived database in that it does not contain actual oceanographic observations, but instead consists of statistical representations of the temperature and salinity fields drawn from MOODS. MOODS contains about five million observations worldwide. GDEM was constructed by fitting polynomial curves (with the exception of the surface layer, 0-400 meters) to each depth profile from MOODS and averaging all the equivalent coefficients within each 30 arc minute spatial cell. The surface layer coefficients are those that give the appropriate amplitude response to a filter function. The global results were then gridded with interpolated values filling in any voids. Using these coefficients this model can reconstruct a representative climatological vertical profile of ocean temperature and salinity at any location in the Northern Hemisphere for any of the four seasons. GDEM profiles are available for ocean areas where the water depths exceed 100 meters, except for the Mediterranean, Red Sea, and Sea of Japan where the cutoff depth is 50 meters, and the Persian Gulf and Yellow Sea where it is 0 meters. An update of the public domain GDEM in progress will result in some areas having 10 arc minute resolution. Figure 26 shows where GDEM ocean models exist and some of their important characteristics.

A recent comparison between GDEM and the Levitus Climatology suggests that GDEM provides results very similar to the Levitus Climatology, which is extensively used by oceanographers to initialize numerical global and regional circulation models. These models are providing significant insight into ocean circulation and the role of the oceans in global climate. For areas of strong ocean currents, such as the Gulf Stream and Kuroshio, an unsmoothed version of the GDEM results is available. This unsmoothed version has been reported to provide a better representation of the density structure than does the Levitus Climatology.

V-GDEM stands for Variability for the Generalized Digital Environmental Model, and provides an envelope of plus or minus two standard deviations around the GDEM profile for each 30 arc minute grid cell. While GDEM can be obtained for various parts of the world oceans via the Internet with anonymous File Transfer Protocol (FTP), V-GDEM and the high-resolution GDEM are not available via the Internet, and the Arctic GDEM, while not classified, is restricted to Navy-approved users.

GDEM and V-GDEM could be very useful to a number of oceanographers working on circulation, air-sea exchange, and climate issues. We suspect that many oceanographers may not be aware of these models, their structure, and how they might be obtained. It would seem desirable to make the oceanographic community as a whole more aware of these databases. We are certain that the oceanographic community would like to have the Arctic GDEM available for use as well as the higher resolution shallow seas GDEM. As a broader segment of the oceanographic community uses these products, we expect these models to become better known and used, and that recommendations for enhancements will be forthcoming.

FIGURE 26. GDEM COVERAGE



This figure shows the ocean areas where GDEM ocean profile data models of various resolutions exist.

Table 7 summarizes the most important characteristics of the models. While the lowest resolution GDEM ocean data models have been developed for nearly the entire globe, the higher resolution models exist only for limited regional ocean areas.

TABLE 7. COMPONENTS OF THE GDEM DATABASE

BASIN	AREA	SPATIAL RESOLUTION	MINIMUM DEPTH
Arctic	north of 65N	30 minutes	100 meters
North Atlantic	0-65N	30 minutes	100 meters
South Atlantic	60S-0, 70W-20E	30 minutes	100 meters
North Pacific	0-65N	30 minutes	100 meters
South Pacific	60S-0, 145E-70W	30 minutes	100 meters
Mediterranean	5W-42E	30 minutes	50 meters
Indian Ocean	N of 40S, 20-145E	30 minutes	100 meters
Red Sea	N of 40S, 20-145E	30 minutes	50 meters
Persian Gulf	N of 40S, 20-145E	10 minutes	0 meters
Sea of Japan	34.5N-52N	10 minutes	50 meters
Yellow Sea	23-41N, 116-133E	10 minutes	0 meters

2. ARCTIC BUOY PROGRAM

This unclassified Arctic data buoy program has been very effective in providing realtime ice motion and surface pressure data over the Arctic Basin and, as the sophistication and flexibility of the buoys continues to improve, the collection of an expanded suite of meteorological and oceanographic parameters is now possible. Not only is this data set essential to effective NIC operations, it is also generally useful to a variety of civilian meteorology and oceanography research programs. By piecing together support from a number of governmental agencies within the United States as well as Canada, Germany, and recently Russia, NIC has been able to continue this important program with great benefit to everyone operating in the Arctic region. This has not always been an easy task but the results have proven to be well worth the effort.

3. COMPREHENSIVE ENVIRONMENTAL ASSESSMENT SYSTEM (CEAS)

CEAS consists of a user-oriented software front-end connected to a series of environmental databases that are often collected by classified government assets in support of Navy operations. These databases have, for the most part, already been discussed in this report. The databases run on public-domain Geographic Resources Analysis Support System (GRASS) software, and can be accessed using the widely available ARC INFO Graphical Information Systems (GIS) format. The databases are relational in that they can be superimposed in multiple layers to provide a data package registered to a common base map. This multi-layered registration enhances the utility of all the data sets in that they can be analyzed in context and in various combinations to suit the user's requirements.

Data contained in the CEAS vary in type, measurement precision, and geographic coverage. General categories of data potentially available include high-resolution bathymetry, bottom sediment properties and characteristics (*e.g.*, thickness, physical properties, grain size, area distribution, acoustical properties), and seafloor roughness. These data are typically analyzed in conjunction with other databases to provide operational information to the military client.

Not all data types are available in all geographic areas; they vary by both density and precision of measurement. In general, coverage includes coastal regions and open oceans where Navy operations have been conducted or might be in the future. These areas include the Persian Gulf, Gulf of Oman, western Pacific Ocean, Mediterranean Sea, and other areas. Significantly, many of the areas already covered are of interest to science and industry, where exploration for natural resources or pollution abatement programs are planned or are underway.

Figure 27 shows one form of data output obtained from CEAS, an identification of various anomalies in the seafloor in the Persian Gulf.

The availability of these data in ARC INFO format makes them attractive to civilian users because they can be easily added to existing databases. Much of the data available from CEAS is already available in terms of general type and regional coverage. However, the value of this system lies in the high quality of the data (resolution and multiple measurements over a lengthy time) and the data now available from previously denied regions.

