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Changing Oceans and Changing Fisheries: Environmental Data for Fisheries Research and Management

Proceedings of a workshop held 16-18 July, 1996
Pacific Grove, California

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Changing Oceans and Changing Fisheries: Environmental Data for Fisheries Research and Management

A Workshop

Executive Summary

Fisheries research and management encompass a broad range of activities directed towards maintaining sustainable fisheries, protected species such as marine mammals, and the marine ecosystems upon which they depend. Fluctuations in the marine environment on varied time and space scales have impacts on the abundance and distribution of populations; exploitation by man superimposed upon environmentally-induced fluctuations creates complex dynamics in marine populations. The demise of the California sardine, the Peruvian anchoveta, and declines in west coast salmon are important examples of how the environment can affect fisheries, leading to economic and societal consequences. There has thus been an increasing awareness of the importance of environmental variability in managing fishery populations, protected species, and ecosystems.

A workshop was convened at NOAA's Pacific Fisheries Environmental Group in Pacific Grove, California, on 16-18 July 1996, to examine the uses of environmental data for fisheries. The objectives of the workshop were to i) assess the current and future needs for environmental data bases (oceanographic, atmospheric, remote sensing, model output, and geological) in fisheries research and management, ii) identify data sources and formats, and iii) recommend ways to facilitate access to the data. The workshop brought together fisheries scientists, physical scientists, and environmental data specialists to address the following kinds of questions:

- What are the current environmental data needs for research in fisheries and fisheries oceanography?
- What are the shortcomings of existing data and what are likely future data needs for research in fisheries and fisheries oceanography?
- What data sources are available, in what form, and how are they accessed?
- What are new advances in environmental data, including oceanographic model output and remote sensing products, that could be beneficially applied to fisheries?
- What environmental data products, tailored specifically for biological applications, may be appropriate and require further development?
- How have other federal agencies successfully applied environmental data sets to research problems?

Participants represented a wide range of expertise and organizations, including most line offices of NOAA, NASA, the Navy, NSF, Canada, Great Britain, and 7 academic institutions. To provide common ground for subsequent discussions, presentations by fisheries scientists addressed how environmental data are used in fisheries-related investigations; physical and computer scientists described environmental data available, including that from ocean models and geophysical investigations. The workshop also included demonstrations of ocean model output and data management systems and poster presentations describing applications of environmental data to fisheries problems.

This background information provided an ideal foundation for further discussions and generation of ideas. Five working groups convened during the workshop to address:

- real-time or near real-time environmental data applications to fisheries,
- retrospective environmental data applications to fisheries,
- applications of oceanographic and atmospheric model output to fisheries,
- data delivery systems, data accessibility criteria, and formats, and
- opportunities and mechanisms for partnerships in fisheries oceanography.

A total of 48 recommendations were generated by the working groups. These were further evaluated by participant voting to develop a set of twelve priority recommendations from the workshop. The high priority recommendations can be distilled to the following five themes:

Develop baseline time series of the most important parameters: The two highest priority recommendations apply across real-time and retrospective working groups and point out the importance of i) developing the baseline against which perturbations are evaluated for both real-time and retrospective aspects of environmental data use and ii) the importance of extending time series of important parameters back in time to evaluate resource fluctuations. These important parameters include ocean and atmospheric data, resource fluctuation data, and integrative time series that may include model output or proxy time series.

Apply new environmental data technologies to fisheries problems: New and emerging technologies have the potential to change the way in which environmental data are applied to fisheries. These techniques, however, require further evaluation and demonstration projects to convince fisheries scientists and managers of their utility. Remote sensing, multi-beam sonar, numerical models, and other techniques are expanding more rapidly than the fisheries community can assimilate them into practical applications for research and management.

Communication and sharing of expertise among disciplines and agencies: Fisheries research and management agencies are under pressure to conduct surveys, produce stock assessments, and conserve resources and habitats with often inadequate staffing. The levels of expertise required to incorporate the new technology into fisheries may need to come from other line offices of NOAA, from other agencies, and from the academic community. Mechanisms should be developed which will promote such communication and collaboration to solve high priority problems, including rotational assignments across agency boundaries and directed funding initiatives.

Demonstration of the benefits of applied environmental data in fisheries: Projects demonstrating how environmental data, model output, or new environmental technologies can be applied to marine fisheries are required in order to promote their future use in the community. Past examples of crises in fisheries exist where environmental data or model output are available. In a retrospective fashion, the scientific community should be able to show how prudent use of these environmental data could have helped understand or predict the situation, thereby assisting in management decisions.

Data accessibility for fisheries scientists: Fisheries scientists and managers are not always able to readily access the data required to do their jobs and to develop new, innovative approaches. More appropriate data bases and integrative time series, available on-line and in near real-time, must be developed.

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A Workshop

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Changing Oceans and Changing Fisheries: An Introduction to the Workshop

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> "...it is my belief that in fishery oceanography the challenge and the opportunity lies in studying the changing sea rather than the equilibrium ocean, and in studying the biological consequences of the changes at various trophic levels. .....In the aggregate this implies the necessity of observation of physical and chemical properties of sea water, its motions and mixings, and the numbers, kinds, and perhaps stages of the biota inhabiting the waters, all with space and time continuity sufficient to describe the events that take place and to investigate their inter-relationships." **O.E. Sette** (1961)

Introduction

Marine fisheries have experienced dramatic growth in the 20th century, expanding into nearly all reaches of the world ocean. As greater demands are placed on living marine resources, the rate of increase in total catch has slowed significantly (FAO 1993; Garcia and Newton 1994). The need for management of marine fish stocks is thus greater than ever. Management, however, is greatly influenced by the behavior and dynamics of the fished stocks, specifically fluctuations in distribution and abundance, which in turn are affected not only by fisheries harvests but also by variations in the environment.

A plethora of meetings have addressed questions of environmental variability and fisheries, specifically examining the role of the environment in fish stock fluctuations. FAO Expert Consultations (Bakun et al. 1982; Sharp and Csirke 1983), specialized meetings on operational fisheries oceanography, regional meetings (e.g., Wooster 1983), and a variety of ICES meetings and symposia have all focused on this topic. This dialog exists in part due to the historical approach in fisheries science, in which research and management have concentrated specifically on how fishing alone impacts the stocks, without dealing with the underlying environmental variability (Sharp et al. 1983; Bakun 1996).

Impacts of ocean variability on fish distribution have been known to fishermen for centuries. Only recently has science uncovered the relationships, and we can now categorize them on spatial and temporal scales (Smith 1978). Short term movements may be keyed to small scale fluctuations in the environment (Mendelssohn and Cury 1987; Rose and Leggett 1988). Seasonal patterns of availability are often tied to migrations. Migrations are in turn dependent upon the physiological requirement for specific environmental conditions at different life history stages, invoking adaptive behaviors such as movement between spawning and feeding grounds (McCleave et al. 1984; Lynn 1984). On interannual time scales, fishing success may often be attributed to differential movement patterns of fish in response to environmental conditions (Sette 1960), simple habitat submergence or emergence (Sharp 1978) or even basin-scale food availability (Polovina 1996). At longer time scales, we must be concerned with not only climate changes (Beamish 1995; Everett et al. 1995) but also with decadal scale changes in the ocean which impact production throughout the ecosystem (Aebischer et al. 1990; Ebbesmeyer et al. 1991; Polovina et al. 1994).

Assessing how ocean variability affects the abundance of fish is somewhat more difficult. The importance of variability in the ocean environment was made clear after the realization that fish produced in a given year could make variable contributions to the fishery. Johann Hjort (1914, 1926) was first to develop hypotheses to explain variability in year class strength that incorporated the concept of ocean variability. Hjort's *Critical Period hypothesis* invoked two types of environmental variability; first, unusual patterns of advection could direct the young fish to regions inappropriate for further development and survival. Second, variability in the availability of food when the yolk sac was absorbed, presumably itself a function of a variable ocean, could result in varying larval mortality. The critical period hypothesis has been variously expanded and modernized as the "match-mismatch" hypothesis (Cushing 1975), the "stable ocean hypothesis" (Lasker 1975) or the "member-vagrant" hypothesis (Sinclair 1987). A common thread in these conceptual ideas remains the importance of variability in the physical environment.

Since the end of World War II, major integrated fisheries oceanography programs have been developed to address these issues on various scales. The efforts have included the 1949 to present California Cooperative Oceanic Fisheries Investigations (CalCOFI), the 1984 to present Fisheries Oceanography Coordinated Investigations (FOCI -- Schumacher, this volume), the 1989-1997 South Atlantic Bight Recruitment Experiment (SABRE), and more recently Georges Bank GLOBEC, to name just a few regional programs in the US. Such studies provide the complex data useful for ecosystem models (see Pauly and Christensen 1996).

Large programs in fisheries oceanography as well as smaller scientific investigations have advanced the potential to incorporate environmental data into the field of fisheries, but we are a long way from achieving a systematic application of environmental information to fisheries research and management (Sharp 1995). Although the CalCOFI program was organized around learning the causes of the demise of the California sardine population, most early efforts in fisheries oceanography were tied to *fisheries development* as opposed to management. The Pacific Oceanic Fisheries Investigation (POFI) provides a good example. Although POFI conducted a great deal of the basic oceanographic research in the central and South Pacific in the 1950s, the fundamental goals were for "...exploration, investigation, and development of high seas fisheries of the Territories and island possessions of the United States" (Sette 1949). Environmental determinants of fish abundance and movements can be used to predict successful fishing grounds, something of obvious importance to the fishing industry. As Japan expanded its fisheries to the far seas after World War II, it developed remarkable expertise in fisheries oceanography (see Uda 1961) and a strong partnership between government fisheries research and the fishing industry developed. This remains a strong, important economic alliance today.

As marine fisheries production is reaching its upper limits (Pauly and Christensen 1995), fisheries management for conservation and sustainability becomes of critical importance (Rosenberg et al. 1993; Pitcher 1996). Because environmental variability contributes a great deal to uncertainty in fisheries management advice (Rosenberg and Restrepo 1994), there is a compelling need to incorporate increasingly complex environmental data into fishery research and management (Beamish et al. 1989). There has been no shortage of calls for improving this effort. In addition to the meetings and volumes mentioned above, expert panels of the National Research Council have repeatedly identified the need for improving our understanding of the role of environmental variability in resource fluctuations for fisheries ecology in general (NRC 1980), for managing fisheries (NRC 1994b), for bluefin tuna (NRC 1994a), for salmon (NRC 1996b), and for the Bering Sea Ecosystem (NRC 1996a). It is thus timely to assess where we stand in the application of environmental information in marine fisheries research and management and to plan and implement strategies for improvement.

There is not a shortage of environmental information, only the ability and resolve to apply it. A great deal has changed since Sette (1961) stated

> "...there are only a few things we can measure. ...In oceanography we can only measure the temperature and salinity when we want to know which way the water is running, and how fast. ...For the most part we have to deduce what we want to know from something else that we can measure."

Platforms, both moored and drifting, remotely sensed information from aircraft and satellites, and output from meteorological and oceanographic numerical models have all contributed to a data explosion, and the means of accessing, processing, and visualizing these data are continually improving. Given some of the needs, as expressed above, this workshop was developed with the following objectives:

1. to assess the current and future needs for environmental data bases (oceanographic, atmospheric, remote sensing, geological) in fisheries and fisheries-related ecosystem research;
2. to identify data sources and formats; and
3. to recommend ways to facilitate access to the data.

It was obvious that scientists from a variety of disciplines would be necessary to address these objectives, and accordingly, the workshop participants (see Appendix 4) were chosen with expertise in fisheries research and management, oceanography (physical, biological, geological), remote sensing, numerical modeling, computer science, and data management. We sought to bring together the data "supply side" (computer scientists, data managers, physical scientists and modelers) with the "consumer side" (fisheries scientists and fisheries oceanographers). While the latter are often terminal users of the data, they are not always knowledgeable about, or skilled in using, available data and data distribution systems. Further, data accessibility is changing rapidly, as are the sheer quantities of environmental data currently available. NOAA and other agencies are working to make data accessible on the world wide web (see, for example, papers in this volume by Daddio & Brazille, Stein, and Holt & Digby).

In bringing varied expertise together, it must be realized that the disciplinary *cultures* differ in ways that often make communication difficult (Wooster 1986). In the introduction to a book dealing comprehensively with environmental variability and fisheries, Andy Bakun (1996) put this in a different way:

> **Won't somebody please talk to me!** I am a physical oceanographer who works on biological and fisheries problems. As such, I find myself straddling a gap between two distinctly separate disciplines, physical oceanography and fisheries biology, each growing out of different traditions and points of view. The communication problems go far beyond mere differences in terminology and jargon, involving completely different conceptual frameworks with which information is received and organized. What is "signal" to one group often seems to be "noise" to the other.

The measure of success for fishery biologists may be the accuracy of a stock assessment, for the numerical modeler it may be the accuracy of the model in simulating the behavior of the atmosphere or ocean, and for the database manager it may be the volume of data available. Therefore, a major goal of the workshop was to improve the communication among scientists dealing with data, with oceanography, and with fisheries, potentially developing partnerships to facilitate incorporation of environmental data into fisheries research and management. There is a need to improve the utility of products from one discipline to applications in another, and it is the responsibility of the recipient discipline to clearly specify the basis of its needs.

Participants for this workshop were brought together on 16-18 July, 1996 at the Pacific Fisheries Environmental Laboratory in Pacific Grove, California, to address the following questions:

- What are the current environmental data needs for research in fisheries and fisheries oceanography?
- What are the shortcomings of existing data and what are likely future data needs for research in fisheries and fisheries oceanography?
- What data sources are available, in what form, and how are they accessed?
- What are new advances in environmental data, including oceanographic model output and remote sensing products, that could be beneficially applied to fisheries?
- What environmental data products, tailored specifically for biological applications, may be appropriate and require further development?
- How have other agencies successfully applied environmental data sets to research problems?

The dwindling potential economic benefits of fisheries have made stewardship of marine resources a priority element of the NOAA Strategic Plan ("Build Sustainable Fisheries", "Sustain Healthy Coasts", and "Recover Protected Species" -- NOAA 1996). Fisheries resource management agencies no longer house all the expertise required to address the full range of questions that use of environmental data in fisheries research and management problems entail. Thus an attractive prospect for support from Congress and funding agencies is the implementation of partnerships in oceanography, broadly defined to include interagency cooperation as well as with academia and private industry. This may become the hallmark of scientific advances as well as growth in programmatic funding (NRC 1992). Efforts to this end have culminated in a new law (Title II, Subtitle E, Public Law 104-201), the National Oceanographic Partnership Program, which provides funding incentives to leverage the resources and expertise of government agencies, academia, and industry to address multidisciplinary problems. Understanding how environmental variability influences fisheries is clearly a subject area that could benefit from such support.

Organization of the workshop report

A common basis for the diverse expertise at the meeting was provided by a series of introductory papers, which also set the stage for the working groups. Five papers describe how environmental data are used in fisheries and give a perspective on what future needs might exist; eight others describe environmental data sources of different agencies and how they can be accessed. After a series of demonstrations of environmental data systems and ocean models (descriptive abstracts are included as Appendix 1), the remainder of the workshop was spent in the five working groups. Working groups were charged with specific questions and generated reports with recommendations, which were placed in priority order through voting by participants. Also included are abstracts of posters presented at the meeting (Appendix 2), contributed abstracts (pertinent studies on applications of environmental data to fisheries and data systems that were not presented at the meeting -- Appendix 3).

Acknowledgements

This workshop would not have been possible without the work of many people. Funding to support the workshop and most of the requisite travel was funded by Project ES 96-260 from NOAA's ESDIM program. Supplemental travel funding from the National Science Foundation and the US GLOBEC program allowed participation by a greater cross-section of the academic community than our funding would allow. We thank the staff of the Pacific Fisheries Environmental Group, including Rene Luthy, Tone Nichols, Art Stroud, and Ken Baltz for providing the support to make the workshop productive and enjoyable for the participants, and the participants, whose intellectual contributions provide the value to this volume. Finally, I thank G.D. Sharp for comments on the introductory paper, a long list of scientists for reviews of individual papers, and Ken Drinkwater and Dave Somerton for comments on the volume as a whole.

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Applications of Environmental Data to Fisheries

Environmental data may be used in fisheries research and management in a variety of ways, including historical (retrospective), real-time, or prognostic applications. There are a much broader range of potential applications. The following five papers represent background on how environmental data are used in fisheries and how applications might be improved in the future.

Fishery Fluctuations and the Environment: An Historical Perspective on the Application of Environmental Data in Fisheries Science

James Johnson, Director, Pacific Environmental Group, 1969 - 1976

That weather and ocean conditions impact fishing activities goes without saying. Coastal fishermen do not go to sea in severe sea or weather conditions, and in a like manner, short term movements of fish from fishing grounds have been documented. While life and limb, both to the fishermen and the fish, may be important concerns when dealing with weather variability, fisheries managers have come to appreciate that environmental variability at several scales has major impact on fish populations. The Icelandic herring fishery in the late 1960s serves as an early example. Environmental change did not markedly alter the productivity of the stocks but led to movement of fish beyond the range of a fishing fleet restricted to coastal waters. This disruption occurred for several years and had a severe economic impact to the country. In another example, the well known demise of the anchoveta populations led to national economic disruption in Peru in the early 1970s. We are learning that many of these fluctuations are environmentally driven.

In the United States, one of the first major efforts to examine the role of ocean variability in fish distribution and abundance was at the Pacific Oceanic Fisheries Investigations (POFI). Established in Honolulu as a new laboratory in 1949, POFI's charge was to evaluate what was thought to be immense stocks of tunas in the tropical and subtropical Pacific Ocean. In addition to an impressive roster of fishery biologists, the Director, O.E. Sette, developed a staff of skilled oceanographers, including Townsend Cromwell, Tommy Austin (later the first director of NODC), Richard Barkley, and Gunter Seckel, who in 1976 assumed the Directorship of the Pacific Environmental Group. POFI is highly regarded for making important contributions to the current understanding of the oceanography in the central Pacific Ocean and beyond and for integrating oceanography into the workings of a modern fisheries laboratory.

This lesson was not lost on the Honolulu Laboratory's Deputy Director, Don McKernan, who later became director of the Bureau of Commercial Fisheries (BCF) in Washington. I had the fortune of working with Don and others at BCF during the mid-1960s in Washington, D.C., developing and providing inputs to the National Ocean Program, a high priority in the US government at the time. In 1967 an important event took place; the BCF signed a memorandum of agreement with the Navy in the collection and sharing of environmental data. At the same time there was a standing invitation to the BCF by Captain Paul Wolff, head of the Navy's Fleet Numerical Weather Central (predecessor to the current Fleet Numerical Meteorology and Oceanography Center) in Monterey; they offered to share facilities, computers, and data bases and to apply them to problems in the fisheries sector. Accepting this invitation, BCF posted me to Monterey to form the Pacific Environmental Group in August, 1969. The group, presently called PFEG, was brought into NOAA and NMFS with the rest of BCF. It has maintained a strong program in fisheries oceanography since that time. Two of the principal reasons for its success were the routine interaction and communication between oceanographers and fishery biologists and, secondly, the ready availability of environmental information from the Navy. PFEG has served as a conduit of Navy environmental data to the fisheries oceanography community, assisting in some of the advances we see today in fisheries oceanography.

Given this brief historical perspective, I am pleased to see the diversity of expertise at this workshop. Promoting communication among the disciplines involved in fisheries oceanography should be an important outcome of this workshop.

Overview of Satellite Remote Sensing Applications in Fisheries Research

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Background

Satellite remote sensing can be an extraordinarily effective and powerful tool in fisheries oceanography research, fisheries management, marine protected species research and management, and operational fisheries oceanography. The promise of satellite remote sensing technology for fisheries research, management, and exploitation has been recognized since the 1960's when the first visible and infrared images of the earth's surface were obtained from orbit. Limited uses of early satellite data were made in fisheries demonstration projects conducted in the early and mid-1970's (Kemmerer et al. 1974; Savastano et al. 1974). A number of important fisheries applications were achieved in the 1980's (Lasker et al. 1981; Fiedler 1983 and 1984; Fiedler and Bernard 1987; Fiedler et al. 1985; Laurs et al. 1984; Maul et al. 1984; and others). Significant strides, progress, and expansion in the utilization of satellite remote sensing data for meeting the needs of fisheries researchers for marine environmental information have been made during the recent decade. This has occurred primarily because of increases in the availability and improvements in the access to some satellite data, the development of easy to use satellite data processing and display software packages combined with low cost computer hardware systems, and the increasing awareness of the successes in demonstrating the application of the technology to marine fisheries problems.

Noteworthy advances have also been made in the use of satellite-derived ocean measurements to meet the operational fishery oceanography needs of various segments of fisheries industries. In the US, these have progressed from the first use of satellite-received data in fisheries-aids charts provided to cooperating tuna fishermen in the eastern tropical Pacific (Laurs 1971), to satellite-derived ocean boundary charts provided to salmon and albacore fishermen on the West coast (Short 1979; Breaker 1981) and lobster and other coastal fishermen along the East coast (Chamberlain 1981; Cornillon et al. 1986), to demonstration experiments of satellite-derived ocean products for commercial fishing operations (Hubert 1981; Montgomery et al. 1986). Several papers describing operational fishery advisory products based on satellite-derived data, which are available for use in commercial fisheries are found in Le Gall (1989).

Capitalizing on the experience gained from the Government sponsored fishery-advisory programs using oceanic satellite measurements, several US private companies presently market value-added, near real-time Advanced Very High Resolution Radiometer (AVHRR) satellite imagery and digital data products tailored to the specific needs of various segments of the US commercial and sportsfishing industries (Anon. 1994; Wynn 1989). The private sector is also planning to market fishery advisory services based on ocean color measurements made by the Sea-viewing Wide Field-of-view Sensor (SeaWiFS) sensor that has been built and will be launched and operated by a commercial venture (Lyon and Willard 1993).

Nevertheless, in spite of the impressive gains and advances, the full potential of satellite remote sensing for fisheries applications, and particularly for applications to protected species issues, still remains untapped and underdeveloped. This is especially the case in the US, which is ironic because this country has constructed, launched, and operates the majority of the satellite systems that provide data presently used in fisheries applications throughout the world. Several other countries have built on the early efforts and learning experiences gained in the US in satellite applications to fisheries and now appear to have surpassed the initial lead of the US. This is certainly true for Japan (Shinomiya and Tameishi 1988; Yamanaka et al. 1988), some of the European countries, and perhaps, even China (Bilan and Xuejia 1990; Huang 1994).

Literature Reviewing Fisheries Applications of Satellite Remote Sensing

A recent review of the applications of oceanic satellite remote sensing to fisheries is given by Fiuza (1990). Another relatively current survey is found in

Johannessen et al. (1989). Laurs and Brucks (1985) review fisheries applications in the US. Examples of uses of satellite imagery in eastern North Pacific fisheries are given in Fiedler et al. (1985). Yamanaka et al. (1988) describe the utilization of satellite imagery in Japanese fisheries and Hirano and Mizuno (1992) provide an overview of current and planned expansions in Japanese operational fisheries oceanography that will result from expanded use of data from satellite systems. Gower (1982) gives a summary of the different kinds of remote sensing data relevant to fisheries science and oceanography and Montgomery (1981) discusses the utility of satellite imagery to ocean industries, including fisheries. Two publications issued by the UN Food and Agriculture Organization (FAO) deal with the application of remote sensing technology to marine fisheries (Butler et al. 1988; Le Gall 1989).

Why Satellite Remote Sensing Data Can Be Important in Solving Fisheries Problems

Variations in marine environmental conditions affect the distribution, abundance and availability of marine fish populations. Likewise, variations in ocean conditions influence the vulnerability and catchability of fish stocks. In order (a) to understand, model and predict the effects of ocean conditions on marine fish populations, (b) to efficiently harvest marine fish stocks, and (c) ultimately, to effectively and rationally manage many marine fisheries, information is required on the "*changing ocean*," rather than the "average ocean".

Satellite remote sensing is exceptionally well-suited for measuring and monitoring the "*changing ocean.*" It offers the combined benefits of large-scale synopticity, high spatial resolution, and frequent repeatability of coverage. The primary disadvantages are that satellite measurements are mostly limited to the very near-surface film of the ocean and visual and infrared measurements are restricted to cloud-free areas. However, these drawbacks are not always serious. In many oceanic regions, conditions at the surface have been found to be representative of those in the upper 100 - 250 m (Godfrey and Ridgeway 1985 and others). The cloudiness problem can often be at least partially overcome by combining infrared or visual images of the same area acquired over several days, resulting in a temporally averaged image which oftentimes contains extensive cloud-free areas. The use of new neural network methods for satellite image processing has great potential for reducing the impacts of cloudiness (Yhann and Simpson 1995).

Satellite Oceanic Remote Sensing Cannot Replace *In situ* Measurements

It must be emphasized that oceanic satellite remote sensing systems are not, and cannot be, replacements for ships, data buoys, fixed and floating instrument arrays, and other means of making *in situ* measurements of the ocean. As noted earlier, oceanic measurements made by satellite systems, except for ocean color which is integrated over depth depending on water optical characteristics, are restricted to the most exterior portion of the ocean. The conventional means of making oceanographic observations are crucial for obtaining information on the status of the interior of the ocean and for calibrating and validating measurements made from space.

Types of Satellite Data Used in Fisheries Applications

Most fisheries and protected species applications of satellite remote sensing have made use of AVHRR infrared temperature and Coastal Zone Color Scanner (CZCS) ocean color measurements. This has been the case primarily because these data (a) have been readily available, (b) after conversion to SST and chlorophyll or related optical data, the derived data measurements can be used directly in marine resource applications, and (c) there is general understanding and confidence in the meaning of the satellite-derived data. The marine science community, and especially fisheries oceanographers, are eagerly awaiting the launch of ocean color sensors to replace the CZCS, which failed in 1986.

There has been only very limited use in fisheries applications of satellite data from active sensors. However, it is highly likely that as Synthetic Aperture Radar (SAR) satellite data become more available, its use will markedly increase. SAR can be used as an all-weather sensor to define ocean features, e.g., eddies, frontal structure, river plumes, etc., that form important habitats for marine resources. SAR data also has tremendous potential for detecting and monitoring fishing activities, possibilities for detecting schools of large pelagic fishes and marine mammals (see later section), and opportunities for supporting fishery management actions. Only a few fisheries studies dealing with transport of developmental stages (see description in Laurs and Brucks 1985), have taken advantage of oceanic wind structure measured from space by scatterometers. Nevertheless, information from scatterometers have high possibilities for expanded fisheries applications. Mitchum and Polovina (pers. comm.) are evaluating the use of altimeter data to define the occurrence and locations of high levels of mesoscale circulation activity believed to be important in central North Pacific fisheries. Some coastal and coral reef fisheries studies have employed the use of LANDSAT (Kemmerer 1980) or SPOT (Bour et al. 1986; Preston 1991) data to define habitats important to inshore and reef fisheries.

The ARGOS satellite location system is widely used in fisheries, marine mammal, and sea turtle research investigations. Global Positioning System (GPS) location systems are also used in fishing vessel monitoring systems and are under development for use on marine mammals. The eventual development of the operational system using low earth orbit satellites (Seay 1994) will provide fisheries and protected species researchers and managers with a huge expansion in the possibilities of satellite networks for both data communications and position determination. Cooperative efforts are underway between the NMFS Honolulu Laboratory and Commonwealth Scientific and Industrial Research Organization (CSIRO) Division of Fisheries in Hobart, Tasmania to use communications satellite technology for transmitting data collected on electronic “archival tags” that will be programmed to disengage from a fish and “pop-up” to the surface for relaying data via the ARGOS satellite system.

Sources of Satellite Data

For US fisheries researchers, the major source of real-time and near real-time AVHRR satellite data is the NOAA CoastWatch Program. There is little doubt that the expansion during recent years in fisheries applications using AVHRR High Resolution Picture Transmission (HRPT) satellite data is the direct result of the CoastWatch Program. This successful NOAA program, which had its beginnings to fill a need for satellite data for use in research regarding marine mammal deaths and fisheries needs on the east coast, has seven sites throughout the mainland US, Alaska, and Hawaii. Five of these sites are co-located at NMFS laboratories. The primary mandate of the CoastWatch program is to make satellite data readily available to federal, state and local agency managers and investigators, and to university scientists for use in marine research, policy and management decisions. Actions are underway to attempt to make satellite data from new sensors available at some CoastWatch sites. The new satellite data include ocean color from the planned US commercially owned and operated SeaWiFS sensor on the SeaStar satellite and the Ocean Color and Temperature Sensor (OCTS) on the Japanese Advanced Earth Observing Satellite (ADEOS), SAR data from several satellite systems, and possibly satellite wind scatterometer data. Other sources of satellite data for fisheries applications have been NASA, NOAA/NESDIS, and university satellite receiving stations. For further information on available sensors, see papers in this volume by Pichel, Maynard, and Holt and Digby.