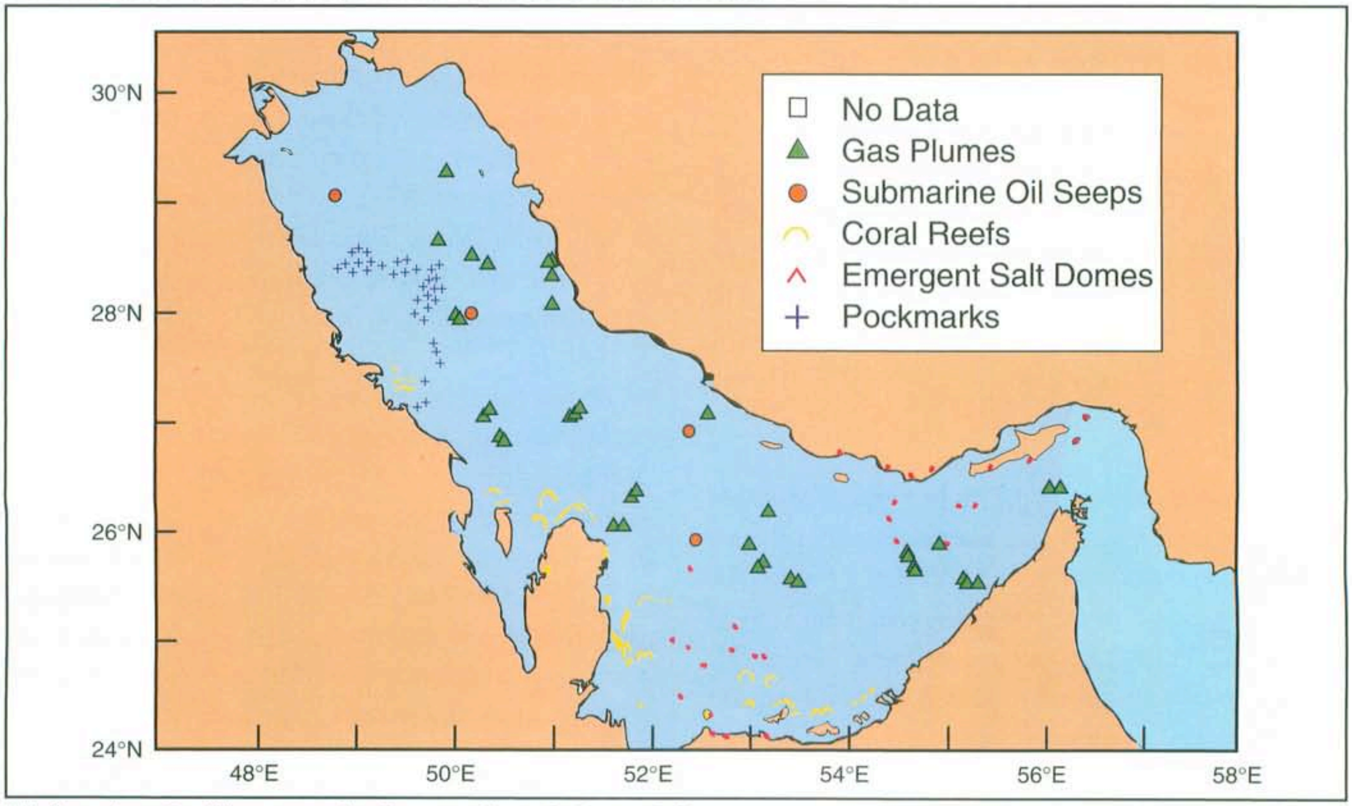
The CEAS database has an effect on a number of marine engineering issues:

- Natural resources exploration—oil and gas, minerals;
- Engineering studies—siting offshore platforms and facilities, port access channels, ice hazards and grounding potential, submarine slump potential and slope stability, undersea cable, and pipeline routing;
- Environmental baseline studies, pollution control;
- Hazards to navigation—detection of shoals, coral reefs, shipwrecks, and abandoned structures; and
- Contribution to global change and solid earth geophysics studies.

CEAS would be particularly useful in developing and applying interpretation methods to remote sensing data from many parts of the world's oceans (e.g. Space Radar Laboratory SAR imagery). CEAS would help provide the "surface truth" to enable interpretation to be done in a cost effective manner. Surface information not only aids in confirming correct interpretations, but allows false interpretations to be discovered and discarded.

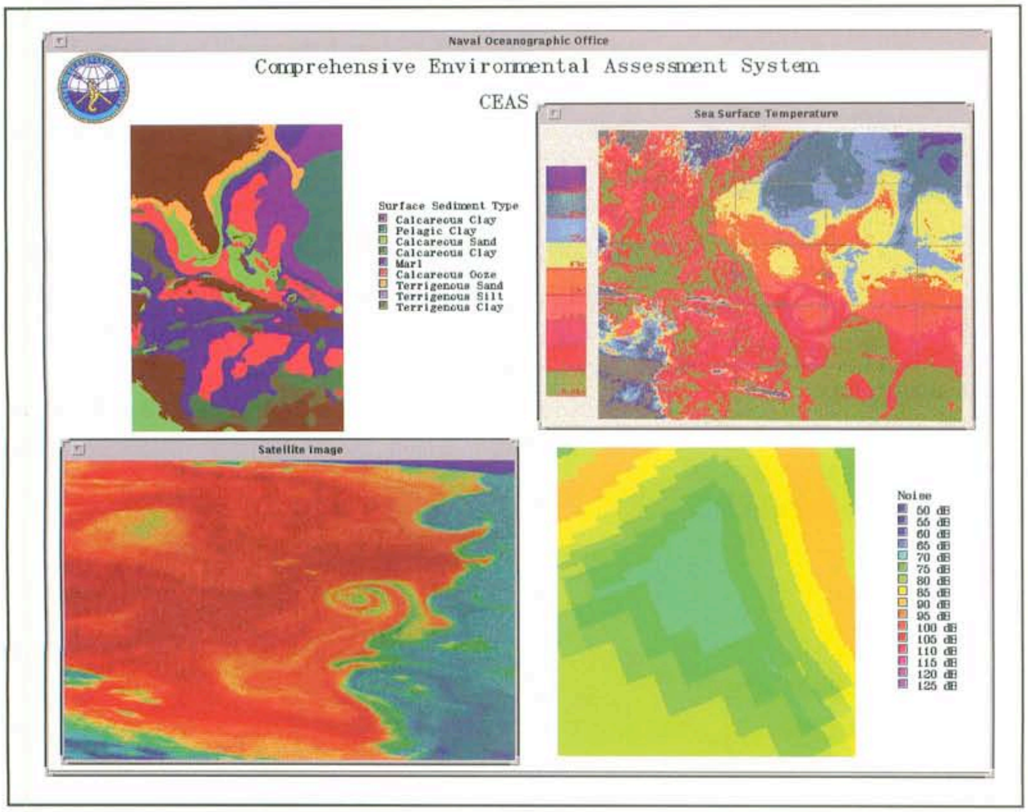
To convey some sense of how CEAS might appear to a user, Figure 28 shows several database access options for the western Atlantic. Depicted are sediment type data, ocean temperature at a specified depth from MOODS, sea surface temperature from satellite data, and acoustic ocean noise.

FIGURE 27. CEAS-GENERATED PLOT OF SEAFLOOR ANOMALIES



This figure shows five different types of seafloor anomalies in the Persian Gulf.

Figure 28. Example of CEAS Database Access Options



CEAS offers the user relatively easy access to an entire variety of NAVOCEANO ocean data.

Included are the seafloor sediments data, bulk properties such as temperature and salinity, satellite data, and some acoustic data.

4. ACOUSTIC DATA AND ACOUSTIC SENSING OF THE OCEAN

Except as mentioned, the MEDEA study did not review or consider the large acoustic data holdings of the Navy. The majority of acoustic data held by NAVOCEANO are the multibeam bathymetric survey data, although there are extensive holdings of ambient noise measurements and transmission loss.

In a broad sense, acoustics is the major measurement tool for ocean environments (bathymetry, distance, bottom roughness, bottom characteristics, seismic noise, etc.). Acoustic measurement systems work well because of the physical transmissivity properties of the water medium. Electromagnetic measurements are not possible in water except over short distances or at very low frequencies. (Not coincidentally, this is why the Navy was interested in sensing for submarines with acoustics.) Therefore, the acoustic measurement data and acoustic measurement expertise resident within the NAVOCEANO oceanographic departments represent a valuable part of the Navy's classified holdings.

Within the acoustic data collected for system development and the systems designed for submarine detection, there are possible opportunities for scientific use of ancillary products. For instance, for many years there has been a interest in data that would reveal long-term trends in ocean noise levels due to shipping. The oceanographic community has long debated the trends in the ocean noise environment and the natural and man-made components of the ocean noise condition and variability.

It is also known that acoustic sensing of seismic events is a sensitive method of measuring undersea seismic activity and variations. Studies by the NOAA-Pacific Marine Environmental Laboratory (PMEL) and others have demonstrated the utility of undersea acoustic data for long range seismic monitoring of ocean seismic activity.

The Navy's acoustic data holdings and acoustic surveillance systems could be given wider use similar to the efforts being carried out within the Strategic Environmental R&D Program's to employ the Integrated Undersea Surveillance System (IUSS) to study endangered whale populations and ocean seismic events.

F. SUMMARY

During the past 30 years the Navy's ocean surveys have systematically collected bathymetry, gravity, magnetics, and salinity/temperature field data on a global basis, in particular, encompassing almost all of the Northern Hemisphere. Altogether more than 100 ship-years of data acquisition have been devoted to this effort. It is highly unlikely that such an effort will ever be repeated. Equally, as with any historical data, the National Ice Center's ice morphology charts from the 1960s and the ice keel draft acoustic data from 1970s can never be obtained from any future measurement program.

The major findings of this chapter concern, first, an assessment of the potential for each of the databases to support scientific research should public release become possible. The second dimension concerns a prioritization of these findings in terms of the importance of the research that could be supported.

The major findings identified in this chapter are encapsulated in Tables 8 and 9, which also include a prioritization. We have arrived at this prioritization by considering a number of factors, including the uniqueness of the data, the intrinsic merit of the scientific problems to which the data can be applied, the practical difficulties associated with the use of the data (*e.g.,* the need to convert voluminous uncalibrated analog records to calibrated digital records), and the likelihood that if the data were not made available, the civilian community would find some means of replicating it in the foreseeable future.

TABLE 8. FIRST TIER OF SCIENTIFIC SIGNIFICANCE

DATA	DESCRIPTION	SCIENTIFIC UTILITY
Marine Gravity	• Relational database of point observations with latitude, longitude, observation time, free air anomaly, and gravity values, supported with survey, data processing, and statistical information. • Includes Lacoste and Romberg Air-Sea Gravity Meter measurements from 1966 to 1983. Bell Aerospace BGM-3 and BGM-5 gravimeters were introduced in 1969.	• Classified marine gravity data provide a view into the underlying geological structure at very short spatial wavelengths currently inaccessible to public data. • Classified gravity data could be used to address three problem areas: (1) spatial variations in gravity at mid-ocean ridges, (2) mapping of crustal thickness, and (3) the structure of fracture zones. • Classified gravity data would provide the information needed for the Northern Hemisphere to facilitate research into the genesis of Earth's surface.
Current Accessibility: • Entirely classified; no public access.		
Geomagnetics	• Consists of both aircraft (Project Magnet) and satellite vector data. • Ship collected data; consists of scalar point data by latitude and longitude.	• Magnetic surveys could be used to constrain the age of the age of the seafloor accurately, to calculate more accurate plate reconstruction rotation parameters, to analyze the Jurassic and Cretaceous Quiet Zones, and to determine the origin of intermediate wavelength crustal anomalies.
Current Accessibility: • Ship data are classified; no public access; aircraft data are unclassified. • Classified largely because of association with specific ship tracks and ship track densities.		
Ice Keel Depth Acoustic Data	• Measures ice roughness, ridge frequency, and ice depth (ice draft) below the sea surface. • Data are collected using upward-looking sonar starting with the Arctic journey of SSN Nautilus in 1957. • Approximately 50 data sets exist.	• Data are significant in their own right, and as calibration for satellite-borne instruments. • Knowledge of the mechanical redistribution of ice thickness categories would improve our ability to forecast ice conditions for navigation. • Submarine sonar profiles might settle the question of whether or not ice thickness has undergone a secular trend.
Current Accessibility: • Classified; no public access. • Classified primarily because of the association with specific submarine tracks and dates.		
Marine Bathymetry	• A large collection of ocean undersea topography databases. • Gridded digital databases resulting from survey measurements, many using multibeam profilometers. • Data as fine as 0.1 arc minute are available for some areas.	• The accuracy of current representations of the seafloor is not sufficient for many studies. The scientific uses of more accurate data include evaluating the square root relationship between age and depth of the seafloor. • Availability of these finely sampled data would allow for a detailed study of the spatial variations in this important evolutionary process.
Current Accessibility: • Most data having a resolution as high as 1 arc minute are unclassified. • Data at 0.5 arc minute resolution may be declassified as part of the classification review of bathymetric data. • That data chosen for release would then be made part of DBDB-V.		
Geosat Altimetry	• Geosat altimetry measures sea height with world coverage of ± 72 degrees latitude and 3.4 km spacing (1.7 km footprint). • 3 km track spacing at the equator. • 3.5 cm sea height precision.	• Provides important reconnaissance information over vast, largely uncharted areas such as the Southern Ocean and Antarctic margins. • If declassified it could be used with the ERS-1 data to improve the resolving power beyond the capabilities of either data set alone. • Large bathymetric features can be inferred from altimetry sea height data.
Current Accessibility: • Classified north of 30° S; no public access.		