Examples of Satellite Remote Sensing Applications in Fisheries Research and Management and Protected Species Research

No attempt will be made here to provide a comprehensive review of fisheries research and management applications of satellite remote sensing. Instead, categories of research and management applications utilizing satellite-based technology, with examples of representative studies will be given. The categories are: fish early life history and survival, definition of marine fish habitat and migration patterns, stock assessment, fishery management, protected species, and operational fishery oceanography in support of research cruises.

Fish Early Life History and Survival. Satellite ocean measurements are becoming increasing more common in research concerning the early life history and survival of marine fishes. The spawning habitat for northern anchovy in the southern California Bight can be defined using a combination of satellite-derived sea surface temperature (SST) (Lasker et al. 1981) and surface chlorophyll distributions (Fiedler 1984). In the Gulf of Mexico, larval fish assemblages have been related to the Loop Current boundary determined by satellite images (Richards et al. 1993). AVHRR satellite imagery played an important role in the investigation of the distribution and advective transport of larval fishes over the continental shelf off North Carolina (Govoni et al. 1994).

Marine Fish Habitat and Migration Patterns. A relatively large number of studies of marine fish habitat and research on pelagic fish migration have utilized satellite remote sensing data. For example, Laurs et al. (1984), using AVHRR and CZCS data demonstrated the role of oceanic frontal structure in the habitat and migration patterns of albacore. Reddy et al. (1995) used satellite-derived sea surface temperatures to show that distribution and movement patterns of southern bluefin tuna and albacore off Tasmania, Australia are related to persistent mesoscale, warm-core eddies and strong thermal fronts. Similar findings were reported for southern bluefin tuna off western Australia by Myers and Hick (1990). Using AVHRR satellite data, Kumari et al. (1993) found that the distribution of yellowfin tuna in waters off the coast of India are related to thermal boundaries. Stretta (1991) used a variety of satellite data as input into a proposed model for tuna fishing in the Gulf of Guinea region. Using satellite imagery and advanced image analysis techniques, Podesta et al. (1993) found that the probability of very high catch rates in the US longline fishery for swordfish in the Atlantic was greater in the vicinity of SST fronts. Satellite infrared observations of Kuroshio warm-core rings and their influence on Pacific saury migration was reported on by Saitoh et al. (1986). Satellite-derived ocean temperature and chlorophyll were used by Herron et al. (1989) to define the habitat of butterfish in the northeastern Gulf of Mexico.

Stock Assessment. Cram et al. (1979) used satellite ocean color data to minimize the search component of fishing effort and to refine stock assessments of pilchard stocks off South Africa. Ocean temperatures and habitat information determined by satellite remote sensing are being used in research to support stock assessment of large oceanic pelagic fishes and other living resources in the Western North Atlantic Ocean (Browder and Turner 1992). Satellite-derived environmental data are being incorporated into general linear models to develop standardized annual abundance estimates for improved stock assessments.

Fisheries Management. The application of satellite data to near real-time bluefin tuna catch projections for quota management is described by Browder et al. (1992). Also see Petit et al. (1992) and Clemente-Colon (1995) in the following section concerning the potential for direct detection of fish schools by satellite.

Protected Species. AVHRR satellite imagery is being used to reduce the impact of commercial trawl fishing on populations of threatened and endangered sea turtles (Chester et al. 1994) and to identify sea turtle habitat (Epperly et al. 1995) off the east coast of the US. Satellite remote sensing and GIS technology are being used in ecological investigations of sea turtles and marine mammals in the Western North Atlantic (Huang et al. (1992).

Operational Fishery Oceanography in Support of Research Cruises. The use of AVHRR satellite data for guiding fisheries research vessel operations is important and relatively widespread in the US. For example, most federal and many state or university fisheries oceanography cruises conducted in the Pacific and Gulf of Mexico have some sort of real-time or near real-time satellite data support. The same is generally true in the Atlantic, however, apparently it is not as routine. In some cases, the satellite-derived data simply consists of isotherm charts transmitted by radio or telephone facsimile. It is more common, however, to transmit digital satellite data or products from shoreside satellite image processing sites to research vessels at sea. In some cases, research vessels are equipped with systems for direct reception of HRPT or Automatic Picture Transmission (APT) AVHRR satellite data. An important use of satellite data is to locate ocean features important to the success of the mission of research vessel operations and to guide sampling accordingly. The satellite data are also used to interpolate and to extrapolate *in situ* oceanographic measurements made from research vessels.

Potential For Direct Detection of Fish Schools, Fishing Activities, and Marine Mammals Using Satellite Remote Sensing

Direct detection of fish schools, fishing activities and marine mammals has not been possible using satellite measurements that have generally been available to the civilian community. However, recent studies conducted off the western Mediterranean coast demonstrate that tuna schools, marine mammals and fishing activities can generate a SAR signal modulation and indicate that it is likely that with further research, it will be possible to convert radar images to pelagic fish school abundance or fishing effort estimates (Petit et al. 1992). Research conducted off Canada (Freeburg et al. 1995) has verified the application of space-based radar systems for fisheries monitoring, control and surveillance. SAR imagery has been used effectively in fishery surveillance in an Alaskan herring fishery to monitor fishing activity and could be used to manage the fishery (Clemente-Colon et al. 1995). It also appears that SAR imagery can be used for surveillance of illegal fishing activities on the high seas, e.g., detecting illegal pelagic drift gillnet fishing (Montgomery, D.R., pers. comm.). Direct observation of fish schools, marine mammals, and sea turtles may be possible from classified satellite assets.

Actions That Can Assist the US to Take Advantage of the Full Potential That Oceanic Satellite Remote Sensing Offers For Fisheries Applications

Several actions will be required in order for the US to take full advantage of the potential that satellite remote sensing can contribute to solving problems and issues in marine fisheries and protected species research and management. These actions include:

- (1) senior officials of Federal and State marine fisheries agencies need to be educated to understand the usefulness of satellite remote sensing as a major tool for use in solving appropriate fisheries and protected species research and resource management issues;
- (2) commitments are needed between the NOAA Assistant Administrator's for NMFS and NESDIS, with follow-through by appropriate senior staff, to enhance and where possible to fully develop US capabilities in satellite applications to marine fisheries and protected species;
- (3) adequate funding is required to conduct research on the application of satellite remote sensing to appropriate fisheries and protected species issues;
- (4) resources are needed for training fishery research scientists in applying satellite remote sensing to agency fisheries and protected species research needs;
- (5) NOAA should establish university fellowship programs in satellite remote sensing applications to fisheries and oceanography (similar to programs sponsored by the NWS for meteorological applications) to train students that show promise as prospective fishery scientists;
- (6) a satisfactory data management system is required which is linked with GIS for investigations using multidisciplinary data, including oceanic satellite-derived measurements; examples of systems that may be appropriate are described by Savastano and Bane (1986) and proposed by Simpson (1992); and
- (7) provisions must be made to ensure easy access by fishery scientists to data from new satellite sensors, e.g., SAR, wind SASS, ocean color, altimeter, etc. (this need may partially be met by efforts which are presently underway to expand the satellite data available from the NOAA CoastWatch Program).

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Use of Environmental Data in Biological and Assessment Surveys

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Introduction

The need for fishery independent information on the status of commercial resources is unquestionable. Technological changes associated with fishing, restrictive catch quotas, misreporting of catch and changing catchability or availability of the stock have, either singly or collectively, rendered commercial catch rates unreliable indicators of stock abundance. Standardized assessment surveys are intended to fulfill the need for reliable index information of stock abundance. The surveys are "standard" in the sense that they are fixed in time and space, use a sound statistical design, employ consistent sampling methods from year to year, and particularly for bottom dwelling species such surveys tend to be used to generate indices for several groundfish species which can give insight into compositional changes in fish communities (see for example Simon and Comeau 1994). As might be expected environmental data (historical or real time) is generally not used to direct the location or timing of these surveys.

In contrast to assessment surveys, biological surveys tend not to be standardized. The location and timing, target species, methodology, etc. of the survey are dependent on the question under investigation. Furthermore, such surveys generally use environmental data (historical and real time) as well as relevant biological data to direct the surveys. Some examples include surveys of offshore banks directed at the egg or larval stages of a particular species for examination of factors influencing survival and growth and acoustic surveys of fish aggregations designed to examine spawning and migration behaviour.

The overview to follow is intended to highlight the potential application of environmental data to assessment surveys and to review two examples of biological surveys conducted at differential spatial scales.

1. Assessment surveys

As a convenient starting point for the discussion of the use of environmental data in assessment surveys, I have chosen the research framework devised by Pinhorn and Halliday (1985 - A classification of fisheries management related problems associated with the influence of environmental factors on the distribution and migration of marine species). This framework is broken down into three levels of organization (population/stock/species) involving increasingly larger spatial and temporal scales. For example, environmental effects on a localized scale (local hydrographic conditions, currents, frontal positions) will influence fish at the population level, whereas larger-scale effects (shelf-wide circulation patterns, tidal fronts, gyres) will be influential at the stock level. At the population level the influence of environment on the location, timing and degree of aggregation are considered to have major effects on fishing success, managerial planning and stock assessment. At the stock level, the influence of environment on stock structure and distributional dynamics are considered most important in relation to management unit definition. Concerns at the species level relate to zoogeography and both long-term population trends and management plans.

a) <u>Environmental effects on a localized scale</u>: The Canadian Department of Fisheries and Oceans conducts annual bottom trawl surveys to monitor changes in the abundance of commercially important groundfish populations. Some of these multispecies surveys have been in operation for over 25 years. Like most countries, Canadian Atlantic groundfish surveys use a stratified random design with bottom depth as the major stratifying variable. For example, the Scotian Shelf is divided into 48 strata for its annual groundfish survey. Strata boundaries are defined primarily on the basis of depth and secondarily on knowledge of the distribution of the major groundfish species. Each year sampling stations within each strata are chosen at random. On the Scotian Shelf approximately 200 stations are allocated in total and individual strata receive from 2 to 10 stations with the allocation made on an approximately proportional basis. As a result of this sampling protocol the same sampling stations are not occupied each year.

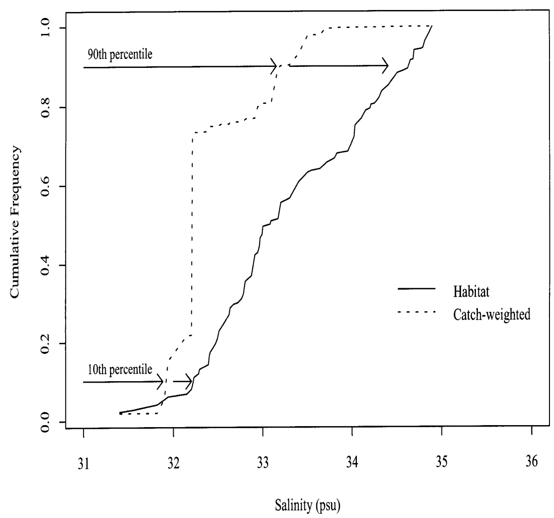

Figure 1. Cumulative frequency distributions of salinity and catch-weighted salinity for age 3 cod on the eastern Scotian Shelf for the 1983 survey. Salinity is shown as the solid line and catch-weighted salinities as a dashed line. The 10th and 90th percentiles for the salinity cdf were 32.2 and 34.6 psu, respectively, while the catch-weighted salinities were 31.9 and 33.2 psu.

Recent analyses based on the concurrent collection of catch and environmental data from surveys have shown that many different groundfish species exhibit strong and repeatable associations for particular environmental conditions (summarized in Smith and Page 1996). A methodology for identifying associations between environmental (habitat) conditions and fish distributions using survey data has been developed by Perry and Smith (1994). The method is essentially a three step process involving the i) construction of a cumulative distribution function (cdf) from the frequency distribution of the habitat variable such as temperature, salinity, oxygen or depth, ii) construction of the cdf for the habitat variable weighted by the catch data, and iii) determining the strength of the association between catch and the habitat variable by assessing the degree of difference between the two curves. An example of this methodology is shown in Figure 1 for catch weighted and available salinities for age 3 cod in the 1983 survey of the eastern Scotian Shelf. In general cod were caught in a narrower range of salinities than that generally present. There are other examples of the application of this approach including the study by D'Amours (1993) on the distribution of cod in relation to temperature and oxygen in the Gulf of St. Lawrence and studies by Page et al. (1994) and Smith et al. (1994) on association between cod (and haddock) and temperature, salinity and depth within the Canadian groundfish bottom trawls surveys (1970-1993) on the Scotian Shelf and Gulf of Maine and by Perry et al. (1994) on the association between groundfish species in Hecate Strait, British Columbia and bottom type.

An example of habitat information collected and used in a somewhat different manner was recently reported by Gregory et al. (1996). They suggested that by integrating information on substrate associations of juvenile cod (derived from *in situ* observation using submersibles) with acoustically sampled bottom classification data over broad spatial scales, the amount of suitable habitat for juvenile cod could be estimated. Their finding that the amount of suitable habitat for juvenile cod was a small portion of that available and that the location of suitable habitat was age specific led them to suggest that this information could be used to refine the use of juvenile survey data and help to determine survey designs. Because the juvenile stage in the life cycle of most marine fishes is poorly understood the ramification of such findings on guiding sample effort in research surveys is even more readily apparent - we would know where to look in the first place.

The methodology outlined by Perry and Smith (1994) may lead to improved definition of habitat space (prerequisite for expansion of spatially explicit models of fish distribution); it may provide an oceanographic basis for understanding changes in fish distributions and provide corrections to the assumption of homogeneous conditions and distributions of fish within strata, leading to correction to survey estimates of abundance. However, it should be remembered that the catch and environmental data are snapshots of conditions at the time of the survey and that the information content within the survey is assumed to be all that is necessary to explain the observed patterns. For example, if the survey design is fixed and the spatial distribution of the fish changes over time, then the result is inaccurate abundance estimates.

b) <u>Environmental effects on a regional scale:</u> Temperature is one of the most obvious environmental variables that can affect bottom trawl survey results. Temperature influences schooling and spawning behaviour (maturation), growth, distribution, migration, reaction time, and so on. Thus, variability in the

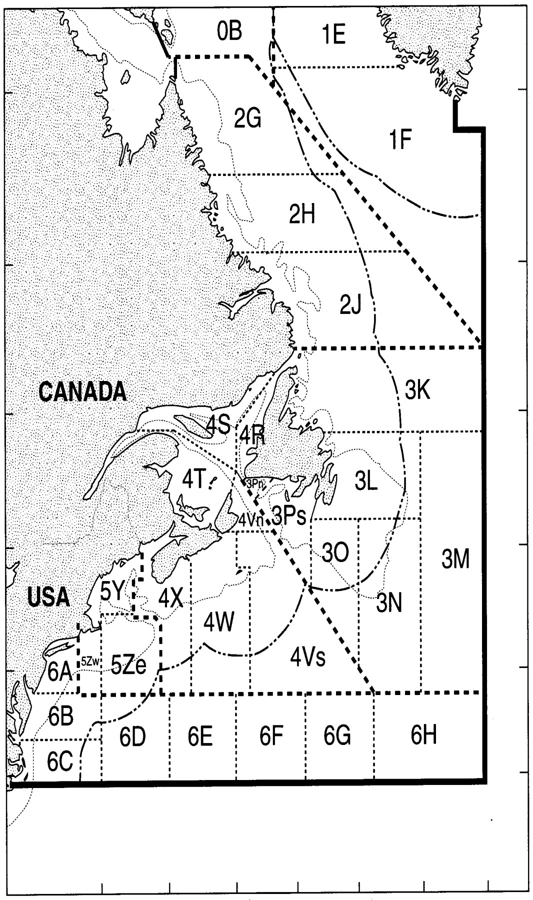

Figure 2. Northwest Atlantic Fisheries Organization (NAFO) statistical fishing areas.

temperature regime between surveys may greatly influence survey results. Survey results for species which exhibit annual patterns of migration are probably most sensitive to environmental variability. The availability of these species to the bottom trawl may vary significantly between years. Differences in migratory patterns are probably linked to environmental conditions. In order to compare results from one survey to another it is important that surveys are conducted under similar environmental conditions, otherwise, differences in catch rate may reflect difference in spatial distribution instead of abundance. Obviously, it is impossible to exactly match environmental conditions from one survey to the next. Thus, the best approach is to conduct the survey during the season when the distribution of important species is most stable. Where there are several important species it may be necessary to compromise or to conduct more than one survey per year.

The sensitivity of survey results to temperature is illustrated in the following examples:

Example 1: Disappearing capelin in the northwest Atlantic: Capelin support a lucrative roe fishery in the Newfoundland region (its principal centre of distribution is in Div. 2J3KL; Figure 2) and is a major diet item of most commercially important groundfish species. Acoustic surveys of this stock had shown a steady increase in biomass since the mid-1980s reaching a peak in 1990 in excess of 6 million mt. In 1991 the acoustic survey yielded a biomass estimate of 120 mt (Figure 3). The survey was repeated that same year with a similar result and in subsequent years the acoustic survey estimate has remained extremely low (< 200 mt). What happened to the capelin stock? Exploitation rates are generally less than 10% of the mature biomass so fishing effects would appear to be minimal. Part of the answer appears to lie in the large-scale redistribution of capelin to other geographic areas to the south and east of its principal centre of distribution, particularly in the southern Gulf of St. Lawrence, eastern Scotian Shelf, and Flemish Cap (Frank et al. 1996). These events coincided with the occurrence of atmospheric and oceanic extremes in the Labrador Sea/Newfoundland Shelf region in terms of colder-than-normal air and water temperatures, and severe ice conditions that have prevailed in these regions during the past 4-6 years (Drinkwater et al. 1995).

Capelin is a particularly difficult species to survey (not unlike pelagic schooling species in general) and excerpts from Vilhjalmsson (1994) regarding the experience of Icelandic fisheries scientists attest to this fact. "The highly mobile nature of the Icelandic capelin stock, its variable distribution and behaviour pattern from year to year and the ever changing environmental conditions, present large problems when measuring stock abundance. The success of this task under such conditions depends not only upon correctly timing the surveys, in view of past and present knowledge of stock movements and behaviour, but also on environmental surveying conditions. It has furthermore become evident long ago that the design of such surveys must allow for *in situ* adjustments to current situations, even to the extent of canceling the entire surveys or delaying them to a later date." In several years since 1978 the initial autumn acoustic surveys of Icelandic capelin have been

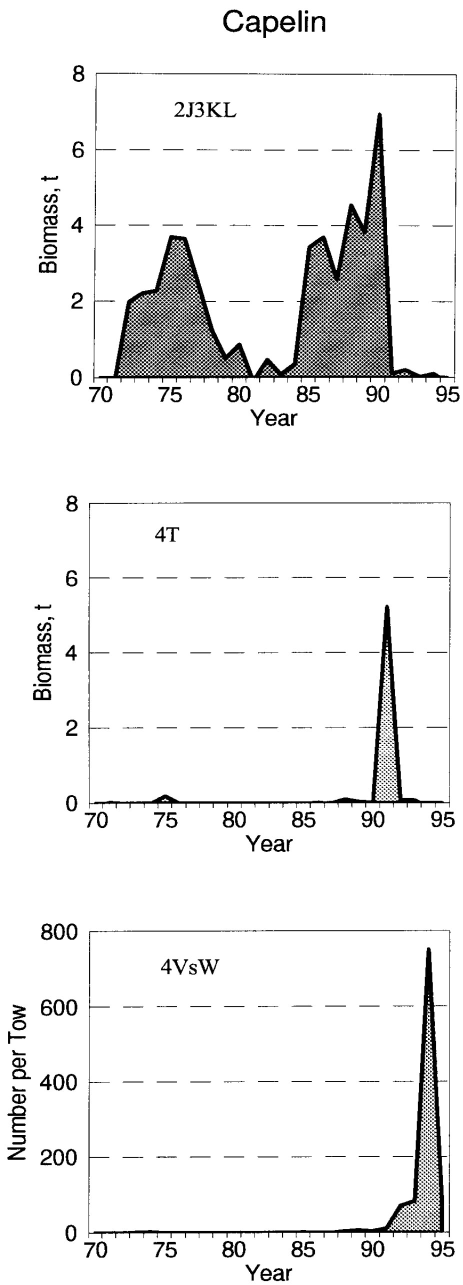

Figure 3. Estimates of capelin abundance from three geographic areas arranged from north (top panel - NAFO Div. 2J3KL) to south (bottom panel - Div. 4VsW) in the northwest Atlantic. Abundance estimates are based on acoustic surveys in Div. 2J3KL and bottom trawl surveys for the other two areas.

considered invalid and repeated due to ice conditions and/or abnormal capelin distribution and behaviour (see Table XII in Vilhjalmsson 1994).

Example 2: Changes in the availability of cod in relation to changing temperatures: Unlike capelin in the northwest Atlantic, cod is heavily exploited and attempts to relate distributional changes to environmental effects can be confounded with fishing effects. Nevertheless, it appears that the Northern cod stock (in Div. 2J3KL) has exhibited large-scale changes in geographic distribution consistent with a response to the prevailing environmental conditions (Rose et al. 1994). In general, the fall survey of this stock has indicated that cod exhibited more northerly distributions during warm years and more southerly distributions in cold years. For example, the periods 1981-1983 and 1986-1988 were characterized by markedly northerly cod distributions. These were the warmest periods of the decade. Two periods of more southerly distribution were evident: 1984-1985 and 1990-1992, which corresponded to cool periods. The magnitude of the shifts in distribution are substantial (on the order of several degrees of latitude) and the southerly shift since 1989 has been long lasting. Recent distributional changes on the scale of capelin (i.e., beyond the survey area) or greater have not been addressed.

c) Climatic effects and zoogeography: Returning to capelin, the southward expansion of capelin to the Scotian Shelf may represent a colonization event given that in 1993 successful reproduction occurred there. The newly established stock on the Scotian Shelf appears to be flourishing and experimental fishing has commenced with the issuing of licenses to several purse seiners. In the fisheries literature capelin have occasionally been reported to occur in areas outside of their normal distributional range. For example, between 1965 and 1968, unusually high numbers of capelin were recorded in the Bay of Fundy herring weir fishery coincident with colder-than-normal ocean temperatures associated with a cooling trend from 1952 to 1967. Capelin were also reported from the Bay of Fundy during other periods of below normal water temperatures between 1915 and 1919 and around 1903 (Figure 4). The current expansion of capelin onto the Scotian Shelf shows no signs of ceasing and in this respect it would be unique from other past events in terms of its persistence. It is possible that we are experiencing a regime shift in the ocean climate having profound ecological consequences.

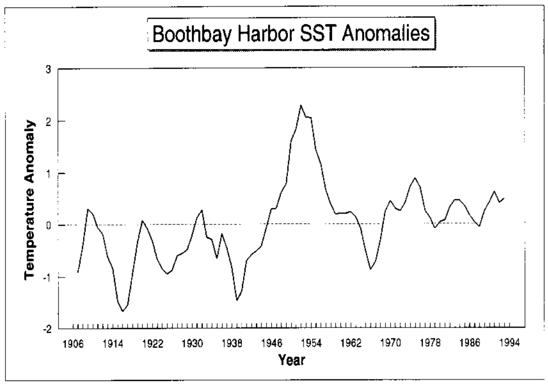

Figure 4. Long-term temperature trends in the Gulf of Maine. Nearly all of the episodes of negative anomalies (pre-1970) coincided with the appearance of capelin as by-catch in the herring weir fishery in the Bay of Fundy.

2. Biological surveys

The approach taken to reviewing the use of environmental data in biological surveys is based simply on a review of two examples, albeit at opposite ends of the spatial scale continuum. Here we will be dealing with two examples of biological surveys using environmental data to direct the sampling.

Example 3: <u>Tracking larval cod on Western Bank using data assimilation</u>: One type of biological survey commonly used in study of the egg and larval stages of marine fishes involves tracking a parcel of water containing the target population in order to estimate survival. Under the assumption that samples have been drawn from the same population, growth and survival rates can be estimated with some certainty. However, reducing the so-called advective bias is difficult and has plagued many studies using buoys to follow and sample distinct patches of larvae. One of the goals of the Ocean Production Enhancement Network (OPEN) was to develop an operational circulation model of the Scotian Shelf that would allow hydrodynamically directed, biological sampling of patches of larval cod in order to determine what was special about the small number that survive this period of their early life history. The approach was to combine physical data provided in real time (Bowen et al. 1995) with specially designed data assimilative models (Griffin and Thompson 1996) and visualization software. Based on historical ichthyoplankton data and monthly larval surveys of the Scotian Shelf conducted by OPEN, it was decided to conduct the larval tracking experiment in November 1992 on Western Bank. As expected a major concentration of larval cod was encountered and a radio-telemetering drifter was deployed in its centre followed by the deployment of thirteen additional drifters within a 30 X 30 km water mass containing the distinct group of larval cod. The Ocean Probe system (Bowen et al. 1995) and a data assimilation hydrodynamic model run in real-time on board the ship (Griffin and Thompson 1996) were used to track the water mass and resample the resident cod larvae. Observations available in near real time for assimilation were from 14 drifting buoys, 2 telemetering moored current meters, the ship's acoustic Doppler current profiler and the local wind. The experiment was successful and the patch was sampled over a 19-day period that included two intense storms (Taggart et al. 1996). An interesting feature of the circulation on the bank was a nearly stationary eddy atop the bank crest. Larvae within the eddy were retained on the bank until the onset of the storms. Based on research completed in this program shelf-wide assimilation models that can both hindcast and forecast circulation and also allow the density field to evolve with the flow have been developed.

Another biological survey using environmental data to guide sampling involves the identity of spawning locations. Using a combination of field observations, lab studies and modelling, surveys have been conducted in order to identify the most probable spawning locations.

Example 4: <u>The search for spawning short-finned squid in the western Atlantic</u>: A fishery in excess of 150,000 mt developed for short-finned squid (<u>Illex illecebrosus</u>) in the northwest Atlantic in the late 1970s. Historical data suggested that large cyclic fluctuations in the population may occur but given its short life cycle (12-18 months), there was no possibility of predicting stock abundance more than a few months in advance of the fishing season. Mature adults disappear from the continental shelf in late fall and immature animals of a new generation return next spring. Although larvae and juveniles were found in the Gulf Stream in February and March, no field information was available for the breeding period. Recognition of the need to develop a biological basis for management of the resource led to a major research effort directed at determining the

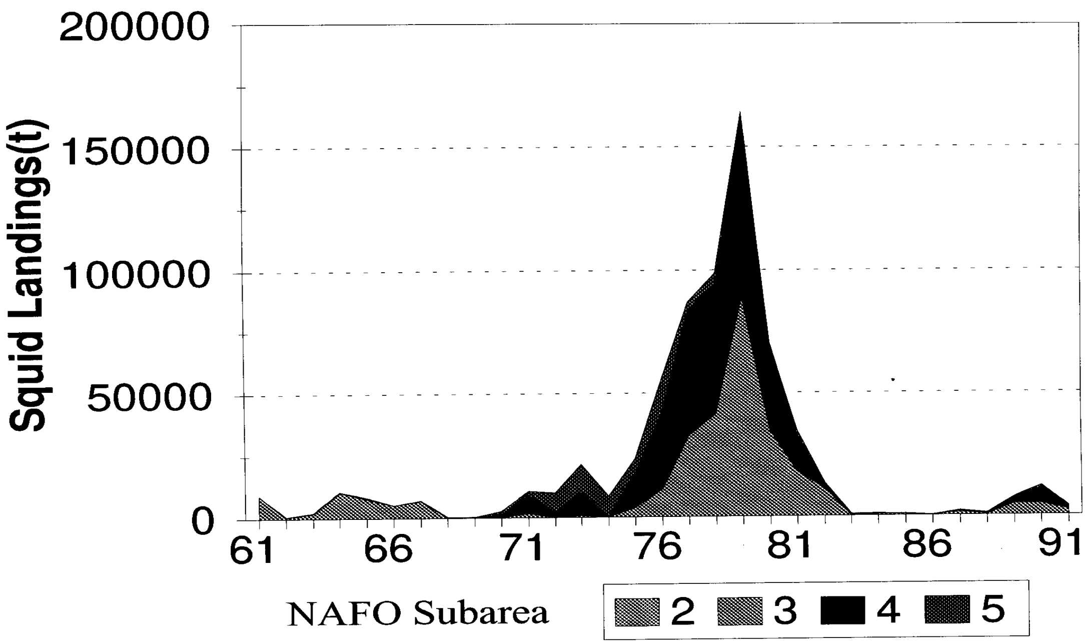

Figure 5. Landings of short-finned squid from the Northwest Atlantic by NAFO Subarea from 1961 to 1991.

essentially unknown timing and location of reproduction in the species. The question of where to look was highly problematic. Based on the assumption that Illex spawn on bottom, in water above 13˚C, and larvae are subsequently found in the Gulf Stream, the only geographic area meeting these criteria was located south of Chesapeake Bay. Trites (1983) developed a larval dispersion model that would predict an idealized distribution of larval and early juvenile stages over a 1-2 month period after spawning. Under this model, egg masses, larvae, and possibly juveniles are entrained by the Gulf Stream and transported at variable speed northeastward to areas seaward of the continental shelf along the northeastern United States, the Scotian Shelf, and Grand Banks. During the course of this transport, the juveniles either passively, along with warm core eddy formation, or actively leave the high velocity core of the Gulf Stream as it progresses northeastward and subsequently actively migrate shoreward to the continental shelf. This advection model scenario was used to guide the field sampling of eggs and larvae from the assumed spawning areas over the Blake Plateau to the offshore areas south of the Scotian Shelf and Grand Banks (Rowell and Trites 1985). Although the exact spawning locations were not firmly established, it was clear that the Gulf Stream system played a key role in determining the geographic distribution of Illex during the early life history. Catch statistics and size frequency distribution pointed to the area off Cape Canaveral, on the shoreward side of the high velocity core of the Gulf Stream, as one place where major spawning is probably occurring. Entrainment into the shoreward edge of the Gulf Steam would result in the rapid advection of larvae/juveniles northward (Rowell and Trites 1985). The weak conclusions of this study may be related to bad timing, given the stock was collapsing during the conduct of the surveys (Figure 5).

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Time, Space And Fish Scales: Applications of Retrospective Environmental Data to Fisheries Research

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Biologists often tend to ignore time and space scales when they design field programs established to support fishery management. In many cases there is a mismatch between the time and space scales addressed by the field research programs and those utilized for the development of the retrospective models that are used to manage the studied populations. Large marine fisheries field programs usually expend the bulk of their research dollars on micro-scale observations taken on mesoscale grids. In contrast, fishery models developed for management purposes are almost exclusively statistical models which attempt to describe what has happened in the past and then use these statistical relationships in combination with recent observations to establish harvest guidelines or quotas for the upcoming fishing season.

The environmental data taken during field surveys is seldom used for retrospective analyses and fishery modeling. The environmental time series these analyses and models most often utilize tend be routinely monitored meteorological and oceanic parameters which represent factors which are annual in time (i.e., one value per year) and regional in space (i.e., the entire habitat or spawning habitat of the stock). However, the actual data used are often proxy values for these scales. For example, the annual time scale may be represented by a two month average temperature representing the environmental conditions which occur during a spawning season. The spatial scale is generally assumed to represent conditions over a regional spatial scale; however, the data used are often derived from a single shore station and are therefore micro-scale proxy indices for the larger spatial scale.

One of the limiting factors associated with retrospective environmental data needs is the lack of long time series which are temporally unbiased. This generally excludes remotely sensed environmental data as well as data taken from large process oriented field studies, suggesting that NMFS is not a likely source of environmental data for retrospective analyses. For example, the temperature at Scripps Pier has been used for at least ten times as many retrospective studies as the temperatures taken in the CalCOFI field program. For retrospective uses, the cost/benefit ratio for fisheries management of the Scripps Pier temperatures is easily two orders of magnitude higher than the CalCOFI temperatures and incalculably higher than the remotely sensed temperatures.

Time Scales

Biological processes naturally occur over a wide range of time scales, from behavioral responses to individual storms to extinctions caused by factors operating on geological time scales. For the purposes of this report I have classified time into four usable categories; weather, seasonal, inter-annual and regime scales (Table 1).

From a marine fisheries perspective, weather scale effects are primarily storm related and wind is the most important factor, although flooding may be a major factor for marine species with estuarine life history stages. Events at this scale have generally limited affects on adult marine fishes and are primarily associated with behavioral responses and microscale distribution changes. However, storms can have a major effect on early life history stages and in fact a major fishery paradigm is based on factors which occur at this time scale.

Seasonal scale environmental effects, that is effects which occur over a several month period (i.e., a spawning season), are of major concern in many fisheries. The environmental factors operating at this time scale are quite broad and include transport, upwelling of nutrients, spawning season temperatures, winter turbulent mixing, and spring blooms. Biological responses at this time scale include growth, distribution, development of energy reserves, reproductive output and reproductive success. There has been a heavy reliance on environmental data at this scale for retrospective studies.

Inter-annual environmental factors have biological responses similar to most of those associated with the seasonal time scale listed above. The principal difference between environmental factors at these two

Table 1. Time, Space and Fish Scales

A. TIME SCALES

Type	Period	Environmental Factors	Biological Responses
Weather	1-5 days	Storms, Floods.	Behavior, Distribution, Early life history effects
Seasonal	2-3 months	Winter turbulent mixing, Offshore transport, Spawning season temperature, Spring bloom.	Growth, Energy reserves, Reproductive output, Larval drift, Reproductive success
Inter-annual	1-2 years	El Niño phenomenon	Growth, Recruitment, Distribution
Regime	5-30 years	Shifts in oceanic circulation, Fleet development	Carrying capacity changes, Overexploitation effects
Geological	100+ years	Erosion and sedimentation, Sea level changes, Plate movement.	Extinctions and evolution

B.SPACE SCALES

Type	Scale	Fishery Research Programs
Microscale	.001-1 km.	SPACC (GLOBEC Program)
Mesoscale	5-200 km	Georges Bank GLOBEC Program, FOCI, Tiburon Rockfish Surveys
Regional	500-2000 km.	CalCOFI Program, RACE trawl surveys, Most fishery population analyses (by default)
Basin scale	5000-20000 km.	SWFSC Albacore Program (by default), Regime Group (larger than individual stocks)
Global	The whole ball of wax	The World's fishery

C. FISH SCALES*

Species	Age at Maturity (yr)	Multiple Spawner	Maximum Age (yr)	Maximum Size (cm)	Annual Movement (km)	Stock Area (km)
Anchovy	1-2	yes	7	22	400	600
Herring	2-3	no	9	40	300 ?	400
Sardine	1-3	yes	14	34	2000	2500
Mackerel	1-2	yes	11	64	2500	3000
Albacore	5-7	yes	15 ?	150	7000	9000
Bocaccio	3-6	no	40	92	100 ?	1000
Splitnose	6-9	no	80	40	1 ?	1000

* Examples are all from the California Current Region

scales is that factors at the seasonal scale may be the result of environmental variations at the more local, intermediate spatial scales, whereas environmental variations at the annual scale, for example El Niño phenomena, are more likely to be the result of environmental process operating at the larger space scales.

Regime scale environmental factors are, almost by definition, associated with large scale shifts in oceanic circulation, upwelling, and vertical mixing. At this time scale it may be difficult to separate abiotic environmental process, biotic environmental processes, density-dependent processes and overexploitation effects; however, this time scale is the one most often associated with the failures of marine fishery management.

Space Scales

For the purposes of this report spatial scales have been divided into four usable categories; micro, meso, regional and basin scales (Table 1). It should also be noted that the temporal and spatial scales are assumed to be linked (i.e., storms are associated with micro and meso spatial scales and El Niño events are associated with regional and basin spatial scales). This does not necessarily imply that events which occur at other scale combinations (i.e., a mid-Atlantic strike of a large meteor; microscale temporal and basin scale spatial scales), are unimportant, only that they are largely outside of the realm of fishery research and management.

Large fisheries field programs have been designed to sample on a broad range of spatial scales and these scales were heavily influenced by the fishery paradigms in vogue when the programs were started. Older programs such as the CalCOFI Program of the Southwest Fisheries Science Center and the Resource Assessment and Conservation Engineering trawl surveys of the former Northwest and Alaska Fisheries Center were designed to cover the distribution of wide-ranging stocks and they are therefore regional in spatial coverage. Others such as the North Pacific Albacore program were designed as basin scale programs due to the even larger stock area occupied by albacore. More recent field programs such as the Shelikof Strait (FOCI) and Georges Bank (GLOBEC) programs have focused on meso or sub-regional spatial and the smaller temporal scales in response to early life history paradigms (i.e., as in "critical early life history stages"). Planning is currently underway in the Small Pelagics and Climate Change Program (SPACC; GLOBEC) to study climate change scale processes by examining daily zooplankton production and daily somatic growth rates of small pelagics. Here comes that meteor again.

Fish Scales

Although it is seldom mentioned, it is just as important to know the scales at which fish **populations** interact with their environment as it is to know the scale at which abiotic oceanic processes occur. The emphasis on fish populations rather than fish is critical as fishery management is based on the population response not on the individual response. For example, a large scale warm anomaly could be viewed as negative for individuals at the lower latitude edge of a stocks range and positive for individuals at the high latitude edge. Very precise, smaller scale process oriented studies in the two locations would, in this case, be expected to give opposite results to the same environmental forcing.

Fishes have evolved a wide range of life history characteristics which allow their populations to minimize the adverse effects of environmental variability at various time and space scales. These include differing longevity, age at maturity, fecundity, body size, mobility, and even large differences in the size of the geographic area that they occupy (Table 1). Some clupeid stocks spawn a single batch of eggs per year at a single site at essentially the same time each year. (i.e., Pacific herring, Clupea pallasi), others spawn 40 batches per year at a multitude of sites (i.e., South African sardine, Sardinops sagax ocellata) Some species mature at a young age, can fully develop and spawn a batch of eggs in just 24 hours, or two batches in 48 hours, and often move thousands of kilometers in a matter of months (i.e., Pacific mackerel, Scomber japonicus). Others have a delayed age at maturity, are viviparous, take several months from insemination to extrusion of larvae and they may move less than a kilometer in 50 years (i.e., splitnose rockfish, Sebastes diploproa). In quite different ways both Pacific mackerel and splitnose rockfish have life history characteristics which largely buffer their populations from environmental variation at the smaller scales (Table 1). In contrast, the Pacific herring is likely to be affected by environmental events at the smaller time and space scales as well as those at the larger scales.

Table 2. Scales vs. Fishery Paradigms

Critical Stage Paradigm, Early Life History (ELH) Paradigm
Concept: Hjort, (single spawners, favorable ELH window)
Weather time scale (i.e., intense storm, turbulent mixing)
Mesoscale - Sub-regional spatial scale (i.e., storm spatial scale)
Concept: Lasker, (multiple spawners, i.e., not enough forage for first feeding)
Seasonal time scale
Regional spatial scale
Larval Transport Paradigm
Concept: Various researchers, (crucial larval drift patterns)
Weather to Seasonal time scales
Regional spatial scale
Equilibrium Carrying Capacity Paradigm
Concept: Environment with normally distributed white noise
Concept: With red and white noise
Concept: With edge effect (i.e., temperature tolerance)
Weather - Seasonal time scales
Regional spatial scale
Regime Paradigm
Concept: Jyungman*, (large scale oceanographic cycles)
Decadal time scale
Regional, Basin or Global spatial scale

*Jyungman, A. 1880. Contribution toward solving the question of the secular periodicity of the great herring fisheries. U.S. Comm. Fish and Fisheries, Rept. of the Commisioner for 1879 p. 497-503.

Fishery Paradigms

Following the above pattern the most common present paradigms concerning the effects of the environment on fish populations are divided into four categories; critical stage, larval transport, equilibrium carrying capacity, and regime paradigms (Table 2). A fifth very important paradigm, “it's all due to overfishing,” was excluded from the classification scheme since it has no environmental component. Any readers should note that when the boundaries of one of these paradigms is extended far enough it enters the boundaries of what another reader would classify as another of the paradigms. In addition, the critical stage and larval transport paradigms focus on recruitment and they are popularly limited to the early life history stages when mortality rates are at a maximum. Recruitment, however, is not exclusively a ELH problem since it is also critical that a fish survive the juvenile and pre-adult stages before it can be recruited to the adult population. Note that it is not uncommon for recruitment to the adult population to take 5 or more years. It is also very important to realize that modeled populations generally only have to cope with one of the paradigms whereas real populations must cope with all of them.

The critical stage paradigm can be subdivided into two quite different problems. The first primarily deals with higher latitude species such as herring which mature a single batch of eggs per year, have quite short and precisely timed spawning seasons, and deposit all of their eggs at a single site. The second deals with subtropical or tropical species such as sardine or mackerel, which produce numerous batches of eggs over spawning seasons lasting from 3 months to the entire year, and individuals may spawn over a very wide geographical area. In the first case it would be expected that weather time scale and meso spatial scale environmental variations could play a key role in the determination of recruitment. In the second case these scales are less likely to influence recruitment since there is a continuum of critical stages occurring over a broad expanse of time and area. A very large amount of early life history research has been carried out under this paradigm in the last decade. To date the majority of this work has been utilized in the real time, descriptive mode and there has been little practical application of retrospective analyses. This may primarily be due to the fact that few of these ELH studies have been carried out for a long enough period of time for retrospective analyses to be more than anecdotal.

The larval transport paradigm has been applied to a wide range of species and its basic concept is that variations in wind and thermohaline-driven transport between a species spawning and nursery grounds is a major factor in the determination of recruitment. The principal environmental data sources which have been used to test this paradigm are wind-speed time series derived from meteorological models (available for meso (1946-present) and weather (1967-present) scale retrospective analyses. Weather to annual scale time series for ocean circulation, which include the thermohaline driven circulation, have generally not been available to fisheries researchers in the past, and sea level height has been extensively and successfully used as a proxy for the intermediate to larger time and space scales. Recent and proposed coupled ocean-atmosphere models are well suited to this paradigm and the usage of these models to produce mesoscale hindcasts extending back to the 1950s will allow a great expansion of retrospective studies under this paradigm.

The carrying capacity paradigm is of course borrowed from terrestrial ecology and its original usage is based on the concept of a steady-state system. For the present classification scheme, its meaning is limited to the steady state, or equilibrium, carrying capacity concept. Under this paradigm environmental effects are viewed as variance about a mean (the carrying capacity). This still allows a very wide range of definitions. For example the variance could come about through temporal variation in the "quality" of a given geographical region. It could occur through geographical expansion and contraction of the region with a constant "quality". For example, a subtropical species which lives adjacent to a large area that has temperatures just outside of the species temperature tolerance could temporarily occupy a much larger geographic range, with a greatly increased carrying capacity if the region experiences anomalously warm temperatures. The carrying capacity paradigm differs from the critical stage and larval transport paradigms in that carrying capacity is often viewed as a process which limits the adult component of the population rather than the early life history stages. These stages are not necessarily excluded from the paradigm, however, as the carrying capacity limits could be acting upon ELH stages or juveniles.

Typically environmentally induced variance from the equilibrium carrying capacity concept is considered to be white noise at the seasonal or interyear time scale. Introduction of autocorrelation at the longer time scales alters the concept and when this autocorrelation approaches decadal time scales the carrying capacity paradigm becomes the regime paradigm. The basis of the regime paradigm is that there are natural decadal, or longer, shifts in basin, or global, scale environmental conditions which result in alterations in the carrying capacity for the dominant, and perhaps other fishes, of a region.

Retrospective Environmental Data Requirements

The many fisheries oceanography workshops which I have attended over the past two decades all had two things in common. None of them stated which specific environmental data are needed for fisheries and they all developed a similar shopping list of environmental variables which included everything that anyone present could think of. I have therefore attempted to make a short list of environmental variables I believe would be useful to a wide range of fisheries and other biological researchers engaged in retrospective analyses and modeling. In each case the utility of the time series will be greatly enhanced by each year that it can be extended into the past. In each case NOAA, the US Navy, and US Academia currently have programs which are presently producing, or have the capability to create the time series.

1. Monthly or bimonthly time series of the geostrophic transport of the major current systems of interest to US fisheries (i.e., the Alaska, California, Labrador, Loop, and North Pacific Currents and the Alaska and Gulf Streams). This will require hindcasts of nested, coupled ocean-atmosphere models. As a comment, it might be noted that if NOAA cannot provide fisheries management with accurate time series of **the principal oceanographic feature** of each of our major marine ecosystems, we cannot expect to either understand or manage our fisheries.

2. Daily time series of surface winds at mesoscale spatial resolution for the US EEZ. This information is presently available both as raw data (COADS and meteorological buoys) and model output from US Navy and NOAA meteorological models. Incremental increases in the accuracy and availability of products should be of very high priority to NOAA.

3. Monthly time series of sea surface temperature are currently available and should be maintained (COADS, shore stations, and model output). It is particularly important to maintain the existing shore stations (SST and sea level) **which have long time series.**

Perspective

Most of the models and analyses presently utilized for fisheries management are retrospective. Although most researchers believe that environmental factors have major effects on fish populations, many (and probably most), of the retrospective analyses and models utilized for fisheries management do not include any environmental input. Although most researchers believe that inter-species interactions have major effects on fish populations there is a similar lack of utilization of interspecific information in fisheries management. The track record of fisheries management is dismal and, although it is obvious to those of us who have observed the process for several decades, much of the problem is caused by an institutional failure to make the hard choices; it is also obvious that the track record of fisheries predictions is nothing to be proud of.

The vast majority of current research resources has been directed into large process-oriented field studies which are very unlikely to provide management quality results within the next decade; it is my opinion that many, perhaps most, of these studies will not, and probably should not, be carried out for a long enough period of time to provide such results. Meanwhile the basic fishery sampling programs, which have never been of even moderate priority within many of the NMFS Regions, are providing an inadequate fishery data source to the small cadre of mathematically adept (but not necessarily oceanographically or biologically adept), modelers that are providing the information presently utilized for fishery management decisions.

How can NOAA/NMFS alter present trends? Let's have a workshop!

Applications of Environmental Data in Fishery Assessments

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The assessment of the status of exploited fish stocks provides the technical basis for estimating a level of fishery harvest that achieves optimum yield while preventing overfishing. These assessments are typically based on demographic models which incorporate much biological and fishery data, but rarely incorporate environmental information. However, environmental factors are known to affect fish biology, fish distribution, and recruitment of young fish into adult populations. In turn, these factors affect the productivity of the fish stock and our ability to relate standard fishery and survey data to true changes in the population. This document explores some of these relationships in order to better understand the potential benefits from including environmental data in fishery stock assessments. The focus will be on west coast bottomfish (termed groundfish), particularly Pacific hake (whiting), to illustrate the important issues. Most of these species are demersal and live for decades so are not expected to be highly responsive to short-term fluctuations in surface ocean conditions. A similar examination of short-lived, pelagic species would find more responsiveness to environmental conditions on shorter time scales, and a greater role for near real-time environmental information.

Stock Assessment Modeling

A stock assessment is designed to evaluate the abundance of a fish stock and its potential yield. The potential yield is typically determined as the product of a forecasted available biomass and the constant exploitation rate estimated to produce the optimum long-term average yield (Clark 1993). Thus, fishery harvest is expected to fluctuate in proportion to changes in the size of the harvestable population. Most major west coast and Alaska groundfish stocks have annual quotas set primarily on this basis.

The forecast of available biomass is rarely based on a current resource survey of absolute biomass. Instead, demographic models, termed stock assessment models (i.e., Methot 1990) are used to infer the historical and current absolute biomass from fishery data (total removals and catch-at-age), survey data (trends in relative abundance), and life history information (growth, natural mortality, maturity). Like all models, stock assessment models are approximations of the true processes affecting the exploited populations. The accuracy of the model output depends on the stability of the relationships between the relative indices and the true population; but these relationships may change with environmental change.

The exploitation rate that will produce optimum yield depends on natural mortality, fish growth, age at maturity, and age at recruitment to the fishery. As environmental factors change these biological characteristics of the stock, the optimal exploitation rate and yield will also change. The optimal exploitation rate also depends on the shape of the spawner-recruitment relationship. If recruitment declines substantially as the spawner stock is fished down to moderate levels, then the long-term optimal exploitation rate must be lower to assure long-term protection of an adequate spawning stock. Estimation of this spawner-recruitment relationship is hindered by environmental effects on two time scales. First, environmental factors may cause a high degree of inter-annual recruitment variability which hinders detection of any stock-recruitment relationship without a long time series of data and observations over a wide range of spawner abundance. Second, estimation of the true spawner-recruitment relationship can be confounded when long-term trends in the environment are correlated with long-term fishery-caused declines in spawner abundance.

Growth and Maturation

Annual fishery quotas are normally set in terms of a tonnage of fish that can be safely harvested. However, the number of fish that are actually taken by the fishery will depend on the average weight of the harvested fish. Thus, environmental effects on fish growth are important to understand and to monitor. Lenarz et al. (1995) describe how body weight of central California rockfish declined during the 1992-1993 El Niño and caused an increase in the fishing mortality rate. Dorn (1992) notes a low weight-at-length for Pacific hake in the 1983 El Niño and relates long-term declines in weight-at-age to an environmental effect, indexed by ocean temperature, and a density-dependent effect linked to the abundance of hake. From these studies, it appears that a one-year forecast of environmental conditions that affect fish growth could refine forecasts of the potential yield of fisheries.

Environmental effects on the maturation of fish are likely to be similar to the effects on growth, although in some circumstances fish may trade-off growth in order to devote more resources to reproduction. Changes in the reproductive output of fish may have two effects. First is a direct effect on the number of eggs produced, thus a potential effect on future recruitment. Second is an effect on ichthyoplankton based estimates of spawner abundance. Methot (1989) needed to adjust for temperature effects on maturation of northern anchovy, a small pelagic fish, in order to use larval abundance as an index of historical spawning biomass. Because there were not annual estimates of age-specific reproductive output by adult anchovy, a relationship between temperature and fraction mature was used to predict the per capita egg production. He concluded that the high anchovy biomass during the early 1970s did not show up in the ichthyoplankton surveys because the cold temperatures retarded reproduction.

Distribution

Environmental factors that change the geographic distribution of a fish stock can have profound, immediate effects on resource surveys, fisheries, and assessment models. Changing distributions can also affect the biological productivity of the resource. Pacific hake on the US west coast (Methot and Dorn 1995) offer excellent examples of these effects. Pacific hake typically spawn during winter off southern California. During spring a northward migration occurs so that by early summer the adult stock is spread from central California in the south to Queen Charlotte Sound in the north. Larger individuals tend to migrate further north, but many age groups are broadly distributed along the coast. US and Canadian fisheries occur from about May to September, and a hydroacoustic survey is conducted triennially during July-August. The return southward migration occurs in late fall-early winter. Although details of the migration are not well known, including lack of knowledge of environmental cues for migration timing, it is obvious that the extent of the migration is highly responsive to El Niño conditions.

An environmentally-linked model of hake migration appears feasible. Dorn (1995) determined that the extent of the northern migration into Canadian waters was closely correlated with water temperatures during the migration. About 15% of the adult hake are in Canada in a cold year like 1989, and 50-65% of the older age groups are in Canada during El Niño years like 1983 and 1992. A model of this process can improve the precision/cost of hydroacoustic surveys by predicting the northern extent of the stock, and can adjust data from pre-1992 surveys which did not extend to the northern limit of the stock.

Allocation of hake yield between the US and Canada is based partially on the distribution of biomass as observed in the hydroacoustic surveys, although there is not complete international agreement on the details of the implementation. Efforts to date have focused on development of a single allocation factor based on historical average distribution levels. The environmentally-driven variability in the biomass distribution has complicated the development of an agreement. Annual fluctuations in the distribution have been shown to be responsive to environmental conditions during the northward migration so it may be technically feasible to develop a migration forecast a few months before the summer fishery and adjust the allocation accordingly. However, the value of such an environmentally-driven allocation formula has not been shown to be sufficiently beneficial to offset the uncertainty it would create for fishery managers and the fishing industry. A regime shift in the ocean climate could have a major impact on this allocation issue. The historical period used for the allocation discussions is 1977 to present, but there is evidence of a regime shift during the late-1970s and colder conditions during the early-mid 1970s (Dorn 1995). A return to these conditions could reduce the northward extent of the hake migration.

After the 1992-1993 El Niño, there is evidence of hake spawning and successful recruitment off Oregon and northward to Vancouver Island. During 1994 -1995 there was unprecedented bycatch of age zero and age one hake in the shrimp trawl and other fisheries off Oregon - Washington. The 1995 hydroacoustic survey found two-year old hake of the 1993 year class in their normal geographic location off central-northern California. However, one-year olds of the 1994 yearclass were confirmed to be most abundant off Oregon and northward into Canadian waters. The northward displacement of this young, and not yet marketable, yearclass has created bycatch problems for the 1996 fishery. The northward displacement also creates great uncertainty when trying to estimate the actual magnitude of the 1994 yearclass from the level of bycatch in the fishery and the survey. Preliminary estimates of the range of potential yield in 1997 ranges from about 260,000 mt to 340,000 mt depending on the projected abundance of the 1994 yearclass when it recruits to the fishery as three-year olds in 1997. The total impact of the environment on this yearclass' contribution to the fishery may be even greater. Its northward distribution may cause it to have different rates of natural mortality and body growth, and the northern distribution will almost certainly cause it to be more available to the 1997 fishery than is normal for three-year old hake. During the 1960s and 1970s, a reasonable recruitment index for hake was obtained from midwater trawl surveys off southern California (Bailey et al. 1986). While there is interest in developing a new recruitment index for hake, obviously such an index must account for the possibility of extreme geographic shifts.

Recruitment: Long-term Patterns

If the dominant mode of environmental fluctuation is multi-decadal, then our 20-30 years of monitoring stock-recruitment relationships for fish stocks may have produced little more than one independent observation. During the past twenty years, fisheries for many west coast bottom fish have increased to a full exploitation level and have caused an expected decrease in stock biomass. In the same twenty year period, there has been a regime shift in the ocean climate and evidence of a decline in zooplankton productivity (Roemmich and McGowan 1995). For several species of rockfish, recruitment and adult biomass appear to have declined substantially. Is the decline in recruitment dependent primarily on the decline in adult biomass, hence indicating that the stocks are less resilient to fishing than previously assumed? Or is the decline in recruitment primarily dependent on the long-term shift in the ocean climate? Answers to these questions may have a profound effect on recommendations for future, safe levels of fishery harvest. It is not unreasonable to postulate that one evolutionarily significant reason for the longevity of these species is to provide population resilience during multi-decadal cycles in recruitment. Thus, better understanding of these long-term patterns will provide a basis for improved, long-term stewardship of these fish stocks.

Recruitment: Short-term Forecasts

Improved recruitment forecasts are valuable on a time scale that is sufficiently long so that much of the population's biomass will be in yet-to-be-recruited year classes, and sufficiently short so that there is reasonable precision to the recruitment predictions. Forecasts of pollock recruitment in the Gulf of Alaska from environmental data (Megrey et al. 1996) show that crude (i.e., low/medium/high) recruitment estimates can significantly improve the one-year forecast of population trend and fishery potential yield. The cost, timeliness, and precision of recruitment estimates ranges greatly among various potential methods. The shortest range forecast comes from incidental catch in the fishery. This is cheap and imprecise, but may be adequate for some purposes. The longest range recruitment forecasts will require better skill at forecasting low-frequency changes in future climate (including regime shifts) coupled to an improved understanding of the linkage between recruitment and climate. In between are estimates based on recent environmental data, larval surveys, and pre-recruit surveys. The economic value of these predictions will depend on the management and fishery response. Can errors in fishery management be better avoided if there is more advance information on changes in stock level? Can overfishing be better avoided if a downturn in the stock is predicted several years in advance? Can more value be obtained from the fishery if it has a longer planning horizon for changes in available yield? Technical answers to these questions depend upon several factors including value and timeliness of the improved fishery forecast, precision and cost of the forecast, and magnitude of the recruitment fluctuations.

Conclusion

The ocean climate affects the productivity and distribution of fish stocks and our ability to understand fish population dynamics through fishery stock assessment modeling. Some of these factors affect our interpretation of standard survey and fishery data, other factors directly affect the biological productivity of the fish. The most dramatic effects are with regard to fish distribution and recruitment of young fish. Subtler changes in fish growth and maturation also have an important impact on fishery stock assessments. This paper has focused on fishery assessment issues common to North Pacific groundfish stocks. The environmental data needs for improvements in these assessments focus on improved long-term indices and improved understanding of climate regimes. However, even for these long-lived species, some environmental indices that predict groundfish growth, distribution, and recruitment can have value on a few months time scale. For shorter-lived pelagic species, environmental data needs will also have a shorter time scale.