Table 9. Second Tier of Scientific Significance

DATA	DESCRIPTION	SCIENTIFIC UTILITY
Ice Morphology	• Describes sea ice conditions and extent over the Arctic Outer Continental Shelf. • Contains information describing ice drift and movement and includes ice edge boundary data in hand-drawn charts.	• Data would be of considerable use to climatologists; to scientists studying the near-shore transfer of pollutants; and to individuals studying near-coastal sea ice dynamics. • Data set would also be of particular use to a variety of U.S. companies who are currently faced with difficult offshore design problems for sites in the marine Arctic region.
Current Accessibility: • Classified; no public access. • Includes a synthesis of classified and unclassified data.		
Seafloor Sediment Properties	• Consists of a collection of ocean basin wide sediment thickness and sediment type. • Is the first (only) global seafloor sediment thickness database for geological studies.	• Having these data available digitally is a starting point for additional studies. • Availability of an existing global estimate of sediment thickness and approximate sediment types would provide a background against which the quality of future data could be assessed and upgraded.
Current Accessibility: • Many of these data are unclassified. • Sediment type and sediment thickness is largely unavailable. • Some sediments data are restricted because of bilateral international agreements.		
Realtime Salinity and Temperature Fields (GOODS)	• GOODS contains a wide variety of ocean measurements collected from drifting buoys, moorings, ships, and aircraft. • These data are assimilated into a near realtime view of the oceans. • GOODS contains approximately four months of global temperature and salinity fields.	• Ship observations could be adapted based on the state of the ocean, greatly increasing the efficiency of costly civilian sampling resources. • Would allow testing of satellite algorithms for either sensor calibration or validation. • As in weather forecasting, ocean models could incorporate GOODS data into the nowcast system. • Techniques could migrate into civil systems to support commercial and regulatory needs.
Current Accessibility: • Most data incorporated into GOODS are unclassified. • A small fraction are classified data because of locations of platforms providing the data, rendering the entire database inaccessible publicly.		
Archival Temperature and Salinity Fields (MOODS)	• Contains a variety of ocean measurements from drifting buoys, moorings, ships, and aircraft. • Data include salinity and temperature profiles. • MOODS is the Navy archive location for GOODS.	• Public domain transfer capability already in place (NAVOCEANO to NODC). • Can ensure timely progression of data. • Availability to ocean science community would increase ocean data explorations.
Current Accessibility: • Majority of MOODS data are unclassified and eventually enter NODC. • The classified fraction, primarily in the Arctic region, is classified because of platform locations.		
Ocean Optics and Bioluminescence	• Contains ocean clarity in specific measurement locations. • Bioluminescence data more prevalent at selected measurement sites. • Observations include both underway and on-station measurements.	• Next-generation satellite ocean color sensors will provide much better measurements in complex coastal waters. Access to both civilian and operational databases of in situ observations would significantly improve the quality of these satellite retrievals. • Could enhance the usage of less capable sensors (less expensive) in greater densities or in areas where loss of sensors is likely.
Current Accessibility: • Many of these data are classified.		

III. Improving Capabilities in Ocean Science

A. OVERVIEW

Thus far in this report we have dealt primarily with assessing the scientific utility of specific oceanographic and geophysical databases. Here we will address the more general issue of identifying opportunities for mutual benefit that might arise from a closer technical relationship between academic ocean science and the Navy's oceanographic establishment.

With congressional support, and following recommendations made by the ETF and by MEDEA, the intelligence community has established a program to collect and archive classified NTM imagery data collected from a set of locations that will be regularly surveyed over periods ranging from years to decades. The data are to be used in scientific studies of the global environment, albeit requiring classified access. Some of these measurement sites are ocean areas. One important result of the present MEDEA study has been the realization that scientific exploitation of these ocean fiducial data must involve analytical use of correlative oceanographic data from the data archives of NAVOCEANO. These "correlative data" are in many cases the same as those discussed in Chapter II: ocean thermal and salinity structure, high-resolution bathymetry, etc. The proper scientific exploitation of the ocean fiducial data is, therefore, bound up with access to NAVOCEANO's databases and modeling capabilities.

Section B discusses the rationale for the NTM Global Fiducial Data Program and the need for correlative oceanographic data in its exploitation. Section C addresses the NAVOCEANO data access capabilities, which we believe are important to scientific research in and of themselves, as well as to the exploitation of the ocean fiducial data. The final section, Bridge Building, describes our recommendations for addressing all these issues: exploitation of the NTM fiducial data, use of NAVOCEANO's oceanographic capabilities, and development of closer ties between the Navy and the civilian ocean science community.

B. GLOBAL FIDUCIAL DATA

1. SCIENTIFIC BASIS

The desirability of establishing a long-term record of well-sampled environmental databases on a fixed set of sites has been identified by the scientific community as a critical resource in identifying and analyzing global environmental change. The capability to make systematic observations over many years is essential in gaining an understanding of the fundamental physical and biological processes. Long-term data will reveal variability, such as low-frequency cyclic phenomena and decadal to centennial processes such as global warming, that cannot be resolved in data sets gathered for shorter periods. Long-term observational data also provide long lead-time indications that the global environment trends may be moving in undesirable directions and that actions may be needed to reverse these trends.

There are also discrete, or time-limited, events of both natural (*e.g.*, volcanic eruptions) and manmade origin (*e.g.*, the Kuwait oil field fires, large oil spills, or dumping of radioactive materials in the ocean) with longer term effects on the global system. Studying the effects of such events may provide important insights into how the global environmental system adjusts to these discrete perturbations as well as to longer term changes.

Another dimension of the fiducial data concept involves exploiting the unique capabilities of the nation's classified space-based reconnaissance system. Characteristics of these sensors are complementary to those of civilian and commercial sensor systems. Whereas civilian sensing systems have emphasized relatively low-resolution imaging that covers very large surface areas, classified systems provide high-resolution coverage of relatively small areas. There are also significant differences in their treatments of spectral resolution and bandwidth. Thus classified systems will add a significant dimension to the civilian environmental remote sensing program. Detailed and periodic studies can, therefore, take place at a variety of sites relatively difficult to observe by conventional means. Intense, small-scale studies can also be conducted in oceanic environments, another capability not readily available with civilian sensing systems.