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Environmental Data Sources and Accessibility

The papers in this section were designed to demonstrate the range of environmental data presently available. Eight present environmental data sources and systems at different agencies of the government and an approach to using geological data for characterizing fisheries habitat. These topics are complemented by a several demonstrations from the workshop (Appendix 1), poster abstracts (Appendix 2), and contributed abstracts (Appendix 3).

NOAA/NESDIS Ocean Remote Sensing Data Resources and Delivery Systems

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I. Introduction

The first half of the decade of the 1990's has seen a proliferation in research and operational satellite remote sensing systems devoted to oceanography. The number and variety of these sensing systems will continue to increase in the latter half of the decade. This paper provides a summary of these systems. In order to bound the set of systems to be described, only operational and pre-operational systems currently available or planned to be available through the National Environmental Satellite, Data, and Information Service (NESDIS) of the National Oceanic and Atmospheric Administration (NOAA) until the year 2000 are included. It should be noted that NOAA involvement in some of the future missions described is subject to the availability of funding.

First, the remote sensing systems will be summarized, grouped by the following sensor types: (1) infrared/visible (medium resolution, high resolution, and ocean color), (2) passive microwave, and (3) active microwave (altimeters, scatterometers, and synthetic aperture radars). This summary will be followed by a description of the ground systems in place or planned for operational delivery of data from these satellite remote sensing systems.

II. Current and Near Future Ocean Remote Sensing Data Resources

There are three main classes of satellite sensor systems being used currently for oceanography: (1) passive systems sensing in the visible to thermal infrared portion of the electromagnetic spectrum, (2) passive microwave systems sensing emitted microwave radiation, and (3) active microwave systems which provide their own illumination and measure the properties of the scattered return from the ocean surface. Table 1 is a summary of the ocean parameters capable of being measured from each of these classes of sensors. Some of these parameters are already being measured routinely and are available operationally in near real-time (indicated by bold type), whereas other parameters are produced experimentally or are under study for future production (indicated by normal type). The current suite of satellites carrying ocean remote-sensing instruments with data made available through NOAA are listed in Table 2a. Future satellites are listed in Table 2b. In these tables, the satellite names and operating agencies or countries are given across the top with planned year of launch added in Table 2b. Satellite and sensor name acronyms found in Tables 2a and 2b are explained in Appendix A. Information for these tables came primarily from Patzert and Van Woert (1996), German Remote Sensing Data Center (1996), and NOAA/NESDIS (1996). The ocean instruments given in Tables 2a and 2b are described in the following section.

A. Visible and Infrared Satellite Ocean Remote Sensing Systems

Satellite oceanographic sensor systems measuring radiation emitted by the earth/ocean/atmosphere in the visible to thermal infrared (IR) portion of the spectrum (0.4 µm - 15 µm) fall into three general classes: (1) medium resolution instruments (0.5 km - 8 km resolution) for general land/ocean/atmospheric remote sensing, (2) high resolution instruments (10 m - 120 m) for coastal/land remote sensing, and (3) special purpose instruments for measuring ocean color and associated parameters such as chlorophyll concentration. Table 3 summarizes the characteristics of the current and future visible/infrared satellite ocean remote-sensing instruments which are listed in Tables 2a and 2b.

<u>1. Medium Resolution Visible/Infrared Systems</u>; Medium resolution visible/IR satellite remote-sensing instruments have been used for sea surface temperature (SST) determination; mapping of ice edge, concentration, and motion; calculation of ocean currents (Breaker et al. 1994); and mapping of turbidity and ocean features (such as eddies and fronts). These geophysical measurements have wide-ranging application; for example, as input to numerical weather and ocean models, as tactical support to oceanographic surveys in support of fisheries science or physical oceanographic research, in the protection of endangered species such as sea turtles (Epperly et al. 1995), and in the study of red tide outbreaks (Chester and Wolf 1990). It is important to remember, however, that visible and IR instruments from space are not useful for ocean

Table 1. Remotely sensed ocean parameters

TYPE OF INSTRUMENT	OCEANOGRAPHIC PARAMETERS OR APPLICATIONS
VISIBLE & INFRARED	
1) Medium Resolution	**SST***, **Ocean features**, **Ice edge/concentration**/motion, Currents, Turbidity
2) High Resolution	**Land use, Land/water boundary**, Coral reef mapping, Turbidity, Pollution
3) Ocean Color	Water-leaving radiances, Chlorophyll, Total suspended solids, Diffuse attenuation, Ocean features, Phytoplankton bloom identification, Currents, Primary productivity, Pollution
PASSIVE MICROWAVE	**Ice edge/concentration/type**/motion, **Scalar winds**
ACTIVE MICROWAVE	
1) Altimeters	Sea surface height, **Scalar winds**, **Significant wave height**, **Ocean features**, Ice edge/topography, Ocean circulation,
2) Scatterometers	**Vector winds**, Ice location
3) Synthetic Aperture Radars	**Ice edge/concentration/type**/motion/, **Wave spectra**, Vector winds, Ocean features, Currents, Slicks, Internal waves, Vessel surveillance, Land/water boundary

*Bold-face applications are currently operational, others are experimental or planned

observation when there is thick, unbroken cloud cover. These clouds are opaque to visible and IR radiation coming from the ocean's surface. Refer to Table 3 for characteristics of the current and future medium resolution visible/infrared systems described below.

a. AVHRR/2, AVHRR/3, and the GOES Imager; The operational workhorse for satellite oceanography since 1979 has been the Advanced Very High Resolution Radiometer (AVHRR) flown on the NOAA Polar Orbiting Operational Satellites (POES) designated as "NOAA." The current satellites in this series are NOAA-12 and NOAA-14. The AVHRR instrument with its 2700 km swath width (i.e., east-to-west viewing swath on the ground) was designed for global coverage, so each point on the earth is imaged approximately every 6 hours by the two-satellite system. The current generation of AVHRR instruments, AVHRR/2, dates back to the NOAA-7 satellite launched June, 1981. The first AVHRR of the next generation, AVHRR/3, will be launched no earlier than February, 1998 on NOAA-K. Band 3 of the AVHRR/3 will be switchable between a near IR band (1.58-1.64 μm) which will be employed during the day and the traditional thermal IR Band 3 (3.55 -3.93 μm) carried on the AVHRR/2, which will be used at night (this switching will only be done on afternoon satellites such as NOAA-L; the near IR band will not be used on morning satellites such as NOAA-K). There will also be a split-gain in the AVHRR/3 visible and near IR bands to allow more definition of areas of low illumination. The accurate calibration available with the IR bands on these instruments allows the calculation of sea surface temperatures which have a global monthly average difference when compared with drifting buoys of only a few tenths of a degree Centigrade and a standard deviation of satellite-buoy comparisons of 0.4°C to 0.8°C (Pichel 1991). The AVHRR provides digital data at two resolutions: (1) global recorded data twice daily from each satellite at 4 km nadir (i.e., looking straight down) resolution, and (2) direct readout data at 1.1 km nadir resolution (capable of being captured anywhere in the world with inexpensive receiving systems), with limited sectors of

Table 2a; Current satellites and ocean instruments (July, 1996)

Instrument Type	NOAA 12 & 14 (NOAA)	GOES 8 & 9 (NOAA)	DMSP F12, F13 (Air Force)	ERS-2 (ESA)	RADARSAT (Canada)	TOPEX/ POSEIDON (NASA/ France)	LANDSAT 5 (NOAA / EOSAT)
Visible & Infrared 1) Medium Res. 2) High Res. 3) Ocean Color	AVHRR/2	IMAGER	OLS	ATSR-2			TM
Passive Microwave			SSM/I				
Active Microwave 1) Altimeters 2) Scatterometers 3) SARs				RA AMI WIND AMI SAR	SAR	ALT (1&2)	

Table 2b; Future satellites and ocean instruments (1996-2000)

Instrument Type	ADEOS* (Japan) (1996)	NOAA-KLM (NOAA) (1997)	SEA-STAR (NASA / OSC) (1997)	AM PLAT-FORM (NASA) (1998)	LANDSAT 7 (NASA/ NOAA) (1998)	JASON-1 (NASA/ NOAA/ France) (1999)	ENVISAT (ESA) (1999)	ADE0S II (Japan) (1999)	PM PLAT-FORM (NASA) (2000)
Visible & Infrared 1) Medium Res. 2) High Res. 3) Ocean Color	OCTS OCTS	AVHRR/3	SeaWiFS	MODIS MODIS	ETM+		AATSR MERIS	GLI GLI	MODIS MODIS
Passive Microwave		AMSU						AMSR	AMSU
Active Microwave 1) Altimeters 2) Scatterometers 3) SARs	NSCAT					ALT	RA-2 ASAR	SeaWinds	

*Editor's Note: The ADEOS satellite was successfully launched on August 17, 1996.

Table 3; Visible/infrared satellite ocean remote sensing instruments

Instrument	Satellite	Nadir Res. (km)	Swath Width (km)	VIS/NIR* Bands	TIR* Bands	Spectral Range (µm)
Medium Res.						
AVHRR/2	NOAA 12 & 14	1.1, 4	2700	2	3	0.58 - 12.5
Imager	GOES 8 & 9	1.0, 4, 8	13300	1	4	0.55 - 12.5
OLS	DMSP F12 & F13	0.5, 2.8	2963	1	1	0.58 - 12.8
ATSR/2	ERS-2	0.5, 1.1	500	4	3	0.65 - 12.0
AVHRR/3	NOAA-KLM	1.1, 4.0	2700	2	4	0.58 - 12.5
AATSR	ENVISAT	0.5, 1.1	500	4	3	0.55 - 12.0
High Res.						
TM	LANDSAT 5	0.03, 0.12	185	6	1	0.45 - 12.5
ETM+	LANDSAT 7	0.015, 0.03, 0.06	185	7	1	0.45 - 12.5
Ocean Color						
OCTS	ADEOS	0.7	1400	8	4	0.402 - 12.5
SeaWiFS	SEASTAR	1.13, 4.5	2800, 1500	8	0	0.412 - 0.865
MODIS	AM/PM PLATFORM	0.25, 0.5, 1.0	2330	19	17	0.405 - 14.385
MERIS	ENVISAT	0.3, 1.2	1150	14	0	0.40 - 1.05
GLI	ADEOS -II	0.25, 1.0	1600	22	12	0.375 - 12.5

* NOTE: VIS = Visible (0.4 - 0.7 µm), NIR = Near Infrared (0.7 - 3.0 µm), TIR = Thermal Infrared (3.0 - 15.0 µm)

each orbit recordable at this higher resolution. From the AVHRR data are derived an extensive group of ocean remote-sensing products (see Table 4). The two basic products are (1) observations of cloud-free SST at 8 km resolution produced from NOAA-14 (Figure 1 is an example of one of the 14 km SST isotherm contour charts produced from these 8 km observations) , and (2) SST mapped images for the NOAA CoastWatch program (Figure 2 is a sample CoastWatch SST image). CoastWatch images are available from NOAA-12 and NOAA-14 for all US coastal regions at both synoptic (approximately 3.6 km) and full (approximately 1.2 km) resolutions. Figure 3 depicts the regions covered by CoastWatch products. Visible AVHRR imagery (bands 1 and 2), which can be used for analysis of regional weather systems or converted into estuarine turbidity images, are also available for these CoastWatch regions.

The new GOES-8 and GOES-9 satellites (positioned at 75ºW and 135ºW to view the entire US and adjacent oceans) carry imagers which are very similar in design and operation to the AVHRR. Although some of the GOES Imager spectral bands are somewhat different and the basic infrared nadir resolution is 4 km, the 11 and 12 µm bands (which are used for SST) are almost identical to the AVHRR. Since the geostationary GOES satellites are in a much higher orbit than the NOAA polar orbiting satellites, the GOES Imager resolution is coarser and has greater sensor noise (and thus yields somewhat less accurate SST) than the AVHRR. The GOES Imager, however, has the distinct advantage of providing imagery of the US coasts at least once an hour and, when needed, as often as every 5 minutes. This high temporal resolution permits compositing to obtain better cloud-free synoptic coverage under partly-cloudy conditions with moving clouds. GOES image sectors of US coastal regions are now being provided to CoastWatch. GOES SST products are under development, and studies are assessing the usefulness of GOES imagery in ice analysis, ocean feature tracking, sea fog identification,

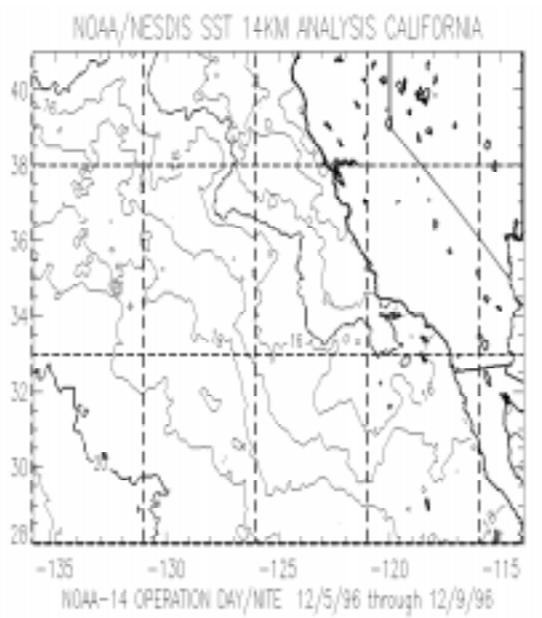

Figure 1. 14 km SST isotherm contour chart. Sample operational 14 km SST isotherm contour chart produced from objective analysis of 8 km observations of SST derived from AVHRR/2 visible and infrared data. These charts are generated twice a week using all satellite observations obtained since the previous chart production.

Table 4; Current NESDIS visible/IR medium resolution satellite oceanographic products.

DATA SOURCE AND TYPE	OCEAN PRODUCTS
POES AVHRR 4 km Global Area Coverage (GAC) Data	Orbital GAC Data Sets (1b) 8 km SST Observations, Globally* Global Telecommunications System SST Transmissions 100 km, 50 km, 14 km Analyzed SST Fields and Isotherm Contour Charts Quality Control Data Bases
POES AVHRR 1.1 km High Resolution Picture Transmission (HRPT) and Local Area Coverage (LAC) Data	Direct Readout HRPT Data Broadcasts Coastal/Regional LAC Data Sets (1b) CoastWatch Mapped VIS & IR Imagery (1.2 km & 3.6 km) CoastWatch SST & Cloud Imagery (1.2 km & 3.6 km) CoastWatch Turbidity (Derived from VIS data)
GOES Imager 4 km IR Data and 1 km visible data	Direct Readout GOES Variable (GVAR) Formatted Data Mapped VIS & IR Sectors CoastWatch VIS & IR Sectors

* Note: This product is now operationally produced by the Naval Oceanographic Office and sent to NOAA via the Shared Processing Network.

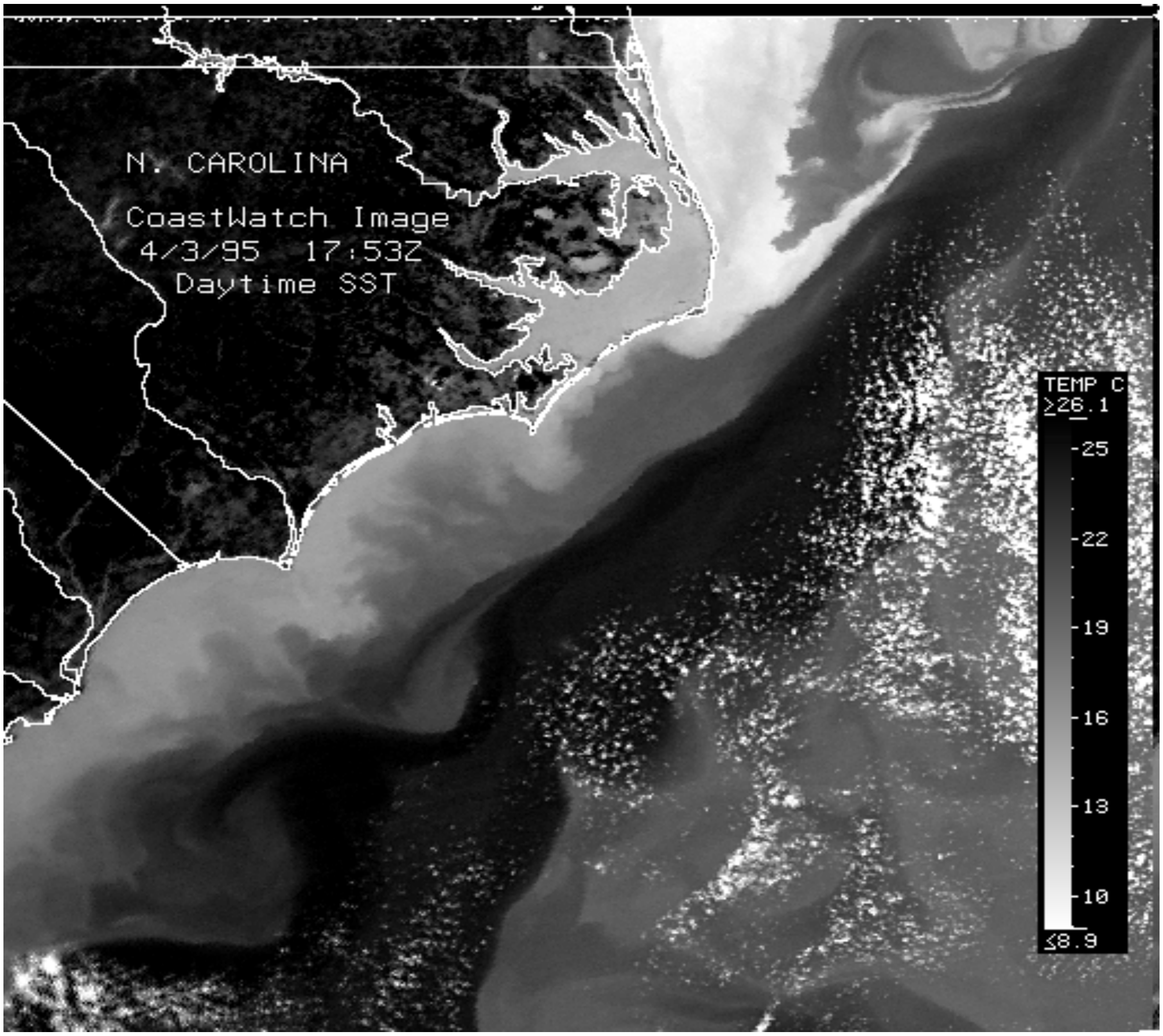

Figure 2. NOAA-14 CoastWatch SST image. Sample SST image generated for and made available to users by the Southeast CoastWatch Node at the National Marine Fisheries Service Laboratory in Beaufort, North Carolina. This is a daytime SST image produced from NOAA-14 on April 3, 1995. The region shown is the North Carolina coast. The Gulf Stream can clearly be seen as the warmer (i.e., darker) ribbon of water stretching from the lower left corner to the upper right corner of the image

and ocean current calculations (Purdom and Dills 1996).

b. OLS; Data from the Operational Linescan System (OLS) carried on the US Department of Defense's Defense Meteorological Satellite Program (DMSP) satellites, are now available from NOAA. The OLS is a two-channel radiometer with one visible and one thermal IR channel. There are two resolutions: (1) 0.6 km fine resolution, and (2) 2.8 km smoothed resolution. The visible band can also be operated in a low-light mode at night (at 2.8 km resolution) using a photomultiplier tube to obtain imagery from scenes with illumination as low as that available from a quarter moon (Heacock 1985). OLS products generated by the Air Force and made available via NOAA include global mapped imagery at 5.6 km resolution, a global automated cloud analysis, and a global snow and ice analysis. The National Ice Center receives OLS data of both resolutions for use in global and regional ice analyses.

c. ATSR-2 and AATSR; The Along Track Scanning Radiometer (ATSR-2) carried on the European Space Agency's (ESA) Second European Remote-Sensing Satellite (ERS-2) has visible and infrared channels similar to the AVHRR's but has the additional capability of viewing the same spot at two different angles. Theoretically this capability can produce a more accurate atmospheric correction. Although the ATSR has a resolution of 1 km with a swath-width of 500 km, only a coarse-resolution SST product at 50 km resolution is available to NOAA via the Global Telecommunications System. An Advanced ATSR (AATSR) is scheduled to fly on ENVISAT.

2. High Resolution - TM and ETM+; High resolution visible satellite imagery has been available since the early 1970's from the LANDSAT series of satellites. LANDSAT was included in Table 2a because EOSAT, the LANDSAT operating and marketing company, is under contract to NOAA. Currently, the LANDSAT data are only available at commercial rates from EOSAT. In the future, LANDSAT-7 will be a NASA satellite, operated by NOAA with data available from the US Geological Survey at low cost compared to the present pricing structure. LANDSAT 5 has a Thematic Mapper (TM) with six visible channels at 30 m resolution and a thermal IR channel with 120 m resolution. The Enhanced Thematic Mapper Plus (ETM+) on LANDSAT-7 will have approximately the same 30 m visible channels, a 60 m thermal IR channel and a 15 m panchromatic channel (0.52 µm to 0.90 µm). Applications of high-resolution visible and IR data include land/water boundary determination, coastal land use mapping and change analysis (Dobson et al. 1995), and mapping of coral reefs, turbidity, and pollution.

3. Ocean Color; There are currently no operational satellite ocean color instruments; however, the Ocean Color and Temperature Sensor (OCTS) was launched on the Japanese Advanced Earth Observation Satellite (ADEOS) in August, 1996 and the Sea viewing Wide Field-of-view Sensor (SeaWiFS) is scheduled for launch on the SEASTAR satellite in May, 1997. The Nimbus-7 Coastal Zone Color Scanner (CZCS), launched in 1978, was the direct predecessor of this new generation of ocean color instruments. Analysis of the CZCS data has amply demonstrated the utility of this class of instruments for: (1) measuring chlorophyll concentration, total suspended solids, and diffuse attenuation, and (2)detection of phytoplankton blooms

Figure 3. CoastWatch Regional Nodes. CoastWatch Regional Nodes are located at NOAA facilities in the cities shown. The rectangles show CoastWatch geographic regions of responsibility. The Nodes receive satellite data with their own satellite ground stations or from NOAA/NESDIS and store CoastWatch products locally for on-line access by a group of approximately 500 registered users.

and ocean features with color signatures (Gordon et al. 1985; NOAA 1994).

a. OCTS and SeaWiFS; Both the OCTS and SeaWiFS are similar to the CZCS, but carry a few extra bands for improved coastal ocean color determination. The OCTS and SeaWiFS both have 8 bands in the visible and near IR (see Table 3). OCTS adds 4 bands in the thermal IR to allow SST and thermal ocean-feature mapping. The SeaWiFS instrument will be launched and operated by Orbital Sciences Corporation (OSC) as a commercial venture financed in part by an up-front purchase by NASA of all the global-resolution data (4.5 km) and research access rights to the high-resolution data (1.13 km). NOAA has added an ocean color reception capability to many of the CoastWatch Regional Nodes (Figure 3) so that SeaWiFS data can be obtained for research and operational demonstrations for any US coastal area. Near real-time availability, however, requires the payment by each user of a license fee to OSC. In contrast, OCTS data for the US (with the possible exception of the US West Coast, Hawaii, and Guam) will be made available by NOAA to US Government users in near real-time at no cost to the user.

Table 5. Microwave satellite ocean remote sensing instruments.

Instrument	Satellite	Nadir Res. (km)	Swath Width (km)	Micro-wave Bands	Spectral Range (GHz)
Passive					
SSM/I	DMSP	50	1290	7	19.3 - 85.5
AMSU	NOAA-KLM, PM Platform	40	2240	15	23.0 - 90.0
AMSR	ADEOS II	5-50	1600	8	6.9 - 89.0
Altimeters					
RA	ERS-2	10	10	1	13.8
ALT (1&2)	Topex/Poseidon	10	10	2	5.3, 13.6
ALT	JASON-1	10	10	2	5.3, 13.6
RA-2	ENVISAT	10	10	2	3.2, 13.8
Scatterometers					
AMI Wind	ERS-2	25	500	1	5.3
NSCAT	ADEOS	50	1200	1	13.995
SeaWinds	ADEOS II	50	1800	1	13.4
SARs					
AMI SAR	ERS-2	0.03	100	1	5.3 (VV)*
SAR	RADARSAT	0.008 - 0.1	50 - 500	1	5.3 (HH)
ASAR	ENVISAT	0.03 - 0.1	60-100, 400	2	5.3 (VV & HH)

* Note: VV=Vertical polarization, send and receive, HH = horizontal polarization, send and receive

b. MODIS, MERIS, and GLI; The Moderate Resolution Imaging Spectroradiometer (MODIS) to be carried on NASA's AM and PM Platforms is a 36-channel instrument designed to measure land and cloud properties, ocean color, atmospheric water vapor, and surface/cloud temperature. There are two channels (0.62-0.67μm and 0.841-0.876 μm) with a resolution of 250 m, 5 channels for cloud remote sensing with a resolution of 500 m, and 29 ocean-color, water vapor, and surface/cloud temperature channels at 1 km resolution (NASA 1996). Although the AM and PM Polar Platforms are research missions, some of the instruments, including the MODIS, are designated as pre-operational and will be available through NOAA in near real-time. The Global Imager (GLI) and the Medium Resolution Imaging Spectrometer (MERIS) will be similar to the MODIS instrument, in that they will be imaging spectrometers with numerous bands. Like MODIS and OCTS, GLI will also carry thermal IR bands for SST calculation. The MERIS bands will be restricted to the visible and near IR.

B. Passive Microwave

Passive microwave instruments measure emitted radiation by the earth/ocean/atmosphere in the microwave portion of the electromagnetic spectrum (i.e., wavelengths of about 1 mm to 1 m, corresponding to frequencies of about 300 GHz down to 0.3 GHz). Resolutions tend to be coarse (12-50 km) since high-resolution sensing would require a prohibitively large antenna.

The advantage of sensing in the microwave region is the relative lack of interference from clouds, except when precipitation is present. Of particular interest to ocean science are passive microwave measurements of sea ice and wind. First year and multi-year ice concentration, ice edge location, and large-scale ice motion can be measured. Wind speed (but not direction) can be measured to a root-mean-square (rms) accuracy of about 1.4 to 2.1 m/sec when compared to buoy wind measurements (Krasnopolsky et al. 1994). Accuracy degrades below 3 m/sec and above 25 m/sec and when there is precipitation. Current research (Gaiser et al. 1996) indicates that wind direction measurements may be possible from future passive microwave polarimeters. Table 5 gives characteristics of current and future satellite microwave remote sensing instruments.

1. SSM/I; The only currently operational passive microwave ocean sensor is the Special Sensor Microwave/Imager (SSM/I) carried on the DMSP satellites. This seven-band instrument provides about 50 km resolution for a swath width of 1290 km yielding global coverage every two days (every day in polar regions). With two operational satellites there is an abundance of wind and ice data. The National Weather Service takes the SSM/I wind-speed measurements, applies a direction to each measurement based on a numerical meteorological forecast, and assimilates these winds into the operational meteorological models. Wind-field imagery is also

available experimentally from NESDIS (Chang 1996).

2. AMSU and AMSR; With the launch of the NOAA-K,L,M series of POES satellites, passive microwave data will be available from the Advanced Microwave Sounding Unit (AMSU), a 15 band (23 GHz - 90 GHz) instrument with 40 km resolution and a 2240 km swath. The AMSU will also be carried on the PM Platform (Grody 1996). ADEOS-II will carry the Advance Microwave Scanning Radiometer (AMSR), an 8-band instrument with 5-50 km resolution.

C. Active Microwave

Active Microwave instruments send out pulses of microwave radiation and then record characteristics of the backscattered radiation. These instruments are very sensitive to surface topography, waves, and surface roughness. There are three types of active instruments used for ocean measurements: (1) altimeters, (2) scatterometers, and (3) synthetic aperture radars (SAR). Table 5 summarizes current and future microwave instruments.

1. Altimeters; Altimeters are used to very accurately measure (within a few centimeters) the distance between the satellite and the ocean surface by sending radar pulses straight down and recording the return echo. When the satellite orbit is known precisely, an analysis of the amplitude and shape of the echo can be used to calculate the sea surface height, the significant wave height, wind speed, ice edge location, and ice topography. Derived parameters include ocean circulation and ocean features such as eddies. Currently flying are the RA on ERS-2 (which is available in near real-time from NOAA) and the ALT (1&2) on Topex/Poseidon. Although the latter is really a research mission, some data are made available within 2 days after overflight (Chaney 1996). Future altimeters scheduled for flight on the JASON-1 (a successor to the Topex/Poseidon) and ENVISAT satellites will make data and derived products from this class of instruments available routinely. A number of satellites are required in order to achieve anything approaching global coverage because measurements are only obtained from a narrow swath at nadir, leaving large gaps between successive orbits.

2. Scatterometers; Scatterometers have a number of antennas positioned at various angles to one another to allow the derivation of wind direction as well as wind speed from the backscattered returns. In addition, recent studies have indicated that scatterometers will have some utility for ice remote sensing (Wismann et al. 1996). Table 5 details the current and planned satellite scatterometers. Wind speed can usually be calculated to within a 1.9 m/sec rms accuracy, with direction to 34.9 degrees rms (Peters et al. 1994). Post-processing with a forecast model wind field is usually required to remove direction ambiguities. The ERS-2 Active Microwave Instrument (AMI) Wind Scatterometer is currently supplying winds from a 500 km swath, leaving large gaps between successive orbits (see Figure 4). In addition to wind vectors distributed by the European Space Agency (ESA), ERS-2 wind-speed and wind-barb imagery is available experimentally from NESDIS (Chang 1996). When NSCAT data are available

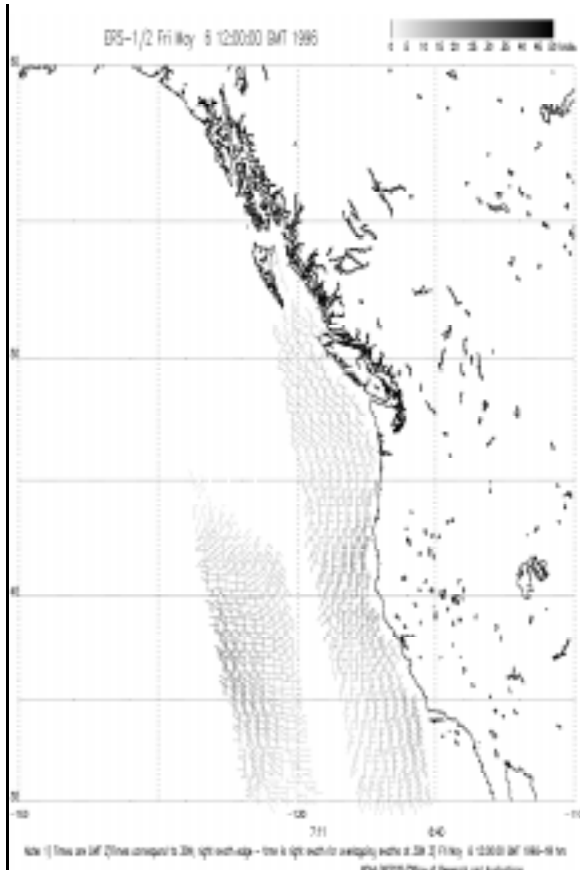

Figure 4. ERS-1 wind chart. Wind barb display of ERS-1winds generated by the European Space Agency from the AMI Wind Scatterometer for an 18 hour period on May 6, 1996. Experimental charts like this for any region of the world are available on-line from the NOAA/NESDIS Office of Research and Applications (Chang 1996).

operationally, its larger swath (actually two 600 km swaths on each side of the satellite nadir track) and the availability of data from both ADEOS and ERS-2 will provide close to global coverage on a daily basis. The ground system for these instruments is designed to provide wind vectors to the operational community within 2-3 hours of observation.

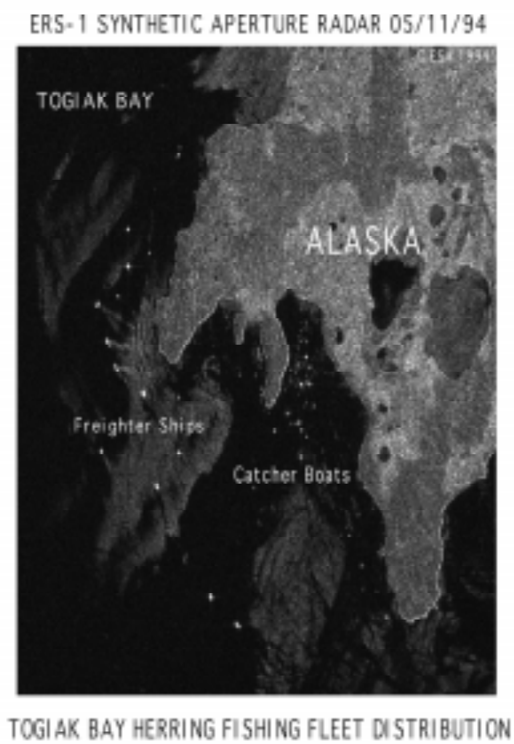

Figure 5. SAR image of the Togiak Bay herring fishing fleet. The herring sac roe fishery in Alaska is managed by the Alaska Department of Fish and Game. SAR imagery may be of use in fisheries enforcement and management by providing a synoptic view of the location of fishing and factory vessels. In this image, the large processing freighter ships are bright targets in the left portion of the image. Clusters of smaller (as small as 10 meters) catcher boats are indicated by the bright targets in the center of the image.

<u>3. Synthetic Aperture Radars</u>; Synthetic aperture radar (SAR) instruments measure both the amplitude and the phase of the returned pulse. Sophisticated signal processing techniques within the ground processing system are then used to produce an image with a spatial resolution (8-100 meters) comparable to high-resolution visible instruments. SAR imagery is currently being used operationally for measurements of ice edge, concentration, and type, as well as for calculation of wave spectra for long-period waves. When repeat coverage allows, ice motion can be calculated from image pairs separated in time by 1 to 3 days. Although at this time, ice and wave spectra are the only operational ocean products derived from SAR imagery, research and development has been under way for many years to develop coastal oceanographic geophysical measurements from SAR images including wind measurement (speed and direction), presence of internal waves, and location of ocean features including current boundaries, eddies, and slicks (both natural slicks and those resulting from an oil spill). By sensing direct returns from vessels and wakes, SAR imagery shows promise as a tool for use in fishing enforcement (see Figure 5). Although the ERS-2 SAR and its predecessor on ERS-1 are research instruments, they have been available routinely and have been used in case studies and operational demonstrations (Leshkevich et al. 1995). The RADARSAT SAR, however, is an operational instrument. In exchange for providing the launch for Canada, the US will receive 15.82% of the RADARSAT on-time. A system has been built to make a portion of this "US allocation" available in near real-time to US Government operational users. The flexibility inherent in the RADARSAT design in being able to choose the resolution (8 m to 100 m), the swath width (50 to 500 km), and the incidence angle (10^{o} - 49^{o}) results in an instrument quite useful for those operational applications which require rapid repeat coverage at moderate resolution or infrequent high-resolution coverage (RADARSAT International 1995).

III. Current and Near Future Delivery Systems

Systems for acquisition, processing, and distribution of satellite data are complex and usually in a state of flux as new satellites are added to the system. Figure 6 is a simplified diagram attempting to provide a high-level schematic of the NOAA satellite ocean remote sensing data system. Current and near-future satellites are arrayed across the top of the diagram and data acquisition and distribution pathways are depicted.

A. NOAA POES (AVHRR/2, AVHRR/3, AMSU) and NOAA GOES (Imager)

Global and regional data from the NOAA POES satellites are received at the NOAA Command and Data Acquisition Stations at Wallops, Virginia (shown in

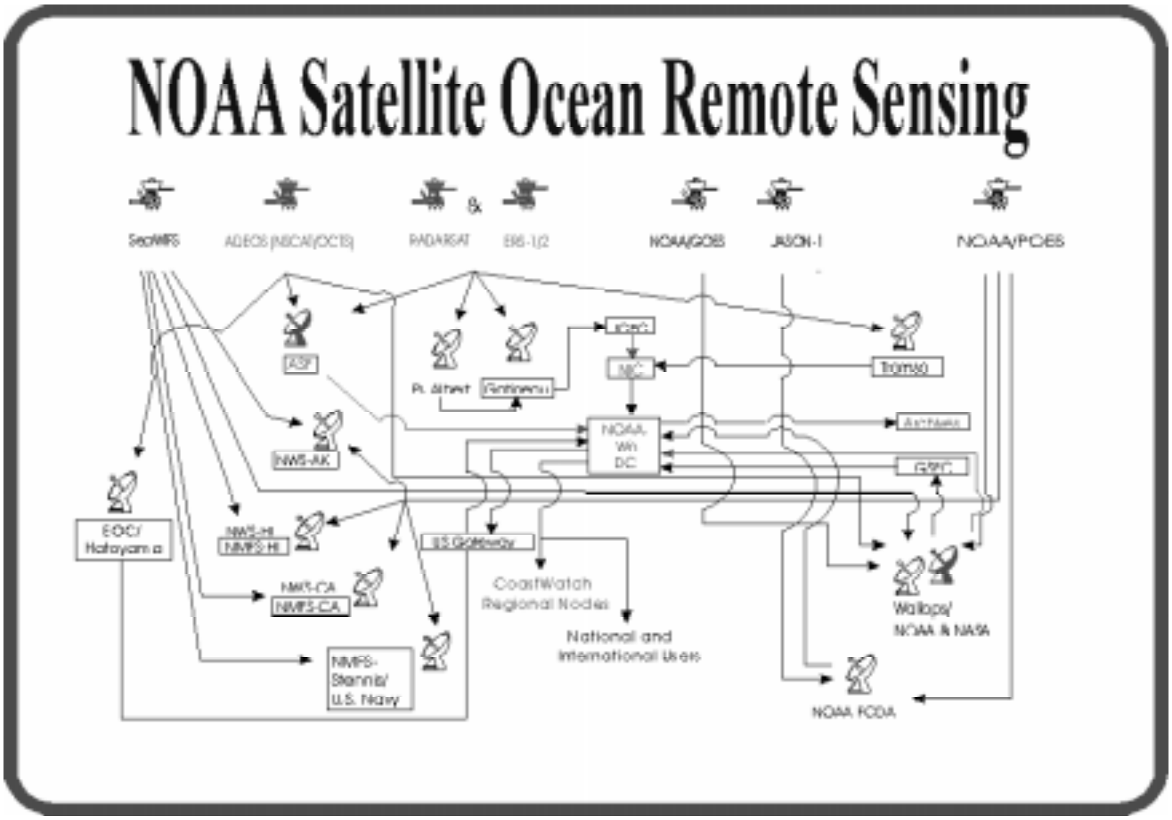

Figure 6. NOAA ocean satellite data reception and distribution. High-level schematic drawing of NOAA satellite reception facilities, data links, processing facilities, and distribution/archival network.

Figure 6 as "Wallops/NOAA & NASA") and Fairbanks, Alaska ("FCDA"). These data are then sent via communications satellite to the NESDIS processing center in the Washington D.C. area ("NOAA, Wn DC"). Here the data are processed into images and other products and sent out electronically to national and international users with access to the NOAA wide-area network ("US Gateway"), and to a group of US and state government users and universities via the "CoastWatch Regional Nodes." CoastWatch regions of data coverage and Node locations are given in Figure 3. High resolution SST, visible, and IR images for the Great Lakes, US East Coast, and Gulf of Mexico are sent in near real-time to the appropriate CoastWatch Nodes where these products are stored and made available to users via the Internet and dial-up modem. The NOAA POES data are archived at the National Climatic Data Center (NCDC) in Ashville, North Carolina, or at the National Oceanographic Data Center (NODC) in Silver Spring, Maryland where retrospective data orders are filled (shown in Figure 6 as "Archives"). These archive facilities make some of their data available electronically. For example, the CoastWatch imagery is available on-line from NODC, and the AVHRR global and regional raw data are available on-line from NCDC via the Satellite Active Archive (SAA). The POES AVHRR data are also readout directly to High Resolution Picture Transmission (HRPT) stations around the world. Shown on the diagram are HRPT stations at Stennis Space Center, Mississippi ("NMFS- Stennis/US Navy"), in Monterey, California ("NWS-CA"), in Honolulu, Hawaii ("NWS-HI"), and Anchorage, Alaska ("NWS-AK"). The stations in California, Hawaii, and Alaska process these data into high-resolution imagery which are made available directly to CoastWatch users as well as being archived at NODC.

NOAA GOES data from both GOES East and West are received at Wallops, calibrated and navigated, and then sent back up to the GOES satellites for broadcast to direct readout users and to NESDIS in the

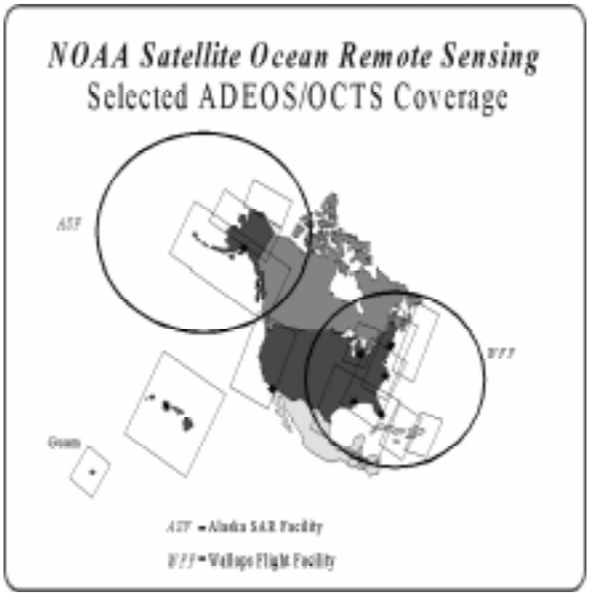

Figure 7. Coverage of coastal ocean color data from ADEOS/OCTS. Geographic areas of ADEOS/OCTS coverage for the United States. Areas within the ASF and WFF station masks will be received in near real-time by those readout facilities. Reception of US West Coast, Hawaii, and Guam coverage is still under negotiation.

Washington D.C. area where image sectors and other products are produced and distributed. The GOES calibrated and navigated data are archived at NCDC.

B. SeaStar (SeaWiFS)

SeaWiFS data will be received in direct readout mode by the same stations which receive POES AVHRR HRPT data as well as by a NASA HRPT receiving antenna at Wallops for US East Coast coverage. These data are then processed into imagery for research use by SeaWiFS investigators after a two-week embargo. Users who have an appropriate license with Orbital Sciences Corporation will be able to decrypt the data for near real-time use.

C. ADEOS (NSCAT/OCTS)

ADEOS data will be readout at three stations: (1) the Alaska SAR Facility ("ASF") in Fairbanks, Alaska, (2) Wallops, and (3) the Earth Observation Center ("EOC/Hatoyama") in Hatoyama, Japan. NSCAT and OCTS data will be sent in near real-time from these stations to NOAA ("NOAA Wn DC") for product production and distribution. Figure 7 shows the areas of coverage for OCTS data. The station masks for Wallops and the ASF are also shown. It has not been decided yet how the OCTS data for the US West Coast, Hawaii, and Guam data will be received. NSCAT orbits not received by ASF or Wallops will, however, be forwarded to NOAA from EOC/Hatoyama.

D. RADARSAT (SAR) and ERS-1/2 (AMI SAR)

SAR data from RADARSAT and ERS-1/2 are received by five readout stations: (1) ASF, (2) Prince Albert, Saskatchewan in Canada ("Pr. Albert"), (3) Gatineau, Quebec in Canada ("Gatineau"), (4) Tromso, Norway ("Tromso"), and (5) McMurdo in Antarctica (not shown in Figure 6). Some of the SAR data received at the ASF are processed into images in near real-time, sent to NOAA in the Washington D.C. area, and made available to US Government users by NOAA via the Satellite Active Archive. The data received by Prince Albert are forwarded to Gatineau for processing into imagery. A small amount of these data covering the Great Lakes in winter and Baffin Bay in summer are obtained in near real-time via an agreement with the Canadian Ice Service ("CIS") which forwards these data to the US National Ice Center ("NIC") and NOAA. Data acquired and processed in Tromso for the NIC are received directly by the NIC and passed on for archive by NOAA. A much greater quantity of SAR data under the US allocation are recorded in Tromso and in Canada and sent via tape to the ASF where they are processed retrospectively for the research community.

E. JASON-1 (ALT)

It is planned to receive altimeter data from the JASON-1 satellite at the Fairbanks Command and Data Acquisition facility ("NOAA FCDA"). These data would then be forwarded to the NASA Jet Propulsion Laboratory for processing, then on to NOAA in the Washington D.C. area for distribution (Silva 1996).

F. Other Data Types

Not shown in Figure 6 are the pathways for additional data which are or will be available from NOAA.

1. DMSP (OLS and SSM/I); OLS and SSM/I data are currently received via the Shared Processing Network from the Air Force and Navy, respectively. The Shared Processing Network consists of four processing centers (three Department of Defense facilities and NOAA/NESDIS) which exchange data and products via a dedicated satellite communications network. NOAA has the responsibility for archival of these data and for

distribution to the civilian community. These data are now accessible on-line from NOAA via the Satellite Active Archive.

2. ERS-2 (RA, AMI Wind Scatterometer, AMI SAR Wave Spectra, and ATSR-2); Except for SAR imagery, data from ERS-2 are processed into products by various member countries of the European Space Agency (ESA) and sent to users on the Global Telecommunications System (GTS). NESDIS receives these data and makes them available to NOAA and other US Government users.

3. Topex/Poseidon (ALT 1 & 2); These data are processed at the NASA Jet Propulsion Laboratory and made available to NOAA via Internet (Silva 1996).

4. LANDSAT (TM and ETM+); Currently, the EOSAT Corporation, under contract to NOAA, is selling LANDSAT 5 data received by its own facilities as well as licensing receiving stations around the world. For LANDSAT-7, NASA will build and launch the satellite, NOAA will operate it, and the data and derived products will be made available by the US Geological Survey's EROS Data Center in Sioux Falls, South Dakota.

5. AM/PM Platform (MODIS, AMSU), ENVISAT (AATSR, MERIS, RA-2, and ASAR) and ADEOS-II (GLI, AMSR, and SeaWinds); The data systems for these satellites have not been determined as yet.

IV. Acknowledgements

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Appendix A - Satellite and Sensor Glossary

Satellite names are given below in the same order as in Tables 2a and 2b, each followed by the complement of ocean sensors on that satellite. The satellite operator is given in parentheses following the satellite name.

NOAA 12 & 14	National Oceanic and Atmospheric Administration (NOAA)	
AVHRR/2		Advanced Very High Resolution Radiometer / 2
GOES 8 & 9	Geostationary Operational Environmental Satellite (NOAA)	
GOES IMAGER		GOES Imager
DMSP F12 & 13	Defense Meteorological Satellite Program (U.S. Air Force)	
OLS		Optical Linescan System
SSM/I		Special Sensor Microwave/Imager
ERS-2	European Remote Sensing Satellite-2 (European Space Agency - ESA)	
ATSR/2		Along Track Scanning Radiometer / 2
RA		Radar Altimeter
AMI Wind		Active Microwave Instrument - Wind Scatterometer
AMI SAR		Active Microwave Instrument - Synthetic Aperture Radar
RADARSAT	Radar Satellite (Canadian Space Agency - CSA, and RADARSAT International RSI)	
SAR		Synthetic Aperture Radar
TOPEX/POSEIDON	Topographic Experiment/Poseidon (NASA and Centre National d'Etudes Spatiales - CNES of France)	
ALT (1&2)		Altimeter 1 & 2
LANDSAT 5	Land Satellite (NOAA, and Earth Observation Satellite Corporation - EOSAT)	
TM		Thematic Mapper
ADEOS	Advanced Earth Observation Satellite (National Space Development Agency - NASDA)	
OCTS		Ocean Color and Temperature Sensor
NSCAT		NASA Scatterometer
NOAA-KLM	National Oceanic and Atmospheric Administration K, L, and M (NOAA)	
AVHRR/3		Advanced Very High Resolution Radiometer / 3
AMSU		Advanced Microwave Sounding Unit
SEASTAR	Sea Star (NASA, and Orbital Sciences Corporation)	
SeaWiFS		Sea viewing Wide Field-of-view Sensor
AM PLATFORM	AM Platform (NASA)	
MODIS		Moderate Resolution Imaging Spectroradiometer
LANDSAT 7	Land Satellite (NASA, NOAA, U.S. Geological Survey -USGS)	
ETM+		Enhanced Thematic Mapper Plus
JASON-1	JASON-1 (NASA, CNES, and NOAA)	
ALT		Altimeter
ENVISAT	Environmental Satellite (European Space Agency - ESA)	
AATSR		Advanced Along Track Scanning Radiometer
MERIS		Medium Resolution Imaging Spectrometer
RA-2		Radar Altimeter 2
ASAR		Advanced Synthetic Aperture Radar
ADEOS -II	Advanced Earth Observation Satellite II (NASDA - Japan)	
GLI		Global Imager
AMSR		Advanced Microwave Scanning Radiometer
PM PLATFORM	PM Platform (NASA)	
MODIS		Moderate Resolution Imaging Spectroradiometer
AMSU		Advanced Microwave Sounding Unit

The U.S. National Oceanographic Data Center: A Source for NOAA Environmental Data Resources, Ocean Models, and Delivery Systems

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The National Oceanographic Data Center (NODC) is one of three national environmental data centers operated by the National Oceanic and Atmospheric Administration (NOAA) of the US Department of Commerce. The main NODC facility is located in Silver Spring, MD. The NODC also has field offices co-located with major government or private oceanographic laboratories in Woods Hole, MA, Miami, FL, La Jolla, CA, Seattle, WA, and Honolulu, HI. In addition to the NODC, NOAA operates two other data centers:

- National Climatic Data Center (NCDC), Asheville, NC and
- National Geophysical Data Center (NGDC), Boulder, CO. The National Snow and Ice Data Center (NSIDC) in Boulder, Colorado is operated for NGDC by the University of Colorado through the Cooperative Institute for Research on Environmental Sciences (CIRES).

These discipline-oriented centers are administered by the National Environmental Satellite, Data, and Information Service (NESDIS) and serve as national repositories and dissemination facilities for global environmental data. The data archives amassed by the National Data Centers provide more than a 100-year record of the earth's changing environment. These irreplaceable records support numerous research, operational, and ongoing applications. Working cooperatively, the centers provide data products and services to scientists, engineers, resource managers, policy makers, and other users in the United States and around the world.

The National Centers play an integral role in the nation's research on the environment and provide public domain data to a wide group of users including:

- private industry,
- universities and other educational facilities,
- research organizations,
- federal, state, and local governments,
- foreign governments, industry, and academia,
- publishers and other mass media, and
- the general public.

The National Centers are responsible for data management activities in support of scientific and technical programs involving remotely sensed and *in situ* retrospective climatological, geophysical, meteorological, and oceanographic data and information. They perform all functions related to data management (acquisition, archiving, inventorying, and quality assessment), data synthesis, climate description, monitoring, modeling, and data and information dissemination and publication. The Centers perform necessary liaison with other NOAA components and with national and international contributors and users of data and information.

The National Centers house and operate World Data Centers A (WDCs-A). These Centers are part of the World Data Center System initiated in 1957 to provide a mechanism for data exchange during the International Geophysical Year. The World Data Center System operates under guidelines issued by the International Council of Scientific Unions (ICSU) with the responsibility to collect and freely and openly exchange without restriction complete sets of global data to anyone in the world. The WDCs are intended to supplement, not replace, the traditional scientist-to-scientist exchanges and the special data collection schemes organized in some scientific disciplines.

National Climatic Data Center

http://www.ncdc.noaa.gov/ncdc.html

The National Climatic Data Center (NCDC) coordinates with other national data centers and with non-NOAA activities concerning weather and climate to ensure comparable services and to avoid duplication of effort. It operates the World Data Center A (WDC-A) for Meteorology. NCDC applies new technology and new approaches to the maintenance of national and global data bases and to the analyses of long-term climate trends for the study and monitoring of climate on national and global scales. It performs quality assurance and re-analysis of historical data and data fields to establish baseline data bases for climate monitoring. NCDC manages the national program of climatological data recall and works closely with other data collection agencies in meeting this requirement. It provides facilities, data processing support, and expertise, as required, to meet US commitments to international organizations and to the World Meteorological Organization (WMO) programs. NCDC assists in training programs to familiarize the representatives of developing countries with modern meteorological technologies.

National Geophysical Data Center

http://www.ngdc.noaa.gov/ngdc.html

The National Geophysical Data Center (NGDC) combines in a single center all data activities in the fields of solid earth geophysics, marine geology and geophysics, and solar-terrestrial physics. It also contracts with the University of Colorado to handle data services for the National Snow and Ice Data Center. Although some NGDC data come from the observation programs of other NOAA activities, much more result from cooperative arrangements with universities, other government agencies, and foreign organizations.

NGDC is responsible for operating World Data Centers A for Solar-Terrestrial Physics, Solid Earth Geophysics, and Marine Geology and Geophysics, and for contracting WDC-A Glaciology (Snow and Ice). The World Data Center mechanism and various data-exchange agreements enable NGDC to make available large amounts of worldwide data collected by both foreign and domestic organizations.

National Oceanographic Data Center

http://www.nodc.noaa.gov

Introduction

The US National Oceanographic Data Center (NODC) was formally chartered in 1961 as part of the US Navy Hydrographic (later Oceanographic) Office. Later, NODC was included in the creation of the National Oceanic and Atmospheric Administration (NOAA) in 1970. It was chartered to acquire, process, preserve and distribute oceanographic data. It has no mission to collect data, and thus can focus its efforts on distributing and preserving data and information.

A large percentage of the oceanographic data held by NODC is of foreign origin. NODC acquires foreign data through direct bilateral exchanges with other countries and through the facilities of World Data Center A (WDC-A) for Oceanography. There are three World Data Centers for Oceanography:

- World Data Center A, Silver Spring, MD, United States,
- World Data Center B, Obninsk, Russia, and
- World Data Center D, Tianjin, People's Republic of China.

The NODC, with the co-located World Data Center A for Oceanography, holds the world’s largest global, unclassified data bases of oceanographic data and information. These data bases have been built with data from US agencies, state and local government agencies, research institutions, and foreign agencies and institutions.

Over the years the NODC has worked with program planners, managers, and principal investigators to coordinate data management support for major ocean science research efforts. Currently the NODC provides data management support for major ocean science projects such as TOGA (Tropical Ocean-Global Atmosphere), GLOBEC (Global Oceans Ecosystems Dynamics), WOCE (World Ocean Circulation Experiment), and JGOFS (Joint Global Ocean Flux Study). To promote improved working relations with the academic ocean research community, the NODC has established three joint centers with university research groups. The three centers are:

- Joint Environmental Data Analysis Center (JEDA) with Scripps Institution of Oceanography of the University of California at San Diego,
- Joint Archive for Sea Level (JASL) with the University of Hawaii, and
- Joint Center for Research in the Management of Ocean Data (JCRMOD) with the University of Delaware.

With declining budgets through the 1980s, NODC's ability to accept data, process and retrieve it in response to user requests atrophied. NODC entered the 1990s with the data inventory and processing technology of the 1970s. Recognizing that not only the NODC but all of its National Data Centers were becoming increasingly obsolete, NOAA embarked on a data center modernization program in 1991. The intent was to bring modern data base and data processing technology to all of its data centers, including NODC.

The Old NODC

In 1990 the NODC received, inventoried, processed, archived, and retrieved data in essentially the same way it had in 1975. The archive consisted of several standard formats for common physical oceanographic observations and thousands of "originator format" ocean observations that did not "fit" into standard formatted files. Originator-formatted data sets were accessioned, inventoried, archived, and retrieved exactly as received from the submitter. For data types which fit in standard formatted files, accessioned data were inventoried, quality controlled, archived, and retrievable in many ways. Legacy data processing systems stored standard format data as flat files by parameter and/or instrument type on nine-track magnetic tape. Separate inventories delineating what parameters had been received and what data sets existed on which tape were maintained. Retrieving this type of data in many different ways was possible, e.g., selecting on fields such as an investigator, latitude/longitude, date range, a ship, country, etc. Since everything was in sequential files on magnetic tape, the retrieval was labor intensive and quite complex, at times requiring hundreds of tapes to be mounted As a result, separate inventories were created with parameter data sorted by region, a time frame, etc. These individualized inventories proliferated until each oceanographer answering data retrieval requests had his or her own set of special ways to find data in the archive.

The archive itself was normally at least six months out of date simply due to data processing equipment limitations. Considering only classical physical oceanography, nearly three million records comprised more than 15 gigabytes of data on 350 magnetic tapes. The logistics of recompiling all of the data tapes, inventories, and tape contents lists to add newly acquired data into the proper location for the geo-sort and time sort data tapes ensured that updates were held to a minimum. In addition, the data processing power at NODC was limited. NODC's data processing was a sequentially loaded magnetic tape operation with legacy application software. On-site computing "power" consisted of a Vax 11/780/785 cluster with 2.5 MIPS and remote batch-job access to a UNISYS mainframe and program library in Asheville, NC.