Two types of fiducial sites have been defined—calibration sites and monitoring sites. Calibration sites are those for which data records already exist, especially long-term records of *in situ* data. Calibration sites will frequently be associated with ongoing research studies, thus offering the possibility of prompt assimilation and utility of the NTM fiducial data. Programs associated with fiducial calibration sites include the National Science Foundation's (NSF) Long Term Ecological Research Site Program, the NOAA National Estuarine Research Reserve System and National Marine Sanctuaries Program, and the U.S. Geological Survey's Water, Energy, and Biogeochemical Sites. Monitoring sites are those not having long-term data records.

2. THE NTM GLOBAL FIDUCIAL DATA PROGRAM

The Global Fiducial Data Program is being pursued by the intelligence community, the DoD, and MEDEA, to utilize classified, space-based sensor systems for the purpose of creating a long-term archive of environmental information. With congressional support, the program began in FY 1995 and is expected to continue.

The objective of this program is an archive of classified data that will grow both in size and value over time. As presently envisioned, this archive would be maintained within host U.S. government agencies, with access available to a community of cleared scientists and researchers.

Following historical trends, it is possible that data from certain sensor systems, as well as the operational characteristics of the sensors themselves, may be declassified. This has recently occurred with the declassification of imagery from the earliest U.S. reconnaissance satellite program (CORONA) covering 1960–1972. However, at least initially, the Global Fiducial Data Program will deal with data at the classified level leaving such evolution to the future.

The MEDEA scientific panels have initiated a process for nominating and selecting fiducial sites to support research in a variety of scientific disciplines. When approved by the United States government, a designated set of sites will then be "locked" to a program of long-term data acquisition. The initial set of fiducial sites and data collections will evolve to reflect technological improvements and expanding capabilities. The future tasking and availability of classified systems will necessitate changes and adjustments in the site populations (by type and location) and data acquisition schedules. Within the set of global fiducial sites is a subset of ocean sites where a variety of NTM data will be collected. It is this subset of ocean data that we will consider.

3. SCIENTIFIC EXPLOITATION OF FIDUCIAL DATA

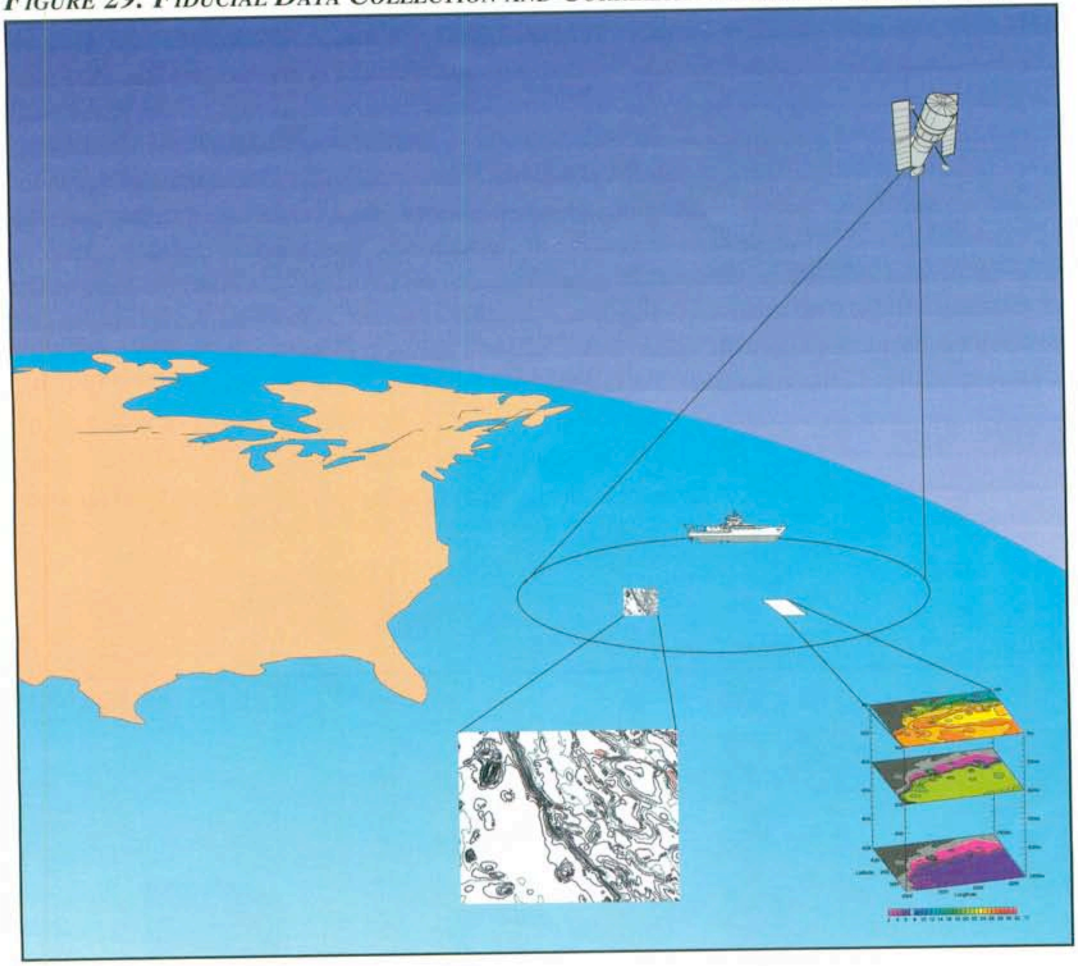
It is expected that ocean fiducial sites will involve both calibration and monitoring sites. Calibration sites can be expected to be limited largely to shallow in-shore waters and beach areas where long-term data records of fixed locations are more common and meaningful. In the open ocean it is expected that scientific exploitation of NTM imagery data will require a combination of *in situ* observations, where the sites can be selected to correspond with planned cruises, and the use of NAVOCEANO's historical archive of oceanographic data.

Effective exploitation of the NTM ocean fiducial data will require simultaneous use of these data in digital form, along with a wide variety of correlative oceanographic data that are resident at the Stennis Space Center (SSC), including both NAVOCEANO and the Naval Research Laboratory (NRL). Figure 29 depicts schematically the idea that the NTM imagery will need to be accompanied by oceanographic data drawn from a variety of Navy databases.

Archiving of the ocean fiducial data at the SSC will facilitate their prompt exploitation for ocean science, whereas waiting until the correlative data are available at the central fiducial archive site would postpone effective use of the ocean fiducial data and jeopardize the very rationale for their collection.

Determination of the number of NTM frames per year that would be made available to populate the database is still required. A 20-year timeframe is envisioned. NAVOCEANO has developed analyses of specific ocean NTM data at its Warfighting Support Center (WSC), where the correlative *in situ* data are available. These results from the WSC should be included in the fiducial database. The WSC could make provisions for a small number of visiting ocean scientists.

FIGURE 29. FIDUCIAL DATA COLLECTION AND CORRELATIVE OCEANOGRAPHIC DATA



This schematic illustration shows the concept of collection of NTM Global Fiducial Data and the use of correlative oceanographic data. For example, the correlative data could involve ocean thermal or salinity structure, bathymetry, or even model outputs involving estimates of ocean currents. Both historical data, such as that resident in MOODS and "realtime" data such as GOODS, will be useful in this analysis.

Many aspects of the database architecture remain unresolved, and these could drastically affect cost. A prominent example involves the need for an offsite/onsite image browse capability, possibly developed in phases. The first phase might involve only receiving and disseminating NTM data via courier with an on-line connectivity to IDBMS (see the next section) appearing only in a later phase. The WSC could evolve to the complete capability not only for data access but also for the analysis of NTM ocean data. This would further extend NAVOCEANO's capability, building a high-resolution, global oceanography center of excellence.

4. FINDINGS

The findings relative to scientific exploitation of fiducial data are:

- Effective exploitation of the NTM ocean fiducial data will require simultaneous use of these data along with a wide variety of correlative oceanographic data that are currently resident at NAVOCEANO.

- Archiving of the NTM ocean fiducial data at the SSC will facilitate their prompt exploitation for ocean science, whereas waiting until the correlative data are available at the central fiducial archive site would postpone effective use of the ocean fiducial data and jeopardize the very rationale for their collection.

C. ACCESS TO DATA: INTEGRATED DATABASE MANAGEMENT SYSTEM

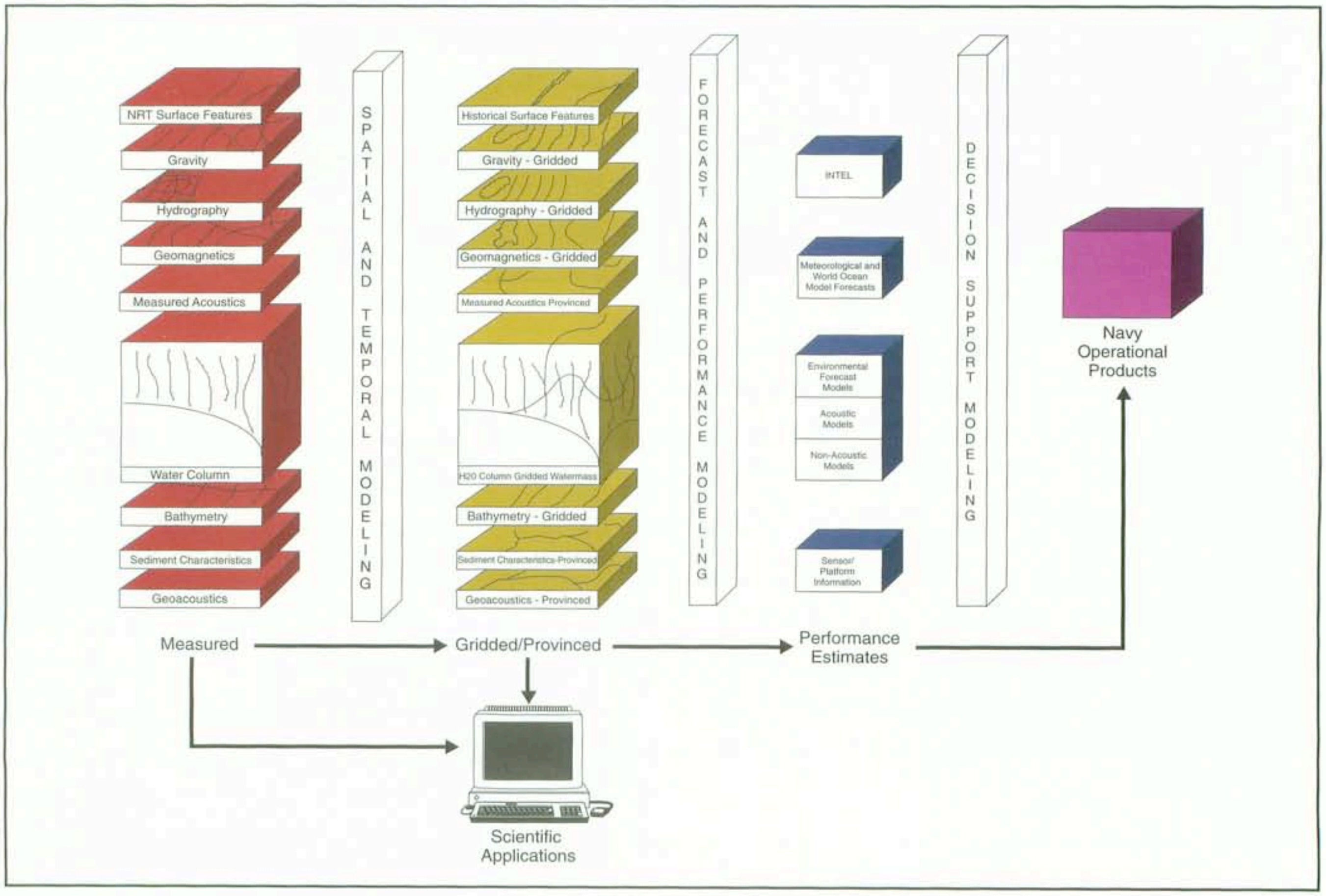
1. BACKGROUND

The results of a 100-ship-year survey program of unprecedented scope, the reduction and analysis of these data, and the development of oceanographic and acoustic modeling tools have left NAVOCEANO with a massive capability that can be cumbersome to access and not at all amenable to external use. Recognizing this problem, the Navy has developed a specialized software system to allow users to interface with an entire suite of oceanographic and geophysical capabilities.