When a client contacted NODC to get archived data, or even to decide whether data existed, an oceanographic information specialist had to work closely with the client to decide exactly what was needed. The old technology systems required a very specific definition of how to search the data bases, and the results were not always as intended. It was not unusual for a data retrieval from the nine-track tape archives to require 50 to 100 separate tape mounts. Batch jobs submitted to the mainframe in Asheville, NC, were sent electronically, but the output was paper and mailed back. As a result, NODC averaged just about 10 working days to answer a request for digital data, and if the request did not meet the client's needs another query took an additional 10 days. These methods were not user friendly. Even so, 7,663 requests for data and information were filled during FY 1990. The primary medium to answer a request was paper. However, 501 digital responses from 29 individual tape files totaling about 75 gigabytes of data were distributed.

NODC Modernization

As part of a NOAA-wide effort to modernize data processing and data management, sponsored by the Office of Environmental Information Services, NODC began to modernize in 1992. The objectives were to bring modern technology to data processing and distribution and to improve user friendliness. An ethernet LAN was installed with a FDDI backbone. A UNIX-based client-server architecture was adopted with PCS and UNIX workstations integrated into the network. On-site computing power was increased to approximately 150 MIPS for both file servers, and with nearly 10 MIPS on each desktop. Massive on-line WORM and spinning disk storage totaling 401 gigabytes was procured, installed, and operating on the network by early 1994.

It was decided that all existing data bases would be published on CD-ROM, with periodic reissues of newly acquired data. Data received in each individual data base since the last CD-ROM was published would be made available on-line across the Internet. In this way, the amount of data that needed to be transmitted across the Internet would be reduced. In addition, potentially hundreds of sub-archives would be established around the world, and NODC would be fulfilling its primary mission to preserve and distribute oceanographic data.

Based on work from an Intergovernmental Oceanographic Commission (IOC) sponsored project, the NODC with the Canadian Marine Environmental Data Service has developed, tested, and obtained IOC approval for an automated quality control system. It tests and flags each data submission for blunders in navigation and date/time reporting, internal format consistency, and climatological parameter range envelope consistency. The QC system has been transferred to other member NODCs of the IOC's International Oceanographic Data and Information Exchange community, including the People's Republic of China, Indonesia, and soon the Australian Oceanographic Data Center.

To improve data distribution within the ideas mentioned above, several projects were undertaken:

a. An automated customer servicing system was developed. This data base is currently available to each NODC oceanographer responding to data and information requests. The intent is to ensure that repeat customers' prior ordering activity, affiliation, mailing and e-mail addresses, etc., would be on-line accessible, thus improving NODC's personalized service. The ultimate objective is to make this information available on the network for interactive data ordering by the client; this capability is expected to be in test in November 1997.

b. The customer servicing system being developed also provides reports on the status of each order, so that choke points and delayed orders are reported to management immediately.

c. NODC entered the World Wide Web of Internet (WWW). Using the tools provided free by the GOPHER and MOSAIC development projects, servers were installed on NODC's UNIX workstations and registered with the WWW. These servers became operational in February 1994, and allow use of common graphical user interfaces to browse information about NODC and available products and order designated oceanographic data via the Internet.

d. At this time, upper ocean thermal data, moored buoy, and US coastal AVHRR meteorological satellite data bases are available for interactive order and download. Tools to allow interactive custom sorting and sub-setting of most of NODC's data bases have been developed. Use of open-client graphical user interface (GUI) browser forms pages allow a client to browse the NODC catalog of holdings. Selections can be downloaded during the same session, or (if the file is too big) copied to an anonymous FTP space for pickup by the client at a later time.

The modernization program has essentially created a new NODC. These processing and data distribution improvements have reduced the average data ordering turnaround time to 2.4 days for orders requiring intervention by NODC customer service personnel, and immediately for online data downloading. In 1992, the NODC provided data and information services on paper to 11,035 clients. In 1995, the NODC served 120,715 clients, of which 93,307 were Internet users who accessed NODC data and information resources using the Web, Gopher, and FTP. In 1992, the NODC distributed 200 gigabytes of data. In 1995, the NODC distributed 1,975 gigabytes of data. Nearly 95 percent of this total was provided on CD-ROM and most of the remainder was provided online via FTP. Today very few data orders are fulfilled using magnetic media (tape or diskette). From 1992 to 1995 the number of NODC clients and the volume of data distributed increased about 1,000 percent. By taking advantage of new technology, these improvements were accomplished as staff decreased by 35 percent.

While the archives of physical oceanographic data have grown by more than 25 percent since 1993, improved data processing techniques have resulted in only a seven week backlog of data received and awaiting processing. With new automated data processing procedures and equipment in place, NODC will be re-processing all existing physical and chemical oceanographic data bases to create solid, consistently managed data bases with defined and well-publicized quality control flags.

The rapid gains made in 1993, 1994, and 1995 are being consolidated during 1996. Additional data bases will be incorporated into the modernization program; more data will be available on-line and improved on-line data catalogs will give an Internet user more interactive search capability. In addition, improved computer system security will be a major emphasis of NODC. With special funding for network security hardware and software, increased Internet access to NODC data will be provided.

Another major improvement at NODC has been the establishment of the Ocean Climate Laboratory (OCL). Besides operating the World Data Center A for Oceanography, this research group's objectives are to build the most complete oceanographic data bases possible and to produce research-quality global oceanographic data sets, objective analyses, and diagnostic studies to define the role of the world ocean in the earth's climate system. The Laboratory has been very active. Recent data accessions under the auspices of the IOC's Global Oceanographic Data Archaeology and Rescue Program (GODAR) operated by the OCL have added to the observation density both spatially and temporally. Since its inception in 1992, GODAR has located and rescued more than 1.4 million historical oceanographic profiles. In addition, publication of the World Ocean Atlas 1994, a set of seven manuscripts and 10 CD-ROMs, has provided the research community the most comprehensive consistently quality-controlled global data sets of ocean temperature, salinity, oxygen, and nutrients ever published. The Laboratory also sponsors visiting scientists and collaborative research with marine science institutions worldwide.

Throughout 1995 improvements in storage and open-client GUI forms-based interactive query and response modules were developed. By June 1996, archive security was improved with the installation of a multiple layer firewall system. As a result of the firewall installation, NODC Internet customers were given access to more than four million oceanographic profiles comprising 425 million observations. Because of the volume of data and limited bandwidth of the WWW, use of CD-ROMs in conjunction with the Web has given everyone open access to more than 100 years of global oceanographic data.

To date the NODC has produced 68 CD-ROMs holding many of its most-used data sets. The CD-ROM publishing capability also has resulted in preparation of "one-off" CDs as a medium to meet user requests for large data sets. An average of 1.4 "one-off" CD-ROMs are prepared monthly.

Where NODC is Going

With completion of the technological improvements just discussed, NODC has initiated a series of internal reviews to evaluate everything at NODC involving data processing and servicing. Since technology has had such a profound effect on NODC work processes, it is clear that what NODC does as well as how it is done must be reconsidered.

It is also clear that more emphasis must be placed on accessioning and archiving many types of oceanographic data heretofore not considered by NODC. Chemical, biological, and coastal oceanography are being emphasized at NODC; new high-resolution sensor development must be followed and evaluated for archive requirements; data management support for large ocean monitoring experiments such as JGOFS and GLOBEC should be considered; inclusion of remote sensing instruments such as altimeters, scatterometers, and/or active radars should be investigated. A dialogue needs to be opened with the marine science community to determine what role NODC should play.

NOAA Library and Information Network

http://www.lib.noaa.gov/

The NODC also manages the NOAA Library and Information Network, which includes the NOAA Central Library in Silver Spring, MD, regional libraries in Miami, FL, and Seattle, WA, and field libraries or information centers at about 30 NOAA sites throughout the United States. The combined libraries contain more than 1 million volumes, including books, journals, data and information CD-ROMs, and audio and video tapes. The Central Library coordinates the NOAA Library and Information Network, which consists of more than 30 member libraries, information centers, and special collections within NOAA.

Summary

The National Oceanographic Data Center has moved into modern data and information processing techniques. It has improved the availability of data through use of modern random access media, relational data base technology, and on-line data. Internally it is an order of magnitude more efficient in data processing and quality control than just four years ago; this is primarily due to use of modern networking, client server architecture, and automated procedures. More of the global standard format data files are being distributed, with a goal of publishing everything in the archive. The Ocean Climate Laboratory has been established and is providing increasingly useful data products from the many data bases held at NODC. NODC is an Internet domain and is on the World Wide Web with interactive data browse and data retrievals. It has published 68 CD-ROMs of popular data bases and data products. In late 1994 a 10 CD-ROM set and seven volume technical report series of the World Ocean Atlas 1994 were published. It is providing a focus for ocean climate research and for international cooperative programs to document and describe the ocean's natural variability.

Operational Marine Forecast Products from the National Centers for Environmental Prediction

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Introduction

The National Centers for Environmental Prediction (NCEP) have the responsibility for providing forecast guidance products to National Weather Service forecasters who use this information to provide forecasts and warnings to the public. This responsibility includes providing forecast guidance products for the coastal oceans which border the continental US and the Gulf of Alaska as well. In order to satisfy these requirements, the Ocean Modeling Branch of NCEP produces a number of marine forecast products which are available to users via the World Wide Web (WWW). Examples of selected marine products plus web site addresses are included below. Also, a description of these products is available in a recent NCEP report (also referenced below).

The Product Suite

The full suite of marine products which are produced by the Ocean Modeling Branch (OMB) of NCEP can be found on the WWW at the following address: http://nic.fb4.noaa.gov:8000. At this address, there is a menu which allows the user to select from a wide variety of products from NCEP's Environmental Modeling Center, including products from the Ocean Modeling Branch. Marine products of possible interest are also available from the Climate Modeling Branch, which can also be selected from the same menu. A complete list of all marine products from the OMB, including a description of how they are produced, is also available in a recently-published NCEP Office Note entitled "Portfolio of Operational and Developmental Marine Meteorological and Oceanographic Products" by L. D. Burroughs (1995; copies available from L.D. Burroughs, same address as author, or email via lburroughs@sun1.wwb.noaa.gov). Certain products which are listed on the NCEP Home Page have restricted access, particularly those which are still under development. To obtain access to these products please send your internet address (local IP number) to R.W. Grumbine at: seaice@polar.wwb.noaa.gov. Finally, many of the fields which are available on the NCEP Home Page can be downloaded in a digital format, if the user so desires.

Table 1. Product Areas

AREA	SPECIFIC PRODUCTS
Marine Meteorology	Ocean surface winds
	Fog and visibility[1]
Ocean Waves	Global
	Regional[1]
Sea Ice	Ice drift forecasts
	7-day hemispheric forecasts[1]
	Other
Coastal Ocean Forecasting[2]	Sea level
	Temperature
	Salinity
	Currents[1]

[1]Examples shown in Figs. 1-4. [2]Still under development.

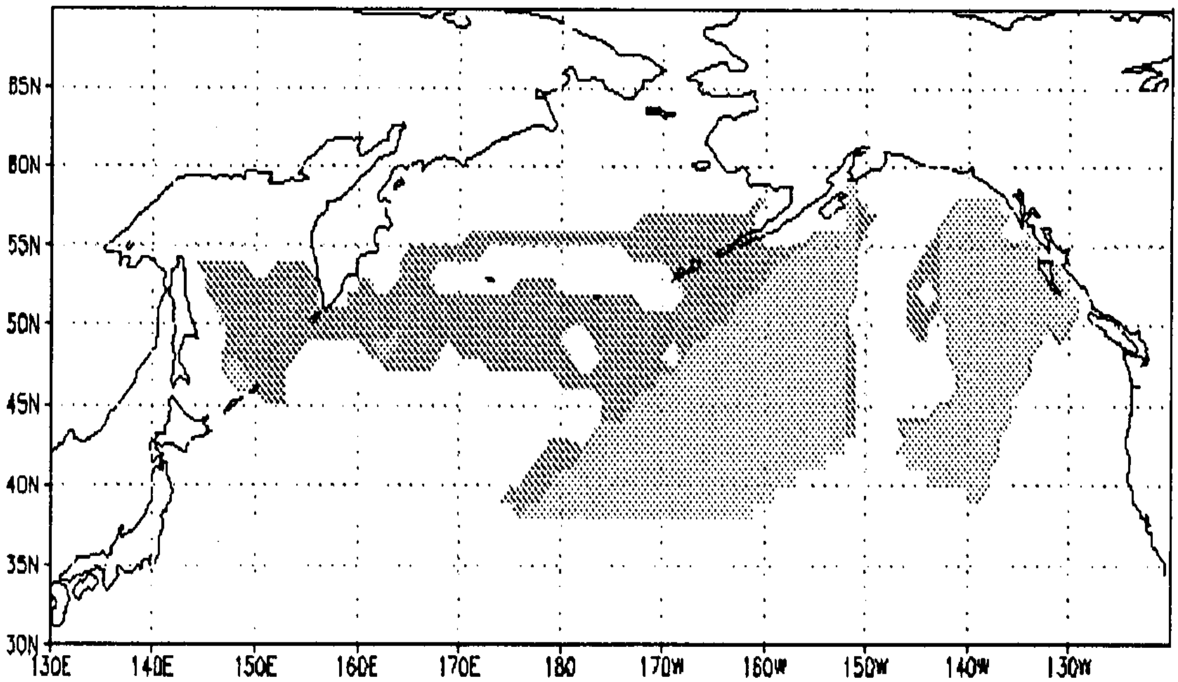

Figure 1. Fog (visibility ≤ 0.5nm) is indicated in light gray, and visibility ≤ 3.0nm is indicated by dark gray. This forecast is produced for the North Pacific and North Atlantic oceans (N. Pacific is shown here) from 30-70N. This forecast is available twice a day (at 00Z and 12Z) out to 72 hours in 12-hour steps.

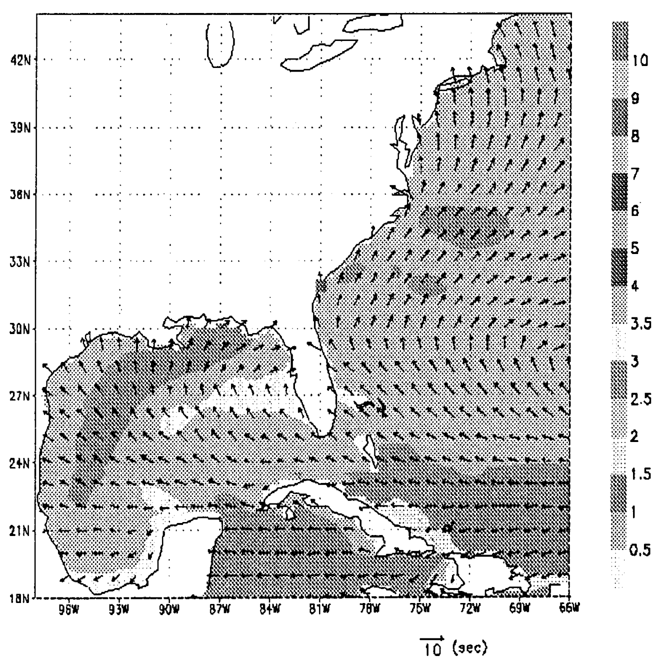

Figure 2. A regional wave forecast for the eastern North Atlantic and the Gulf of Mexico. The shading indicates significant wave height in meters, the arrow heads indicate wave direction, and the length of the arrow indicates the predominant wave period in seconds. The spatial resolution for this forecast field is 1/4° x 1/4° (it has been thinned for display). The wave model that produces these forecasts is driven by surface winds from NCEP's Aviation atmospheric forecast model. These wave forecasts are produced at 00Z and 12Z out to 36 hours.

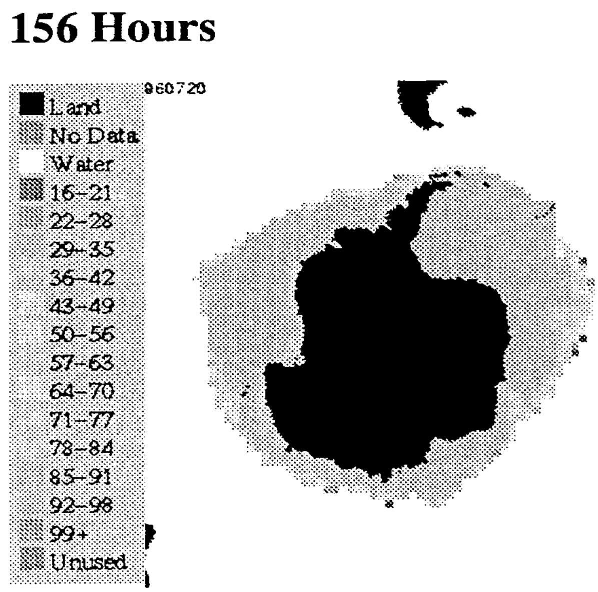

Figure 3. An ice edge/ice concentration forecast for the Southern Hemisphere is shown for a forecast period of 156 hours. Ice concentrations are shown in 14 steps (i.e., gray shades) from clear water to complete ice cover. Ice forecasts are produced every 12 hours and are made out to 7 days (168 hours).

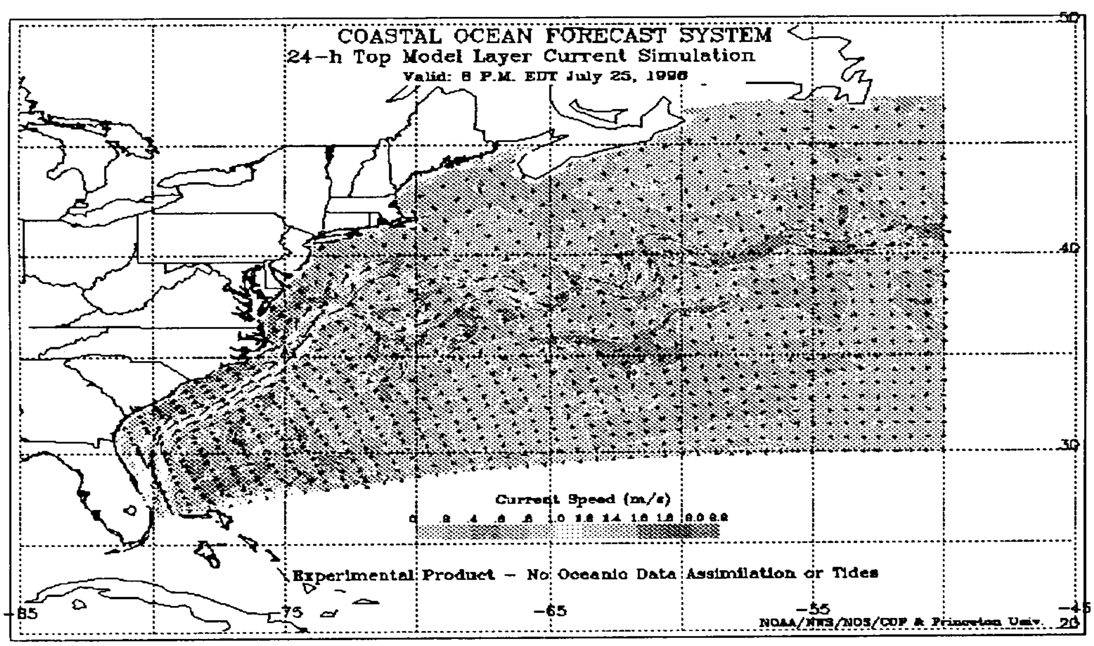

Figure 4. An experimental ocean circulation model was used to produce the surface current field shown. The current speeds are depicted by different shades (see scale below) and the directions are indicated by the arrow heads. The model predicts temperature, salinity, currents and sea level. The model is forced at the surface with wind and heat fluxes from a high-resolution atmospheric forecast model and produces a 24-hour forecast daily. The model is fully 3-dimensional and will include ocean data assimilation in the near-future.

The suite of marine products can be divided into four areas, Marine Meteorology, Ocean Waves, Sea Ice, and Coastal Ocean Forecasting. These product areas, and some of the specific product types which are contained in these areas are listed in Table 1 below.

Examples

Examples of products from each of these areas include a fog and visibility forecast for the North Pacific (Fig. 1), a regional wave forecast for the eastern North Atlantic (Fig. 2), a sea ice forecast for the Southern Hemisphere (Fig. 3), and, finally, a surface current forecast for the US East Coast (Fig.4) are presented.

Conclusion

New and improved marine products will continually be developed depending upon the demand and on the amount and quality of marine observations which are available.

An Overview of Meteorological and Oceanographic Modeling at Fleet Numerical Meteorology and Oceanography Center

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Introduction

The US Navy's Fleet Numerical Meteorology and Oceanography Center (Fleet Numerical), located in Monterey, CA, functions under the auspices of the Oceanographer of the Navy and the Commander Naval Meteorology and Oceanography Command. Fleet Numerical is the Department of Defense (DoD) central production site for all standard automated real-time meteorological and oceanographic (METOC) prediction products. Fleet Numerical fulfills this role through means of a suite of sophisticated global and regional METOC models, extending from the top of the atmosphere to the bottom of the ocean, which are supported by one of the world's most complete real-time METOC data bases. Fleet Numerical operates around-the-clock, 365 days per year and distributes METOC products to military and civilian users around the world, both ashore and afloat, through a variety of means (see Plante and Clancy 1994; Plante 1995).

In this paper we review the METOC models currently operational at Fleet Numerical, and project expected capabilities into the future. Although future emphasis will be on high-resolution METOC models designed to support the Navy's focus on the coastal environment, the global models which provide lateral boundary conditions for coastal models also remain important.

METOC Models

Present: A number of METOC models are now operational at Fleet Numerical. Brief descriptions of these models are given below.

NOGAPS - The Navy Operational Global Atmospheric Prediction System (NOGAPS) model is a global spectral numerical weather prediction model (see Hogan and Rosmond 1991). NOGAPS employs state-of-the-art data quality control, data assimilation, nonlinear normal mode initialization, and atmospheric physics to produce skillful medium-range weather forecasts. NOGAPS generates several thousand operational fields per day, including surface winds and heat fluxes to drive ocean models and lateral boundary conditions to support regional atmospheric models. In one way or another, NOGAPS output supports nearly every operational application run at Fleet Numerical. It is the only global meteorological model operated by DoD.

EFS - The Ensemble Forecast System (EFS) is implemented with a coarse horizontal resolution version of NOGAPS (see Pauley *et al.* 1996). In this state-of-the-art approach, multiple forecast runs are made from slightly differing initial conditions, with each obtained by means of a process that "breeds" the growing error modes that dominate forecast error (see Toth and Kalnay 1993). By averaging the resulting multiple forecast realizations (and hence tending to cancel out the effect of the growing error modes), a forecast is achieved with higher skill than any single forecast produced even with a higher resolution version of the model. In addition, the spread of forecast realizations allows a good estimate to be made of the range of forecast error, which can vary substantially from week to week depending on the global-scale flow patterns in the atmosphere.

DAF - The Derived Atmospheric Fields (DAF) model produces required atmospheric fields and sensible weather parameters (e.g., relative humidity, clear air turbulence, freezing level, rain rate, etc.) from the basic output produced by NOGAPS.

NORAPS - The Navy Operational Regional Atmospheric Prediction System (NORAPS) model is a relocatable regional primitive equation numerical weather prediction model (see Hodur 1987). NORAPS is run at higher horizontal and vertical resolution than NOGAPS for areas of high DoD interest. It can be initialized either from its own high-resolution nowcast, or from the coarser resolution NOGAPS nowcast. It uses lateral boundary conditions provided by NOGAPS, and generally provides a more accurate and detailed depiction of mesoscale weather features than NOGAPS, particularly in areas affected by the land surface.

GFDL Tropical Cyclone Model - The Geophysical

Fluid Dynamics Laboratory (GFDL) Tropical Cyclone Model is implemented at Fleet Numerical to provide track and intensity predictions for hurricanes and typhoons. The model is described by Kurihara *et al.* (1995), and includes a moving triply-nested grid, second order turbulence closure, convective adjustment, infrared and solar radiation, and parameterization of land surface characteristics by vegetation type. The model is initialized from a special analysis constructed by removing the tropical cyclone component from the NOGAPS analysis and replacing it with a synthetic vortex generated from the observed location and structure of the storm. Forecast lateral boundary conditions for the Tropical Cyclone Model forecasts are provided by NOGAPS.

WAM - The Third-Generation Wave Model (WAM) contains state-of-the-art nonlinear physics for forecasting the evolution of directional wave energy spectra and derived wave height, period and direction fields (see WAMDI Group 1988). WAM is run in both global coarse-resolution and regional high-resolution implementations at Fleet Numerical. The regional implementations generally include shallow water physics to account for refraction and bottom friction effects, although these formulations begin to lose validity at depths shallower than about 30 m. WAM uses wind stress forcing provided by either NOGAPS or NORAPS. WAM provides crucial support for Optimum Track Ship Routing (OTSR), the issuance of high-seas warnings, and many other applications.

OTIS - The Optimum Thermal Interpolation System (OTIS) is the primary ocean thermal nowcast model used at Fleet Numerical (see Cummings 1994). Both global coarse-resolution and regional high-resolution versions are in use. All of the OTIS implementations use the Optimum Interpolation (OI) technique to assimilate real-time data. Regional OTIS further employs water-mass-based representation of ocean thermal climatology and ocean front and eddy "feature models" to produce "synthetic" data to supplement the "real" data. This allows a detailed and accurate depiction of subsurface thermal structure associated with fronts and eddies whose surface positions are depicted in operational ocean front and eddy analyses derived primarily from satellite imagery by analysts at the Naval Oceanographic Office.

TOPS - The Thermodynamic Ocean Prediction System (TOPS) is a synoptic ocean mixed-layer model (see Clancy and Pollak 1983). Both global coarse-resolution and regional high-resolution versions are in use. TOPS is initialized by temperature and salinity fields nowcast by OTIS, and includes sophisticated turbulence closure physics and radiation absorption calculations. TOPS produces forecasts of upper-ocean thermal structure and currents driven by surface wind stresses and heat fluxes predicted by either NOGAPS or NORAPS.

PIPS - The Polar Ice Prediction System (PIPS) is a dynamic and thermodynamic sea-ice model designed to forecast ice thickness, concentration and drift in the arctic (see Cheng and Preller 1992). PIPS is driven by surface wind stresses and heat fluxes from NOGAPS, and is coupled with an underlying dynamic ocean model. PIPS is updated daily from an objective analysis of ice concentration data from the Special Sensor Microwave/Imager (SSM/I) instrument aboard the Defense Meteorological Satellite Program (DMSP) satellites.

DART - The DART model is a two-layer primitive equation dynamic ocean model designed to forecast the evolution of the Gulf Stream (see Thompson and Schmitz 1989). It currently produces two-week forecasts of Gulf Stream north-wall positions.

Future: To provide continuous improvement in customer support, Fleet Numerical will continue to seek upgrades to its METOC modeling capabilities. The following improvements are expected in the next several years.

NOGAPS - NOGAPS vertical resolution will be increased and its planetary boundary layer physics will be improved. New and more advanced data assimilation techniques will be implemented in the model.

COAMPS - NORAPS will be replaced with the Coupled Ocean/Atmosphere Mesoscale Prediction System (COAMPS) model (see Hodur 1993). The atmospheric component of COAMPS will feature triply-nested grids down to resolutions of a few kilometers, non-hydrostatic physics, explicit moisture physics and aerosols, and improved data assimilation. The underlying and fully coupled oceanographic component of COAMPS will combine the capabilities of OTIS, POM (see below) and WAM to provide for fully interactive two-way coupling between ocean and atmosphere (see Clancy and Plante 1993; Clancy and

Hodur 1996). With lateral boundary conditions provided by Fleet Numerical global models, COAMPS will provide the high-resolution, relocatable and fully integrated METOC prediction capability required for seamless support of the sea-air-land operations implied by the Navy's new missions.

WAM - Additional high-resolution regional implementations of WAM will be activated in coastal areas of high Navy interest. These regional WAM runs will be forced by high spatial resolution winds from NORAPS or COAMPS, obtain lateral boundary conditions from the global implementation of WAM, and include full shallow-water physics. They will be used to support nearshore maneuver warfare, including surf prediction in support of amphibious operations. Techniques to assimilate observed wave data into WAM will also be implemented as they prove viable.