2. INTEGRATED DATABASE MANAGEMENT SYSTEM (IDBMS)

The IDBMS is a computer system designed as an information discovery tool for all NAVOCEANO data. It has always been a NAVOCEANO goal to make its oceanographic information, data, and tools more accessible to scientists. IDBMS functions as a collection system, repository, and distribution tool for a variety of oceanographic data and products. Components of the system include distributed information systems, platform collection systems, primary oceanographic prediction systems, and computer systems for direct product distribution. The overall purpose of the IDBMS is to integrate all components into a functional system for production and distribution of products.

Figure 30. IDBMS Naval and Scientific Applications



This figure shows the integration of spatial and temporal modeling, forecast and performance modeling, and decision support modeling. IDBMS allows access to oceanographic data that can be either measured or gridded/provinced. The data are geo-referenced. A global catalog with a common user interface provides for access and management of tools, data, and information.

While IDBMS was originally intended by the Navy to generate operationally useful products, it could also be used to extract useful information for scientific studies.

Figure 30 illustrates the IDBMS concept, which shows the integration of spatial and temporal modeling, forecast and performance modeling, and decision support modeling. For the Navy's operational use, these data and modeling capabilities are used to develop specific products, such as sonar system performance. However, IDBMS also could be used to extract data and model results having scientific utility—the very data that has been the subject of much of this report.

The information and data in IDBMS are located in a series of IDBMS gateways on both a classified and an unclassified network. Those gateways on the network contain information such as gravity, bathymetry, geomagnetics, and acoustic data, as well as oceanographic projects, satellite processing, physical oceanography data, and performance tools. Access to the information is made available to users on workstations.

The user is directed through the process of IDBMS access through a main menu, with top-level functions made available for tools (accessing tools directly), catalogs (browsing), locations (global overview map), queries (searching for information), and help.

Categories of *measured* IDBMS data are shown in Table 10. Table 11 illustrates sample categories of *gridded/provinced* IDBMS data. Both types of data can be accessed from within IDBMS; however, the applications, models, and tools within IDBMS may use either one type of data or various combinations of both.

Table 10. Measured IDBMS Data

DATA CATEGORY	REPRESENTATIVE DATA CONTAINED IN IDBMS
Near Realtime Surface Features	• ocean fronts (eddies, ocean fronts, frontal points)
Acoustics	• ambient noise (beam noise, directional, omnidirectional) • echo response (3.5 KHz) • historical wind speed (mean, observed direction, observed percentiles) • acoustic survey horizons (salinity, geophysics, bathymetry, sea surface temperature, seismic) • transmission loss (frequencies, measurements, shots, sound velocity profiles, stations)
Water Column	• drifting buoys • ocean electrical properties • fixed ocean observations (MOODS) • bioluminescence • ocean currents (surface, subsurface) • optics (fluorescence, irradiance, absorbance, radiance) • ice (thickness, under ice roughness, features, forms)
Gravity	• point (satellite [Geosat], marine)
Bathymetry	• point depth
Hydrography	• geodetic control • point depth • navigation aids and hazards
Geomagnetics	• point (satellite, airborne, marine)
Sediment Characteristics	• bottom grab samples and cores
Geoacoustics	• coherence loss (frequencies, measurements, shots, sound velocity profiles) • bottom reflection loss (frequency, sound velocity profiles) • sediment sound speed • high frequency bottom loss (curve points, loss) • transmission loss (frequencies, measurements, shots, sound speed)

The architecture consists of a variety of network functions that operate the overall control of IDBMS and the primary input data and data/product dissemination. Gateway functions protect the core data storage and the client access. Central server functions access and manage data ingest, temporary data storage cataloging, and data backup. Another type of server controls the off-line and archive storage of data, as well as acting as a repository for application development and model library functions. The physical architecture of IDBMS consists of Sun Microsystems SPARC-servers, on-line RAID storage, a large-scale computer server, and high-density magnetic tape silo storage all interconnected through information system gateways, local and wide area networks.

3. FINDINGS

The findings relative to the integrated database management system (IDBMS) are:

- IDBMS should be the primary tool to allow external users to interface with NAVOCEANO's oceanographic and geophysical capabilities.
- On-site accessibility by the civilian community, cleared as necessary, should be made available as soon as IDBMS is completed.
- Upon development of a suitable multilevel security operating system, IDBMS should be made accessible over the Internet.

Table 11. Gridded / Provinced IDBMS Information

DATA CATEGORY	DATA CONTAINED IN IDBMS
Measured Acoustics Provinced	• shipping noise (directional ambient, low resolution omni, high resolution omni) • volume scattering strength (column, volume) • wind and residual noise • sonar ocean acoustic response
Water Column (Gridded)	• temperature and depth by season (GDEM)
Water Column	• drifting buoys (METOC observations) • ocean electrical properties • fixed ocean observations (MOODS) • bioluminescence • ocean currents (surface, subsurface) • optics (fluorescence, irradiance, absorbance, radiance) • ice (thickness, under ice roughness, features, forms)
Gravity (Gridded)	• ship scalar data
Bathymetry (Gridded)	• depth (5 min. and 0.5 min. unclassified, 0.5 min. and 0.1 min. classified) • bottom roughness (0.1 min.)
Geoacoustics (Gridded)	• sediment thickness • shallow water geoacoustics • shallow water geophysical • surface sediments

D. BRIDGE BUILDING OPPORTUNITIES IN OCEAN SCIENCE

1. DISCUSSION

The Naval Oceanographic Office has developed truly unique capabilities for synthesizing oceanographic products from diverse and heterogeneous data and displaying the results in useful graphical forms. Beyond the more traditional forms of product generation involving large-scale ocean thermal, salinity, and density fields, this synthesis now includes the development of small-scale regional models in selected ocean areas of naval interest and the exploitation of imagery, including NTM imagery. This product synthesis capability, if it were open to civilian use, would lead to an expanded national benefit. There has been a considerable previous investment of public funds in these capabilities, and scientific access would pave the way for ocean science to move further into small-scale oceanography.

On the other hand, there are currently few effective mechanisms for the flow of information to naval oceanography from academia. It is our conviction that such a flow of information, involving modest "shoe box" measurements or recent progress in dynamic ocean models for example, would be of considerable benefit to naval oceanography generally and to the accuracy of Navy fleet products.