POM - The Princeton Ocean Model (POM; Blumberg and Mellor 1987) will be implemented at very high spatial resolution in selected coastal regions. POM is a multi-level primitive equation ocean circulation model which contains a sophisticated treatment of vertical mixing. The model includes atmospheric and tidal forcing and is designed specifically for high-resolution shallow-water applications in support of the Navy's new emphasis on coastal operations. Initial testing of POM at Fleet Numerical has been for the West Coast of the United States (see Clancy *et al.* 1996). POM has already been used operationally by the Navy in semi-enclosed seas where lateral open boundary conditions are not an issue (see Horton, *et al.* 1994). The West Coast application of POM is an effort to address the open boundary condition problem in a general way, and will serve as a prototype for other nested and fully automated coastal implementations of the model at Fleet Numerical for other regions of Navy interest. In general, POM is expected to be the Navy's model-of-choice over the next several years for providing high-resolution coastal predictions of currents, sea level and thermal structure.

OCEANS - The Ocean Circulation Evolution Analysis and Nowcast System (OCEANS) model is a global and, at least, marginally eddy resolving implementation of the Navy Layered Ocean Model of Wallcraft (1991), which is a descendant of the model of Hurlburt and Thompson (1980). OCEANS will support coastal implementations of POM through lateral boundary conditions, and provide an improved representation of ocean currents on the global scale. Assimilation of satellite altimetry data into OCEANS and POM will be a crucial requirement for their success.

Product Distribution

Although Fleet Numerical model output is tailored for and distributed primarily to DoD customers, these products have proved to be of great value to the civil sector as well. For example, the NOAA Pacific Fisheries Environmental Group (PFEG) has a long history of using Fleet Numerical products to support its work. To provide for mutual backup while minimizing duplication of effort, Fleet Numerical model products are also made available routinely via high-speed data links to organizations such as the NOAA National Centers for Environmental Prediction (NCEP), the Air Force Global Weather Central (AFGWC), and the Naval Oceanographic Office (NAVOCEANO).

Many users access and display Fleet Numerical products via the PC-based Navy Oceanographic Data Distribution System (NODDS; see Thormeyer *et al.* 1995). The total number of registered military and civilian NODDS users has surpassed 1000, and the customer base continues to grow worldwide. NODDS 4.0, released in early 1996, includes a number of enhanced visualization capabilities, including more versatile display options, improved animation capabilities, a color-fill contouring option, a Lagrangian depiction of ocean currents, and an improved graphical user interface.

In addition, Fleet Numerical is taking advantage of the hypermedia technology afforded by the World Wide Web (WWW). The WWW provides a convenient method of providing information about Fleet Numerical, along with example products, to anyone and everyone who has access to the Internet. In addition, similar hypermedia-based pages are being used to provide products to DoD customers on military networks similar to the Internet. Ultimately, the NODDS and WWW capabilities will merge into the Joint METOC Viewer (JMV) system, which is currently being prototyped.

The Universal Resource Locator for the Fleet Numerical WWW site is http://www.fnmoc.navy.mil.

Summary and Outlook

Fleet Numerical has been in the operational METOC modeling business for over 35 years. Fleet Numerical runs a number of sophisticated METOC models which extend from the top of the atmosphere to the bottom of the ocean. Building on the basic research initiatives of the Office of Naval Research (ONR) and others, and with funding provided by the Oceanographer of the Navy and managed by the Space and Naval Warfare Systems Command, an active applied R&D program is in place to upgrade and/or replace these models. Key aspects of this program are the move toward coupled air-sea models and the operational utilization of new types of data from satellites. To support US Government initiatives for "dual use" of Defense technology, selected Fleet Numerical model products are made available routinely to the civil sector.

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U.S. Navy Environmental Data Resources

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Introduction

The marine environment, above, below and at the ocean surface, is a factor of enormous importance to the US Navy. Not surprisingly, Navy environmental data holdings are also enormous, as is the effort still going into obtaining data and developing various types of environmental models. However, locating and gaining access to this information can pose daunting challenges. One challenge is a result of the enormous size of the Department of Navy (DoN). Many different activities collect, process, analyse and archive environmental data, and there is no one centralized authority familiar with all or even much of the data available. This paper takes a small step towards improving this situation by presenting a brief overview of the most important data-generating and data-archiving activities in the DoN and how to find out more about them. In addition, once useful data are located there may be classification or distribution problems that hamper access to them by non-Department of Defense (DoD) associated researchers. I will touch on recent efforts to make data more readily available outside DoD.

Because data are collected and retained in support of the mission of the US Navy, not all types of environmental data will be found in its archives. Meteorological, physical oceanographic, geophysical and acoustic data are much more likely to be found than other types. Biological and chemical oceanographic data, for example, are likely to be collected and retained only on a limited and special basis. From a time perspective, DoN data may be all of past, present and future: archived or historical data, near real time data and predictions from numerical models. From the standpoint of how the data were collected, data may be obtained from *in-situ* sensors, from remote sensing (satellite and aircraft) , or be generated as numerical model output. Finally, DoN efforts are both operational (prime and most crucial) and research. How data are collected and their accuracy and temporal and spatial resolutions may well be affected by which type of effort was involved. Some frequently found types of Navy oceanographic data are listed in Table 1.

Table 1. Oceanographic data often found in Navy databases. Those of potential fisheries interest are underlined. Parameters are likely to be expressed in ways reflecting Navy interest; for example, zooplankton data may apear as presence/absence/depth of the Deep Scattering Layer.

GEOPHYSICAL
Physical bottom characteristics, acoustic bottom characteristics, seismic, underwater obstacles, gravimetric, and geomagnetic
BATHYMETRIC
PHYSICAL
Turbulence, **temperature** (surface and subsurface), **salinity, tides**, **waves** (internal and surface), swell, **currents, ice, front and eddy features**, **optical properties**
BIOLOGICAL
Bioluminescence, fish, zooplankton, marine mammals
ACOUSTIC
Sound speed, **ambient noise**, **sea state**, volume reverberation, sonic layer depth, convergence zone parameters, deep sound channel parameters, etc.
NEARSHORE
Surf, **sediment transport**, **shoreline positions**, **beach morphology**, **physiographic features**, etc.

Table 2. US Navy activities most likely to provide environmental data of interest to fisheries researchers and managers, along with their geographical location and Internet URL.

Naval Oceanographic Office (NAVOCEANO), including Naval Ice Center (NAVICECEN) Stennis Space Center, MS, and Suitland, MD; http://www.navo.navy.mil
Fleet Numerical Meteorology and Oceanography Center (FNMOC), Monterey, CA; http://metoc.fnoc.navy.mil
Naval Research Laboratory (NRL), Washington, DC; Stennis Space Center, MS; Monterey, CA http://www.nrl.navy.mil
Contacts through the Office of Naval Research (ONR), Arlington, VA; http://www.onr.navy.mil
Naval Command, Control & Ocean Surveillance Center Research and Development Center (NCCOSC / NraD), San Diego, CA; http://www.nosc.mil
Naval Surface Warfare Center, Dahlgren Division (NSWCDD), Dahlgren, VA; http://www.nswc.navy.mil
Coastal Systems Station (CSS) (A detachment of NSWCDD), Panama City, FL http://www.ncsc.navy.mil
Naval Undersea Warfare Center (NUWC), Newport, RI and Keyport, WA http://www.nuwc.navy.mil
Naval Air Warfare Center (NAWC), Patuxent River, MD
US Naval Academy (USNA), Annapolis, MD; http://www.nadn.navy.mil
Contacts through Department of Navy Environmental Program; http://www.enviro.navy.mi

Environmental Data Sources

Different Navy sources are likely to handle somewhat different categories of data. In Table 2 is a list of US Navy activities most likely to contain environmental data of interest to fisheries researchers and managers. Because the types of data found at each activity will depend upon the activity's mission, the Internet URL is given to enable someone researching sources for data to find out more about that particular activity. In the author's experience, the three most likely places to find general purpose data of use in fisheries are:

1.) **NAVOCEANO** (including **NAVICECEN)**: mission is to collect, process and disseminate oceanographic and MC&G products, including in near real time. Main repository of Navy environmental data. Ship-collected data represent 100 ship-years of data collection (nearly $1 billion at today's ship costs).2.) **FNMOC**: mission is to provide oceanographic and meteorological analyses and predictions to DoN and DoD in general

3.) **Naval Research Laboratory (NRL)**: mission is to be Office of Naval Research's (ONR's) In-House Laboratory and to conduct broadly based basic and applied research in support of identified and anticipated Navy needs.

NAVOCEANO and FNMOC are both under the Commander, Naval Meteorology and Oceanography Command (COMNAVMETOCCOM). These are operational commands engaged in day-to-day support of fleet activities. Data archiving and access are considered an important part of their mission, and locating and accessing the databases is relatively straightforward for someone with the appropriate authorization. Some of the environmental databases and other data sources available through COMNAVMETOCCOM are given in Tables 3 (NAVOCEANO), 4 (NAVICEN) and 5 (FNMOC) . More information on these and other databases may be obtained through reference (2).

The Naval Research Laboratory is a research-oriented activity under the Chief of Naval Research and the Office of Naval Research. Large amounts of high quality research data are collected by researchers at NRL's sites in Washington, DC, Stennis Space Center, MS, and Monterey, CA. Data collected as a part of the research efforts are required to be sent to NAVOCEANO and NODC for archiving, and this is often, though not invariably, done when the researchers have finished with them and are sure of their quality. However, quite a few high quality customized databases exist which are available only through the researchers themselves. Finding out about these databases is similar to finding out about databases developed by university researchers. The interested party must make

Table 3. COMNAVMETOCCOM databases found at the NAVOCEANO site.

1.) BBS -- Bottom Backscatter
2.) CEAS -- Comprehensive Environmental Assessment System: software system interfacing with selected databases and with ARC INFO GIS package. In general, databases concentrated in coastal regions of current or potential Navy interest.
3.) DBDB-1 -- Digital Bathymetric Database-1: 1.0 minute resolution
4.) DBDB-2 -- Digital Bathymetric Database-2: 2.0 minute resolution
5.) DBDB-5 -- Digital Bathymetric database-5: 5.0 minute resolution
6.) DBDB-C -- Digital Bathymetric Database-C: enhanced version of DBDB-5
7.) SATMSG -- Enhanced satellite IR imagery (temperature)
8.) DAILIES -- Front and eddy analysis from AVHRR/IR imagery
9.) COMPOSITE -- Enhanced version of DAILIES: boundaries extrapolated through cloud cover
10.) GDEM -- Generalized Digital Environmental Model: 4-D gridded climatology of ocean temperature and salinity profiles
11.) GOODS -- Global Ocean Observation Data Set: near real time temperature and salinity observations, retained for about 3 months, then incorporated into MOODS
12.) HFBL -- High Frequency Bottom Loss
13.) HITS -- Historical Temporal Shipping: global database of surface shipping
14.) HWS -- Historical Wind Speed: global ocean surface wind speed statistics on 1 degree grid (incorporates COADS data)
15.) LFBL -- Low Frequency Bottom Loss
16.) MOODS -- Master Oceanographic Observation Data Set: global archive of temperature and salinity profiles. Unclassified data is required to be transferred to NODC.
17.) Optics and Bioluminescence Data -- Extensive, but presently classified
18.) SN-DIAN -- Shipping Noise-Directional Ambient Noise: horizontally directional ambient noise at 50 Hz for a 1000 ft receiver
19.) SN-LRSN -- Shipping Noise-Low Resolution
20.) SSCDB -- Subsurface Currents Data Base: archive of global current meter data, primarily from coastal areas
21.) SCDB -- Surface Currents Data Base: global database derived from ship set and drift from multinational observations
22.) ICECAP -- Under Ice Roughness and Ridge Frequency Database: polar ice profile statistics from submarine cruises
23.) VSS -- Volume Scattering Strength: seasonally over 5 degree grid squares
24.) WAM -- Wave Model analyses and forecasts (version at FNMOC also)
25.) WRN -- Wind and Residual Noise: spectra for wind generated noise for selected areas

Table 4. COMNAVMETOCCOM databases found at the NAVICEN site.

1.) BERG -- Antarctic icebergs: 1979 to present
2.) BUOYS -- Arctic Drifting Buoys : 1979 to present
3.) ICECLIMO -- Global ice climatology from past 25 years data
4.) SIGRID -- Sea Ice Gridded Data: sea ice data since 1972 derived from weekly Arctic and Antarctic analyses

Table 5. COMNAVMETOCCOM databases found at the FNMOC site.

1.) AMDAR -- Aircraft Meteorology Data Relay: recent met observations from aircraft of opportunity; retained up to 30 days.
2.) AIREPS -- Aircraft Reports: recent upper level winds and temperatures from aircraft of opportunity; retained up to 30 days
3.) BATHY -- Recent temperature and salinity measurements; sent to GOODS, retained at FNMOC up to 30 days.
4.) DART -- Data Assimilation Research Transition: 7 and 14 day forecasts of Gulf Stream region dynamic heights; retained up to 30 days
5.) DAF -- Derived Atmospheric Fields: predictions from model outputs of derived met parameters (e.g., fog, fronts, rain rate); retained 30 da,
6.) GTCT -- Global Tropical Cyclone Tracks
7.) SATWINDS -- Low Level Satellite Wind Measurements: retained 30 days
8.) NOGAPS -- Naval Operational Global Atmospheric Prediction System: numerical meteorological model on 82 km grid, predictions every 6 hr out to 120 hr; output retained up to 30 days
9.) NORAPS -- Naval Operational Regional Atmospheric Positioning System: higher spatial resolution model than NOGAPS, run for selected regions out to 48 hr (every 6 hr); output retained 72 hr
10.) NHECT -- Northern Hemisphere Extratropical Cyclone Tracks Database: 6 hr storm positions and other parameters from 1960 to present
11.) BUOY -- Recent oceanographic drifting buoy data; data sent to GOODS
12.) OTIS -- Optimum Thermal Interpolation System: 3-D gridded nowcast temperature fields on global and regional grids. Global: surface temperature only; regional: temperature profiles; retained for various time periods
13.) PIPS -- Polar Ice Prediction System: model generated gridded forecasts of polar ice parameters out to 120 hrs; retained up to 30 days, products sent daily to NAVICEN
14.) RAOBS -- Radiosonde Observations: global; retained up to 30 days
15.) SSMI -- Special Sensor Microwave Imager: met, ocean and land parameters derived from microwave sensor on DMSP; data retained up to 30 days
16.) AIRWAYS -- Surface Aviation Observations: met reports from Northern Hemisphere airports; retained up to 30 days
17.) LAND SYNOPTIC -- Surface Land Observations: land station surface met data taken every 3 hr; retained up to 30 da
18.) SHIP SYNOPTIC -- Surface Ship Observations: ship met observations taken every 3 hr; retained up to 30 days.
19.) TOPS -- Thermodynamic Ocean Prediction System (v. 4.0): model forecasts of upper 300 m ocean temperatures every 12 hr out to 36 to 72 hr. Global and regional versions; data retained up to 30 days.
20.) UAGC -- Upper Air Gridded Climatology Database: montly means and standard deviations of met parameters from 1980 to present
21.) WAM -- Wave Model analyses and forecasts out to 48-72 hr. Global and regional versions.

many inquiries to find out about the existence of collections of desired data parameters and perhaps pose questions on various appropriate electronic distribution lists. Starting with the URL's in Table 2, a curious researcher can find points of contact at NRL and at other DoN activities from which to begin his or her database inquiries.

An example of work at NRL developing databases which may be of fisheries interest is the ocean color research by Bob Arnone and his colleagues at the SSC Branch of NRL's Remote Sensing Division. From the CZCS satellite they have put together regional and global databases of k(490) and chlorophyll concentrations. From AVHRR they have compiled regional and global SST and c(660) turbidity estimates. Details on these databases are given in Table 6. They have also produced "Probability of fish" prediction

Table 6. Examples of some of the ocean color databases available from the Ocean Color Group (Bob Arnone) at NRL. (arnone@nrlssc.navy.mil or 601-688-5268)

Products from CZCS satellite from 1978 through 1986:
k(490) and **chlorophyll** concentrations at 800 m resolution for the following areas :
Yellow Sea/Sea of Japan
Arabian Sea/N. Indian Ocean
Gulf Of Mexico
AVHRR products starting in 1994:
SST (open ocean & coastal regions) and **c(660) turbidity** (coastal only) at 1 km resolution for the following areas:
Gulf Of Mexico - 1994 - present
Arabian Sea - 1994 - 1996
Yellow Sea - 1996 - ongoing
S. Coast of CA - 1995 - ongoing
Greater Chesapeake Bay region - 1995 - ongoing
Global k(490) and chlorophyll concentrations from 1978-1986: monthly averages at 18 km resolution
Global SST from 1978-1986: bi-weekly averages at 18 km resolution

software based upon species preferences and relevant environmental databases, particularly those from remote sensing. Further information may be obtained from Bob Arnone.

Summary

US Navy investment in oceanographic and meteorological data and models is massive -- past, present and future. However, for non-DoD-affiliated persons, access can be extremely difficult because of:

- Simply finding out what's available and who has it
- Distribution and classification problems

The former problem exists everywhere in a large undertaking and solutions are not unique to DoN: persistent and creative question asking and lead-following. The latter problem is unique among Government agencies to military activities. Some classification and distribution restrictions are very real and necessary, but some have resulted from an over zealous application of classification guidelines or are a legacy of legitimate restrictions which no longer are applicable. It is difficult for an individual researcher to make progress loosening up the latter restrictions. However, institutional progress is being made.

In June 1995 a document was published entitled: MEDEA Special Task Force on "Scientific Utility of Naval Environmental Data" (reference (1)). The acronym MEDEA stands for "Measurement of Earth Data Environmental Analysis." The MEDEA program grew out of then-Senator Gore's request in 1992 to Director of Central Intelligence to investigate possible civilian use of environmental data obtained by the country's space-based systems and capabilities. Several years later the Commander, Naval Meteorology and Oceanography Command, requested a MEDEA study to examine possible civilian use of Navy databases and products. In particular the Task Force was asked to examine all COMNAVMETOCCOM databases and products and:

- a.) Determine the usefulness of classified Navy databases and products for unique and important environmental research
- b.) Prioritize such data for subsequent Navy declassification efforts
- c.) Identify opportunities for civilian/Navy collaboration efforts
- d.) Identify ways to increase national benefits from the public investment made in DoN environmental data collection and modeling

Two important MEDEA Task Force findings and recommendations were (the full set of recommendations is found in reference (2)):

I. Prompt partial or total declassification of following data:

- Marine gravity
- Historical ice morphology
- Geomagnetics
- Seafloor sediment properties
- Ice keel depth acoustic data
- GOODS - real time T and S fields
- Marine bathymetry
- MOODS - archived T and S fields
- Geosat altimetry
- Ocean optics and bioluminescence

II. Establishment of a Data Exploitation Center at the Stennis Space Center in Mississippi, location of COMNAVMETOCCOM, NAVOCEANO, and the oceanography component of NRL.

Considerable progress has already been made in making the listed databases available to the civilian community and more steps are likely to take place in the future, particularly since ADM Paul Gaffney, COMNAVMETOCCOM and also Chief of Naval Research, strongly supports the general principles. How this will translate into the scientific work of individual researchers, of course, remains to be seen. However, the time is ripe for researchers and administrators in fisheries science to begin asking DoN activities about data availability and the possibility of joint research investigations. The latter would be particularly useful in cases where full declassification and removal of restrictions on data is not possible. In many cases, fisheries-relevant products derived from classified or restricted data would not be classified or restricted. Joint research efforts with suitably cleared DoN scientists could allow the work to be partitioned so that the DoN researchers created the unclassified products with which both groups could then work.

One program helping to make DoN and, indeed, all DoD and -- it is hoped -- other US Government environmental databases more readily available is the Defense Modeling and Simulation Office's (DMSO'S) Master Environmental Library (MEL) Project. MEL has developed a distributed environmental data access system that allows a single point of computer access (the MEL Homepage) for all DoD environmental data. The user enters keywords, regions of interest, time, and/or latitude and longitude to obtain atmospheric, oceanographic, terrain, and near-space data. As of the writing of this paper (summer 1996), MEL had several prototype distributed sites up and running. Further expansion of MEL may be monitored through its Internet homepage, found at http://www-mel.nrlmry.navy.mil.

Special References of Interest

1.) MEDEA Special Task Force Report, "Scientific Utility of Naval Environmental Data," June 1995.(Available from NAVOCEANO homepage: http://www.navo.navy.mil; click on Products, then click on Scientific Utility of ....

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Acknowledgments

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The mention of commercial products or the use of company names does not in any way imply endorsement by the US Navy or the Naval Research Laboratory.

NASA's Ocean Remote Sensing Program

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The dynamics of the ocean are important in the evolution of the Earth's climate and key to providing vital information to areas of human health and welfare such as weather, shipping, fisheries, pollution, river discharge, and sea level rise. However, data and information collection from the oceans is particularly difficult to the vastness of the oceans as well as the general inaccessibility of many parts of the ocean. NASA, through the unique vantage point of space, uses satellites to provide data on a global scale that would be impossible to obtain otherwise.

In 1985, NASA was challenged to develop an oceanography from space program in the publication: Oceanography from Space: A Research Strategy for the Decade 1985-1995 (JOI). NASA, together with NOAA and other national and international partners, is in the final stage of completing a set of dedicated missions that demonstrate our ability to observe the global ocean. In addition, NASA has also played a key role in developing algorithms and other space-based oceanographic data sets through partnerships with other agencies and other countries.

NASA's ocean missions are an essential part of NASA's Mission To Planet Earth (MTPE), a space-based global observations system supporting the US Global Change Research Program (USGCRP), the coordinated US Interagency program designed to provide the scientific basis for understanding global change. The centerpiece of NASA's MTPE program is the "Earth Observing System"(EOS) which is a series of satellites, to be launched in 1998, developed for long-term global observations of the land surface, biosphere, solid Earth, atmosphere, and oceans.

NASA's ocean missions and activities address a central goal of using space-based remotely sensed data to establish the global ocean's physical and biological natural variability on seasonal to decadal to centennial time scales, to monitor the ocean environment for changes and trends, and to provide data and information on a timely basis to scientists, decision-makers, and the many other users of our data.

The primary missions designed by NASA and its partners to observe the oceans are comprised of several different kinds of sensors which measure an important set of ocean science variables. These are TOPEX/POSEIDON, NCSCAT, SeaWIFS, MODIS (on EOS) and a unique calibration/validation experiment called SIMBIOS which will collect and merge the diverse data from seven overlapping international missions to create a common data stream. In addition, a number of other missions are already providing critical data and information of ocean-related processes such as sea-ice processes (AVHRR, ESMR, SMMR, SSMI, ERS and Radarsat) ice sheet mass balance and sea-level change (ALT, GLAS, SAR, etc.), and other ocean, ice, atmosphere exchanges. These space-based observations will ultimately be correlated and combined with complementary ground-based observations with information collected by other agencies and countries to create the most complete scientific picture possible under the USGCRP and other international global change research programs.

TOPEX/POSEIDON, one of NASA's most successful Earth science missions, is the first space mission specifically designed and conducted for studying the circulation of the world's oceans. The mission is a joint effort between NASA and the French space agency (CNES) to observe global ocean circulation for 3-6 years using an Earth-orbiting satellite. A state-of-the-art radar altimetry system is being used to measure the precise height of sea level, from which information on the ocean circulation is obtained. The satellite, launched on August 19, 1992, has been making observations of the global oceans with unprecedented accuracy since late September 1992. The main science goal of the mission is to improve the knowledge of the global ocean circulation to an extent that will ultimately lead to improved understanding of the oceans' role in global climate change. Other applications include global sea-level rise, ocean tides, geodesy and geodynamics, ocean wave height, and wind speed.

A second international partnership mission between NASA and our Japanese colleagues will result in the launch in 1996 of the NSCAT (NASA Scatterometer) as one of several important sensors on the Japanese ADEOS mission. ADEOS has, as its mission, to

Characteristics of Ocean Color Sensors

Mission Instrument (launch)	**Visible Bands** (nm)	**Resolution** (km)	**Swath** (km)	**Tilt** (degrees)	**Onboard Calibration**	**Data Collection** (min/orbit)	**Orbit Node** (inclination)
ADEOS-I OCTS (1996)	412, 443, 490, 520, 565, 670, 765, 865	0.7	1400	0, _ 20	Solar Internal lamps	_40	10:30 am descending
ADEOS-I POLDER (1996)	443, 490, 565, 670, 763, 765, 865, 910	6.2	2471	N/A	None	_40	10:30 am descending
SeaSTAR SeaWiFS (1997)	412, 443, 490, 510, 555, 670, 765, 865	1.1 (LAC) 4.5 (GAC)	2800 (LAC) 1500 (GAC)	0, _20	Solar diffuser Lunar imaging	_40 (GAC) < 1 (LAC)	12:00 noon descending
EOS MODIS (AM-1998) (PM-2001)	412, 443, 488, 531, 551, 667, 680, 748, 869, 470, 555 670	1.0 0.5 0.25	1500	None	Solar diffuser (with stability monitor) Spectral Radiometric Calibration Assembly	_40	10:30 ascending
EOS-AM MISR (1998)	440, 555, 670, 865	0.25	400	0, _ 26, _ 45, _ 60, _ 70	Solar diffuser	_ 40	10:30 ascending
ENVISAT-1 MERIS (1999)	410, 445, 490, 520, 560, 620, 665, 681, 705, 754, 760, 765, 775, 855, 865, 900	0.3 (LAC) 1.2 (GAC)	1150	None	Solar diffusers (3)	_ 20	10:30 descending
ADEOS-II GLI (1999)	380, 400, 412, 443, 460, 490, 500, 520, 545, 565, 600, 625, 667, 678, 710, 748, 760, 865	1.0	1600	0, _ 20	Solar diffuser Internal lamps	_ 40	10:30 descending
MOS PRIRODA (launched Apr. 1996)	408, 443, 485, 520, 570, 615, 650, 686, 750, 815, 870, 945, 1010, 1600	0.7	80	None	Solar diffuser Internal lamps	Limited	Asynchronous (51.6_)
MOS IRS (launched Mar. 1996)	Same as MOS-PRIRODA	0.5	200	None	Solar diffuser Internal lamps	Limited	10:30 descending
MSX UVISI (launched Apr. 1996)	400 bands (110-900nm)	0.4 x 0.8	16	Pointable	None	Limited	Near sun-synchronous 3:30, progressively later
ROCSAT OCI (1998)	443, 490, 510, 555, 670, 865	0.8	600	None	None	Limited	Asynchronous (35_)
SAC-C MMRS 1998	490, 550, 660, 795, 1625	1.5	315	None	None	Limited	10:45 descending

acquire data on worldwide environmental changes such as the greenhouse effect, ozone layer depletion, tropical rain forest deforestation, and abnormal climatic conditions. NSCAT, a specialized microwave radar designed to measure winds over the oceans, will under all weather and cloud conditions. Winds are a critical factor in determining regional weather patterns, global climate, and general circulation of the world's oceans. At present, good capability for weather data acquisition exists over land but not over oceans, where our only knowledge of surface winds expected to lead to improved methods of global weather forecasting and modeling and to a better understanding of environmental phenomena (such as El Nino) that greatly affect world economies.

Thirdly, NASA is poised to announce the upcoming launch of SeaWIFS (Sea-viewing Wide Field-of-View Sensor) on Orbital Sciences Corporation's SeaStar spacecraft which will address the crucial measurements associated with changes in water color, or spectral radiance, that accompany the growth of phytoplankton (microscopic plants, the base of the food chain) and suspended sediments near the surface waters of the ocean. SeaWIFS will bring to the ocean community a welcome and improved renewal of the ocean color remote sensing capability lost when the Nimbus-7 Coastal Zone Color Scanner (CZCS) ceased operation in 1986. Designed to monitor ocean physics, chemistry, and biology from space, SeaStar represents a new generation of highly capable, low-cost satellites planned as part of NASA's Mission to Planet Earth. The SeaWIFS ocean color sensor, followed by MODIS on EOS, will provide the fast, repeated global coverage required for advanced studies of marine phytoplankton and ocean surface currents. Phytoplankton form the base of the food chain, and ocean color observation from space let us estimate the concentrations of these algae over large and remote ocean regions worldwide and permit the study of near surface phytoplankton "blooms". These sudden episodes of plant growth (blooms) attract fish and alter ocean chemistry. In addition, the phytoplankton drift with ocean currents, and, therefore, long-term ocean color data help trace these currents, providing information needed for navigation and safety at sea. These data also reveal the fate of river discharge, pinpoint fishing grounds, and track water-borne pollution. Such knowledge is of high operational value to shipping and fishing fleets, other commercial organizations, and Government agencies.