The most important opportunities for bridge building, linking the civilian and Navy oceanography communities, are:

- Deriving greatly enhanced scientific benefit from NAVOCEANO's oceanographic and geophysical capabilities.
- Archiving of the ocean fiducial data in such a way as to facilitate its effective use, and providing the analytical capabilities and correlative data necessary for its scientific exploitation.
- Developing cost-effective mechanisms for much closer coupling between the nation's civilian and military oceanographic establishments to the benefit of both.

2. FINDINGS

The findings relative to bridge building opportunities in ocean science are:

a. Exploitation Center
An exploitation center should be established at the Stennis Space Center. A high data rate local area network would allow access to most classified and unclassified NAVOCEANO databases, models, and product synthesis capabilities to appropriately cleared and United States government-sponsored civilian scientists.

This center would also be the repository for the NTM ocean fiducial data, thus offering access to oceanographic capabilities for their intrinsic value as well as facilitating scientific exploitation of the NTM data.

This digital ocean data exploitation center would include capabilities to receive, store, and process large volumes of data; to decompress, format, enhance, and geolocate on demand; and to visualize and analyze the data on demand.

This center would eventually provide on-line connectivity to selected NAVOCEANO databases including those classified up to Sensitive Compartmented Information (SCI) levels. Access to the NAVOCEANO IDBMS and coregistration with the NTM ocean fiducial data are recommended. The georectification of the NTM data may not be applied routinely because of the large amount of processing required. It probably would only be conducted as part of a scientific analysis when required.

b. Regional Coastal Initiatives
Building on interest in littoral ocean areas, the Navy should expand its current efforts to build regional ocean models to include areas in proximity to the United States, possibly beginning with the Gulf of Mexico, which includes nearly all littoral types. If these models, and the fields used to initialize them, were made available, there would be considerable interest in the ocean science community. This would lead to active use, which would in turn generate feedback to the Navy, leading to improvements in the models.

c. IDBMS Connectivity

Wide access to IDBMS should be allowed. The IDBMS capability, when completed later this year, will represent a unique asset with no parallel in the civilian sector. Remote access to the classified version of IDBMS, with local exploitation through the exploitation center or via an encrypted link, should be arranged.

d. Network Accessability

On-line connectivity to databases approved for public release should be provided, thus vastly accelerating civilian use and generating feedback. It will probably be necessary to make provision for a "help desk" to address user issues.

e. Federal Ocean Science Agencies

The entire oceanography community would greatly benefit from a much stronger partnership among the United States government ocean science agencies (ONR, NOAA, NASA, DoE and NSF). In the past there has been more effective collaboration than at present, a situation which is clearly detrimental to all, particularly in an era of limited public funding for ocean science.

A significant step toward such an improvement in joint activities would be the implementation of the recommendations of this study. The civilian ocean science agencies would find that research efforts to exploit the Navy's environmental data holdings would become the focus of the improved partnership with the Navy. In turn, the Navy would find that the feedback received from close interactions with the civilian research community would lead to an evolutionary improvement in its own oceanographic capabilities. The exploitation center, in particular, would become a major source of collaborative energy in the ocean science community.

f. Visiting Personnel

Provision should be made for one or more visiting senior scientist positions at NAVOCEANO and for civilian participation in ocean surveys (with suitable restrictions regarding limits on release of any information obtained).

g. Overall

It is clear that a better understanding of Navy capabilities and problems by the non-Navy research community would lead to solutions of many problems. Encouraging researchers and students to address Navy issues by attracting them with access to data will accelerate all toward solutions for Navy problems. Clearly, a cadre of researchers would be spawned by the draw of accessible, interesting data.

Glossary

Acronym	*Meaning*
ASW	Anti-Submarine Warfare
CEAS	Comprehensive Environmental Assessment System
CNO	Chief of Naval Operations
CRTF	Classification Review Task Force
DBDB	Digital Bathymetric Databases
DCI	Director of Central Intelligence
DIPS	Digital Ice Profiling System
DGPS	Differential GPS
DMSP	Defense Meteorological Satellite Program
DoC	Department of Commerce
DoD	Department of Defense
DoE	Department of Energy
DoI	Department of the Interior
DSDP	Deep-Sea Drilling Project
EO	Executive Order
ERS-1	Satellite that was launched by the European Space Agency
ETF	Environmental Task Force
FNMOC	Fleet Numerical Meteorology and Oceanography Center (NAVMETOCCOM)
FTP	File Transfer Protocol
GDEM	Generalized Digital Environmental Model
Geosat	Satellite that was launched by the U.S. Navy in March 1985
GIS	Graphical Information Systems
GM	Geodetic Mission
GOODS	Global Oceanographic Observation Data Set
GPS	Global Positioning System
GRASS	Geographic Resources Analysis Support System; an Army Corps of Engineers (USACERL) program that is used for geophysical databases/GIS
HSL	Hydrographic Survey Line
IDBMS	Integrated Database Management System
IGRF	International Geomagnetic Reference Field
IUSS	Integrated Undersea Surveillance System
LFBL	Low Frequency Bottom Loss
MC&G	Mapping, Charting, and Geodesy
MCSST	Multi Channel Sea Surface Temperature
METOC	Meteorology and Oceanography
MOODS	Master Oceanographic Observation Data Set

NASA	National Aeronautics and Space Administration
NAVMETOCCOM	Naval Meteorology and Oceanography Command
NAVOCEANO	Naval Oceanographic Office (NAVMETOCCOM)
NGDC	National Geophysical Data Center (NOAA)
NIC	National Ice Center (NAVMETOCCOM)
NOAA	National Oceanic and Atmospheric Administration
NODC	National Oceanographic Data Center (NOAA)
NRL	Naval Research Laboratory
NSF	National Science Foundation
NSIDC	National Snow and Ice Data Center
NTM	National Technical Means
ONR	Office of Naval Research
OSD	Office of the Secretary of Defense
PMEL	Pacific Marine Environmental Laboratory (NOAA)
ROV	Remotely Operated Vehicle
rms	root mean squared
SAR	Synthetic Aperture Radar
SASS	Sonar Array Survey System
SCI	Sensitive Compartmented Information
SeaBeam	Sea Beam Instruments, Inc., a manufacturer of survey sonar systems
SeaWiFS	Sea-Viewing Wide Field-of-View Sensor
SECDEF	Secretary of Defense
SIMRAD	Manufacturer of ocean instruments
SSC	Stennis Space Center
SWDM	Shallow Water Data Model (GDEM)
Topex/Poseidon	Joint U. S / France satellite mission launched in 1972
ULS	Upward-Looking Sonar
USGS	U.S. Geological Survey
WMM	World Magnetic Model
WSC	Warfighting Support Center