Finally, NASA and several international partners, in a brand new way of doing business, have just begun a new space initiative called SIMBIOS that will provide a special data set from a series of seven different ocean color sensors from different countries (beginning with the launch of SeaWIFS). The success of the earlier ocean color mission (which revolutionized the way in which biological oceanographers view the ocean) led to a number of follow-on satellite sensor missions, within the US and from the European Space Agency, Japan, Taiwan, Germany and France. While several of the instruments are highly complementary, there are significant differences in technical approach which precluded comparisons among the various valuable data sets. SIMBOIS results in the development of a long-term (nearly 20 years) set of consistent time-series of global bio-optical products from the world ocean available to the world oceans community. The presence of multiple ocean color sensors will allow the eventual development of an ocean color observing system that is both cost effective and scientifically based. The data set will present a unique opportunity to understand the coupling of physical and biological processes in the world ocean and help provide answers to ocean issues which directly impact humans on a daily basis.

NASA's Satellite Oceanographic Data Archives

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Introduction

NASA's primary satellite oceanographic data sets are archived at three separate but interconnected NASA-supported data centers. Many of these data sets are quite valuable in many aspects of fisheries oceanography. This note will briefly describe the data sets and how to access the data and correlative information. All three of these centers are referred to as Distributed Active Archive Centers (DAAC), of which there are 9 total within the Earth Observing Data and Information System (EOSDIS), the primary data component for NASA's Mission to Planet Earth Program.

I. Physical Oceanography Data and the JPL PO.DAAC

The Physical Oceanography Distributed Active Archive Center (PO.DAAC) at the Jet Propulsion Laboratory (JPL) archives and distributes products that are largely satellite derived and include: sea-surface height, surface-wind speed and vectors, integrated water vapor, atmospheric liquid water, sea-surface temperature, heat flux, and *in-situ* data as it pertains to satellite data. Much of the data is global and spans up to fourteen years. The JPL PO.DAAC is readily accessible via e-mail (podaac@podaac.jpl.nasa.gov) and the World Wide Web (http://podaac.jpl.nasa.gov/pub). The Web site contains a complete catalog of the DAAC products, an order capability, and routines which allow users to custom produce regional and temporal subsets of SST data. An FTP site (ftp podaac.jpl.nasa.gov) makes many products available from the JPL PO.DAAC. Data is free of charge courtesy of NASA and EOSDIS. Data can also be searched for and ordered through a tool called the Information Management System (IMS) which accesses all nine DAACs (see section IV).

The JPL PO.DAAC has been involved in archiving, distribution, and in some cases processing, physical oceanography data from the major NASA ocean satellites. Products available from the DAAC include project-produced sensor data records (SDRs) and geophysical data records (GDRs) as well as derived products developed by individual investigators or teams of investigators. A summary of the satellites and product groups is presented in Figure 1. Shaded areas denote that the JPL PO.DAAC is a major data holder, light shading indicates that the DAAC has some data products but is not the major data holder. The JPL PO.DAAC is also involved in processing, archiving and distributing so-called Pathfinder products. The Pathfinder program, sponsored by NOAA and NASA jointly, is designed to generate high quality, consistent products in a common data format using data from instruments on more than one platform over a period of time. The major JPL PO.DAAC products are described below.

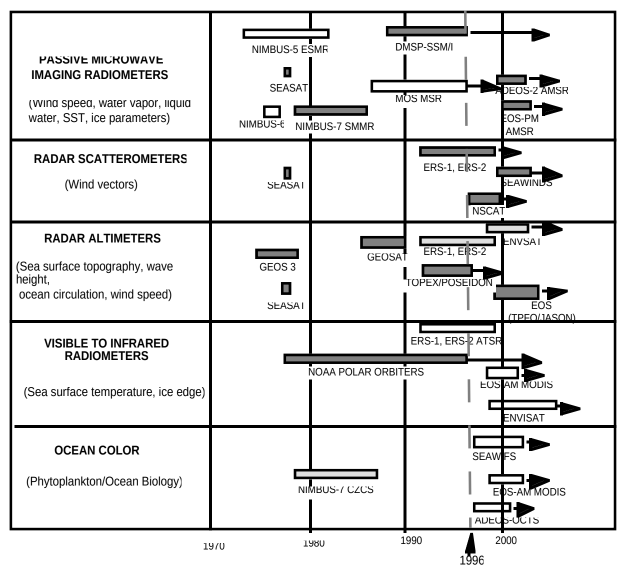

Figure 1. Satellite data sets for physical and biological oceanography.

a) Sea Surface Temperature Products

The JPL DAAC is a major distributor of Advanced Very High Resolution Radiometer (AVHRR) derived sea surface temperature (SST) products. The three main products are the AVHRR MultiChannel Sea Surface Temperature (MCSST) weekly averaged data from 1981 - December 1996, monthly averaged MCSST data on CD-ROM from 1981 - 1995 and daily and monthly averaged MCSST data from the NOAA/NASA

Pathfinder product for 1987 - 1994.

The AVHRR MCSST data set contains weekly averaged, equal angle, global fields. This SST product was produced from the NOAA NESDIS (National Environmental Satellite, Data, and Information Service) MCSST retrievals, by the University of Miami, School of Marine and Atmospheric Sciences. Data is currently available from 1981- December 1996 and may be accessed through either FTP or the PO.DAAC homepage. Weekly averaged SSTs are received quarterly, usually one to two months after the end of the quarter. Monthly MCSST composites for 1981 - 1986 are distributed on CD-ROM together with monthly CZCS (Coastal Zone Color Scanner) phytoplankton data for 1978 - 1986. Monthly averaged MCSST data for 1981-1995 are available on CD-ROM.

The NOAA/NASA Ocean SST Pathfinder task is also producing SST data that is available though the JPL PO.DAAC. The Pathfinder SST data product is improved over the regular MCSST data sets that the JPL PO.DAAC also distributes in that the Pathfinder data sets have been produced using improved data processing including new cloud detection algorithms and inter-calibration among the satellites (Smith et al. 1996). In addition the data are more complete because they are derived from the original AVHRR data rather than from a subset as produced by NOAA for operational purposes; as a result there are considerably more data for northern zones and open oceans. The Pathfinder SST products are in production and the entire data set is not yet available. The currently available Pathfinder data sets cover 1987 to 1994 and the entire data set from 1981 - present will be processed in the near future. This data and on-line subsets of the data are available through http://podaac.jpl.nasa.gov/sst.

Both SST and coastal zone color scanner (CZCS) data have been used in large-scale fisheries studies on productivity and how fish catch is related to these observed parameters. SST data in use by fishing vessels is required in near-real time and at high resolutions, which is available from the NOAA Coastwatch Program (http://www.nodc.noaa.gov/NCAAS/ncaas-home.html.

b) Sea Surface Height - TOPEX/POSEIDON

TOPEX/POSEIDON, launched in August 1992 and still operational, measures ocean topography with two independent altimeter instruments (Fu at al. 1994). With recent improvements in orbits, tide models and other corrections, the sea surface height is measured to an accuracy of 3 cm RMS and the geocentric sea-level to an accuracy of 13 cm. The orbit has a 10 day repeat with track spacing of 315 km at the equator. The main data product is the Merged Geophysical Data Record (MGDR) which are distributed on CD-ROM's. Reprocessing is underway to produce a product containing new orbit calculations, tide models, em-bias, geoid and mean sea surface calculations. Reprocessing of TOPEX/POSEIDON GDRs will begin with cycle 133 and will be issued in spring 1997. This data has been used for a wide variety of applications including global ocean current determination but it is very much a research product. A bibliography is available through http://volcans.tamu.edu/publications/post-nov.html).

c) Ocean Wind Products from Passive Microwave Measurements

The JPL PO.DAAC distributes a number of ocean surface-wind products derived from SSM/I data. The most recent addition, and the one that covers the longest time period is the product 'SSM/I derived global ocean surface-wind components 1987-94 (Atlas et al. 1996). Information was combined from ECMWF 10m surface wind analyses, SSM/I wind speeds (from Frank Wentz, Remote Sensing Systems), and ship and buoy winds to produce new surface wind analyses between -78 and 78 degrees latitude. The JPL DAAC also distributes the Wentz data consisting of wind speeds over the ocean and atmospheric moisture and water vapor; these data are often referred to as the Wentz geophysical products (Wentz 1992). The data, which cover the time period from 1979-92 are derived from the Nimbus-7 SMMR and the SSM/I instruments on the F-8 and F-10 DMSP satellites. The data is currently being reprocessed as part of the NOAA/NASA Pathfinder program with improved algorithms and will be distributed by the JPL PO.DAAC.

d) Ocean Wind Products from the NASA Scatterometer

The NASA scatterometer (NSCAT) measures the ocean and land radar backscatter cross-section (sigma-0), (Naderi 1991). The scatterometer is a NASA instrument that was launched August 16, 1996 on the Japan Space Agency (NASDA) ADEOS spacecraft. Ground processing uses the ice-free ocean backscatter to calculate vector winds at 50 km resolution. The orbit is such that the data will cover 90% of the ice-free ocean every 2 days. Wind speed accuracy will be 2 m/s for winds between 3 and 20 m/s and 10% for winds between 20 and 30 m/s. Spatial resolution is 25 km. NSCAT information can be found on http://www.jpl.nasa.gov/winds. The JPL DAAC is planning to distribute several wind and global radar backscatter products, see http://podaac.jpl.nasa.gov/NSCAT.html. Data are expected to be available to the general scientific community in the spring of 1997 following a calibration-validation campaign.

e) Other Data Sets

The Tropical Ocean and Global Atmosphere (TOGA) product contains related atmospheric and oceanographic data sets, on six CD-ROMs, covering the period 1985 through 1990. In 1997 the data product will be extended to include more versatile software and data from 1985-1996. Of interest is the TOPEX/POSEIDON informational CD-ROM which provides general interest on the science, spacecraft, and mission. It can be previewed and ordered through http://podaac.jpl.nasa.gov/tecd.html. Also available are associated products from the Seasat scatterometer, altimeter, and scanning multichannel microwave radiometer.

II. Radar Imagery from the Alaska SAR Facility

The Alaska SAR Facility DAAC was established at the University of Alaska Fairbanks as a cooperative facility together with the Jet Propulsion Laboratory and NASA to receive, process, and distribute synthetic aperture radar (SAR) imagery from international satellites. The facility has been in operation since 1991. The SAR data is particularly useful for studies in the polar regions since the radar can operate during night and day and cloudy conditions. NASA has developed memoranda of understanding with three international space agencies to make this data available for scientific studies to 'approved' investigators (see below) at little or no cost. ASF currently archives and receives data from four SAR satellites: the European Space Agency's ERS-1 and ERS-2; the Japanese Space Agency's (NASDA) JERS-1; and Canadian Space Agency's RADARSAT. The description of the SARs are shown in Table 1. More information on these data sets is available through the ASF Web Page (http://www.asf.alaska.edu).

Radar imagery provides a fine resolution (usually around 25 m) two-dimensional view of natural surfaces. Information is provided in the form of radar backscatter, where transmitted signals are scattered from the varying roughness components of the surface. In the case of the ocean, surface roughness is primarily derived from wind waves and current-wave modulations. Thus, an ocean during calm winds has little return or appears dark while a rough ocean appears radar bright. Current-wave interactions provide additional feature detection, so that many upper ocean features are detectable from SAR including surface and internal waves, and currents and eddies. Also seen are surface expressions of shallow bottom topography and atmospheric features, such as windrows and rain cells. For sea ice, scattering arises from both the roughness of the ice cover as well as inhomogenieties within the ice cover, since the selected frequencies of satellite SARs are able to penetrate into the ice to some varying depths. A overview of SAR ocean and ice imaging characteristics can be found in Fu and Holt (1982).

As shown on Table 1, each SAR sensor has varying operating frequencies, polarizations, pointing angles, and swath widths. C-band (ERS, RADARSAT) has a wavelength of about 5 cm and a frequency of about 5.3 GHz while L-band has a longer wavelength (23 cm) and lower frequency (1.2 GHz). Surface scattering from ocean, land, and ice principally arises from roughness components that have similar wavelengths to the specific radar wavelength (called Bragg scattering). An example for oceans is that C-band scattering arises from short gravity waves that have wavelengths of about 3-10 cm. Thus, ocean backscatter from C-band is generally higher than L-band since there is generally a higher spectral density of ocean waves present at 5 cm wavelengths than 25 cm. For polarization, VV is generally higher than HH for the ocean. Ocean backscatter falls off strongly in strength at incidence angles (angle of pointing from nadir to surface, perpendicular to spacecraft velocity direction) above about 30 degrees. Thus ERS-1 and ERS-2 have ideal configurations for ocean studies. RADARSAT has the capability for varying incidence angles and swath width, but can also operate in very favorable modes similar to ERS for ocean features. RADARSAT has the added advantage of wider swath coverage, which also improves repeat sampling.

Table 1: ASF SAR Mission descriptions from the MTPE international partners

SPACECRAFT	ERS-1,2	JERS-1	RADARSAT
INSTRUMENT	AMI	SAR	SAR
SAR			
FREQUENCY	C-band	L-band	C-band
POLARIZATION	VV	HH	HH
SWATH WIDTH	100 km	75 km	50-500 km
RESOLUTION	25 m	18 m	10-100 m
INCIDENCE ANGLE	23˚	35˚	20˚ - 50˚
ORIENTATION	right	right	right*
DATA STORAGE	none	20 minutes	20 minutes
ORBIT			
INCLINATION	97.5˚	98.5˚	98.5˚
ALTITUDE	785 km	568 km	790 km
REPEAT	3, 35, 168 days	44 days	24 days
MISSION			
LAUNCH	ERS-1: July, 1991 ERS-2: April, 1995	February, 1992	November, 1995
LIFETIME	3-5 years	8 years	5 years
STATUS	operational	operational	
AGENCY	ESA	NASDA	CSA

*Except to map Antarctica in two dedicated missions in which it will look left

JERS-1, due to its higher incidence angle (35 degrees) and lower frequency radar is generally not favorable for ocean studies and in fact is primarily of use in land applications.

Acquisitions of both ERS SAR sensors can only be obtained through direct downlink to ground reception stations. For the US, the current ground stations include ASF and the more recently installed station at the McMurdo Base in Antarctica. ASF archives ERS data only from these two stations. Both JERS-1 and RADARSAT have on-board tape recorders and thus have global access for data acquisitions. Similarly with ERS, ASF archives JERS-1 data principally acquired within the ASF mask only (not McMurdo). ASF has agreements with Canada to acquire and archive RADARSAT data on a global basis, in addition to the direct downlink acquisitions. Figures 2 and 3 show the ASF and McMurdo station mask reception zones for the various satellites.

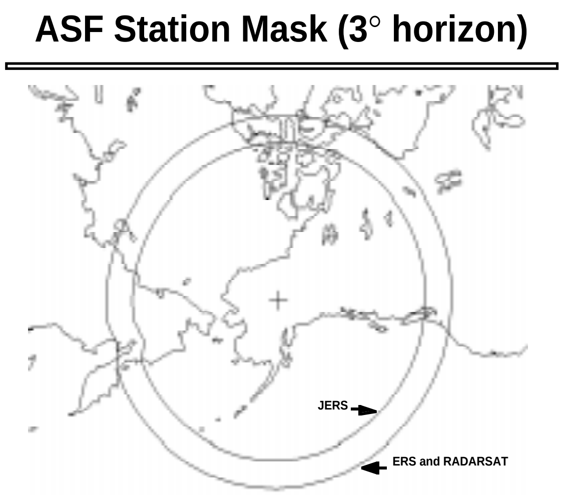

Figure 2. The nominal limit of the reception zones for ASF are shown for the four international SAR satellites.

All data archived at ASF are available for scientific investigations (both US and international) at cost of media reproduction upon approval by NASA of a two-page project summary submitted to ASF (details are available on the ASF home page). Data from these satellites that are not archived at ASF can be obtained at commercial pricing directly from the specific space agencies or their commercial agents to those who are not NASA-approved. Of course, scientific investigators who are approved by NASA (through ASF) or by the specific flight agency may also receive data at essentially no cost.

The ASF SAR data are available in the following formats: full resolution (around 25 m), low resolution (reduced from full resolution, around 100 m), and complex (suitable for deriving land topography using radar interferometry). The data can be supplied on tape media or by file transfer. In addition, derived or geophysical products are available from ERS-1 and in the near future from RADARSAT. These higher level products are derived primarily for sea ice studies (ice motion, ice type, ice age).

As SARs consume considerable satellite power, acquisitions are limited to a finite number of minutes per orbit (generally 20-30 minutes per approximately 100 minute orbits). When combined with the satellite orbital repeat cycles and the comparatively narrow swath widths, SAR provides more limited coverage than many other ocean-related satellite sensors. More advanced planning is usually required to optimize coverage for a specific ocean experiment. Again, RADARSAT provides considerable improvement in this limiting factor because of its wide swath coverage. Only approved NASA investigators can request future SAR acquisitions through ASF.

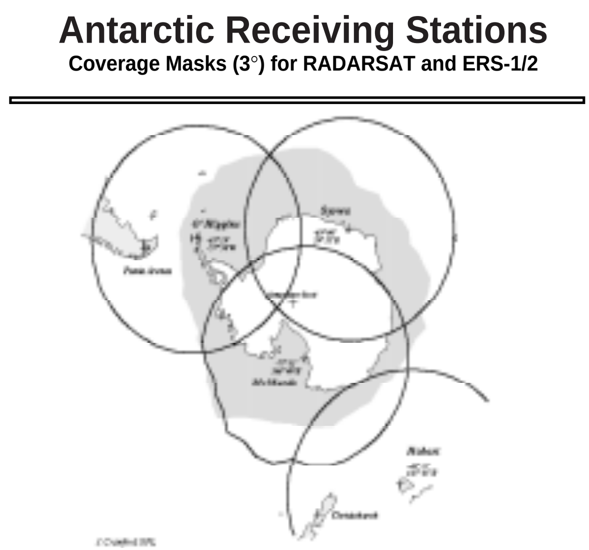

Figure 3. The nominal reception limit of NASA's McMurdo station is shown for three international SAR satellites. The other 3 ground stations are operated by Germany (O'Higgins), Japan (Syowa), and Australia (Hobart).

It is worth pointing out here that several studies have been done to use SAR in fisheries oceanography, specifically for NOAA's Fisheries Ocean Coordinated Investigation (FOCI) in Alaska's Shelikoff Strait and Bering Sea (Schumacher et al. 1991; Liu et al. 1994). In this environment, SAR can provide very useful information on eddies and waves, where useful SST maps from AVHRR are extremely limited due to cloud cover and annual day/night cycles.

III. Ocean Color Imagery from the Goddard Space Flight Facility (GSFC) DAAC

Of particular interest to biological oceanographers is satellite ocean color imagery, which measures ocean pigment and chlorophyll concentration. The GSFC DAAC archives data from the Coastal Zone Color Scanner (CZCS), which operated from November 1978 through June 1986. Awaiting launch, hopefully in

1997, is the follow-on NASA color sensor called Sea-Viewing Wide Field-of-View Sensor (SeaWiFS). Ocean color sensors are discussed in more detail in the companion paper by Maynard (this volume). Information on data archiving and these sensors can be obtained through the GSFC DAAC home page (http://daac.gsfc.nasa.gov).

IV. Ordering NASA Ocean Data Products

The EOSDIS has developed a multi-DAAC search and order system called the IMS (Information Management System). This is a prototype system and is still in development, but it does provide access to all the DAACs. With this system, researchers have the ability to search for data based on a number of criteria that include time, space, geophysical parameter, sensor and instrument. There is a feature-rich X-terminal version, accessible by telnet (either by 'telnet eosims.jpl.nasa.gov 12345', 'telnet eosims.asf.nasa.gov 12345' or 'telnet eosims.gsfc.nasa.gov 12345') and a Web version which is developing rapidly and which is more user friendly (http://harp.gsfc.nasa.gov/v0ims). All NASA ocean products are freely available to anyone, except SAR imagery from ASF where users must obtain individual approval as discussed above.

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Multibeam Sonar: Potential Applications for Fisheries Research

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Abstract

Revolutionary changes in our ability to map and visualize the ocean floor have taken place over the past few decades. Concurrent, rapid advancement of sonar technology, positioning and orientation technology, computer hardware, data bases, signal processing and visualization techniques are providing scientists with detailed depictions of large areas of the seafloor. In many ways, the resulting imagery is analogous to airborne or satellite-derived images of the earth's surface. At the core of these new technologies is the development of multibeam sonar systems, which use beam-forming techniques to insonify large swaths of the seafloor while producing high resolution (both lateral and vertical) bathymetry and seafloor imagery (backscatter). The Ocean Mapping Group of the University of New Brunswick has been pursuing research and developing tools related to multibeam sonar mapping for a number of years. While this work has been directed, for the most part, at hydrographic and geologic problems, many of the tools and approaches developed will have uses for fisheries research.

The extremely high data rates associated with multibeam sonars (as much as gigabytes per hour) present a range of data processing challenges. The Ocean Mapping Group has developed a full suite of software tools for the real-time and near-real time display, editing and visualization of multibeam sonar data that can produce near-finished maps and 3-D images on board the research vessel. These tools have been used on a number of surveys including a 1000 km^2 area off Eureka, Calif., a 3000 km^2 off New Jersey, and the Stellwagen National Marine Sanctuary. In each case the combination of detailed bathymetry and sonar imagery provide quantitative depth information and a qualitative description of the spatial distribution of seafloor materials and textures (e.g., rocky areas, sands, gravels, etc.).

While the qualitative picture of the distribution of seafloor types is a very useful tool for a number of applications (including fisheries research), efforts are currently underway to attempt to extract more quantitative seafloor property information from the sonar record. These efforts include the analysis of the characteristics of the vertically incident acoustic waveforms as well as evaluation of the angular dependence of backscatter. To facilitate this research, several interactive software tools have been developed that allow for the simultaneous exploration of sonar data in both geographic and bivariate space. The ultimate objective of this work is to provide a robust approach to the remote classification of seafloor type.

The Ocean Mapping Group has also developed a suite of interactive 3-D data exploration tools to facilitate the interpretation of these complex data sets. A 6-degree of freedom mouse (Bat) allows for interaction with massive (10's to 100's of megabytes) datasets with simple hand movements and exploration in a natural and intuitive fashion. Data points can be selected in 3-D for position, depth or other attributes and measurements can be made in the 3-D space (3-D GIS); the 3-D scene can be viewed in true stereo with special glasses. We have recently been utilizing these tools for the real-time visualization of midwater targets including schools of fish.

Properly processed multibeam sonar data is well suited for use in a range of fisheries research applications including: 1- real-time use in planning sampling programs dealing with invertebrate and ground fish habitat; 2- use of archival or newly collected data for comparison with retrospective analyses of fisheries survey data in order to identify habitats and species associations; 3- the provision of more detailed boundary condition information to high-resolution regional coupled ocean circulation models and; 4- the assessment of the impact of human activity (trawling, dredge-spoil dumping) on fisheries.

Introduction

Over the past few decades, revolutionary changes have taken place in our ability to map and visualize the ocean floor. These changes, brought about by the concurrent, rapid advancement of sonar technology, positioning and vessel orientation technology, computer hardware, data bases, signal processing and visualization techniques, are beginning to result in detailed depictions of large pieces of the seafloor that are, in many ways, analogous to airborne or satellite derived images of the earth's surface. Just as the first airborne and satellite images of the earth resulted in a quantum leap in our understanding of earth processes, the newly produced seafloor images have the potential to radically change our knowledge and understanding of submarine morphology and processes.

At the core of these new technologies is the development of multibeam sonar systems which use beam-forming techniques to insonify large swaths of the seafloor while producing high resolution (both lateral and vertical) bathymetry and seafloor imagery (from acoustic backscatter -- Figure 1). When collected in slightly overlapping swaths, multibeam sonars can produce a sonar data set that represents 100 percent acoustic coverage of the seafloor. The original impetus for the development of multibeam sonars came from the military and geologic communities and the early systems were designed for deep-water (full ocean depth) work. As the sophistication of these systems improved, shallow water systems were designed (shallow water systems operate at higher frequencies and repetition rates and thus require much more powerful signal processors) and hydrographic organizations, charged with responsibility for safety of navigation, began to explore the potential of multibeam data. More recently, it has become apparent that the detailed images of the seafloor produced by such systems have applications well beyond geologic and hydrographic surveys and, in particular, in the field of fisheries research.

The Ocean Mapping Group of the University of New Brunswick has been pursuing research and developing tools related to multibeam sonar mapping for the past five years. While this work has been directed, for the most part, at hydrographic and geologic problems, many of the tools and approaches developed are equally useful for fisheries research. In this paper, we will review those activities of the Ocean Mapping Group (OMG) that are relevant to fisheries research and then explore the applicability of this work to specific fisheries problems.

Multibeam Sonars

Multibeam sonars were first developed in the late 1960's as a means of producing a narrowbeam echosounder and thus removing the lateral ambiguity that is often associated with a bottom return from a wide beam echosounder. The early multibeam sonars used a large array of transducers mounted along the keel of the ship to produce a transmit pulse that was very narrow in the fore-aft direction (approximately 3˚) and very wide in the athwartships direction (approximately 90˚). A separate receive transducer, mounted orthogonal to the transmit array was used to form a number (16 in the early systems) of receive beams that are wide in the fore-aft direction but narrow (typically 3˚) in the athwartships direction. The intersection of the transmit and receive beams resulted in 16 independent areas of insonification, each 3˚ by 3˚ wide over a swath that was approximately 0.8 times the water depth (Figure 1).

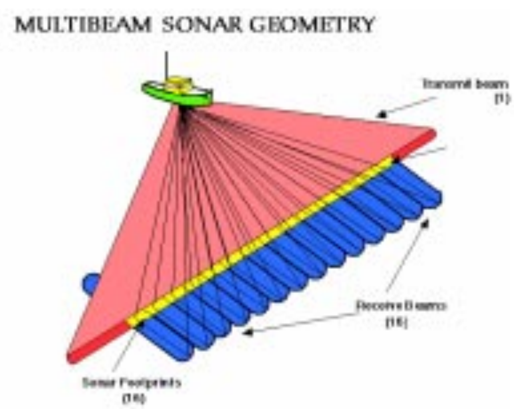

Figure 1. Simplified geometry of multibeam sonar system. Modern systems have 60 or more beams with swath widths of more than 150 degrees rather than the 16 beams and 90 degree swath shown here.

The earliest sonar systems only recorded the center beam but innovations in computer technology allowed for the recording of all 16 beams and thus the first implementation of true multibeam sonars. The past twenty years have seen a rapid evolution of both the sensors used to transmit and receive acoustic energy as well as in the processing systems designed to acquire, verify and display seafloor acoustic data. A range of modern shallow water multibeam sonars from a variety of manufacturers are now available operating at frequencies ranging from 95 kHz to 455 kHz with many of these sonars providing acoustic backscatter data (imagery) along with detailed depth measurements. The swath width, resolution and depth of operation of these systems will vary in a complex manner as a function of frequency, ping rate, pulse length, beam

Table 1. Specifications of some of the more common shallow water swath mapping sonars. Specifications are based on manufacturers' brochures; blank boxes indicate that the information was not available.

SYSTEM	SIMRAD EM3000	SIMRAD EM1000	RESON SEABAT 9001	ELAC BCC-SEE28 SEABEAM 1180	ATLAS FANSWEEP 20	ISIS 100
Frequency (kHz)	300	95	455	180	200	234
Pulse length (ms)	0.15	0.2/1/2	0.07	.3/1/3	.12	.08-.2
Max Depth (m)	100	900	100	300	300	100
Xmit beamwidth athwartships fore-aft	120 1.5	150/120/90 3.3	100 1.5/2/4/10	120 5.2	180 1.3	45 1.0 per side
Rcv beamwidth athwartships fore-aft	1.5 30	3.3 3.3	15 1.5	2.7 5.2		45 1.0 per side
Number of beams	127	60/48	60	56	up to 1440	contin. estimate
Beam Spacing	0.9	2.5	1.5	2.2	1.3	
Max ping rate/sec	20	4	15	5	12	10
Minimum range (m)	0.3	3	1	1.8	0.5	1

forming and detection techniques, and mode of operation, but a general guideline is that these systems can realistically provide vertical resolution that is on the order one percent of the water depth and lateral resolution that is on the order of five to ten percent of the water depth. It is also generally true that both the lateral and vertical resolution is typically higher in the higher-frequency systems but the swath width (coverage) is less and the increase in resolution leads to an increase in data density, with some of the highest resolution systems producing as much as a 500 Mbytes of data per hour. Thus in choosing an appropriate multibeam sonar for a particular job, care must be taken to specify a system that is appropriate to the application. Table 1 presents specifications of some of the more commonly used shallow water multibeam sonars.

The Ocean Mapping Group: The Canadian Hydrographic Service (CHS) was one of the first hydrographic services in the world to realize the potential of multibeam sonars for the collection of bathymetric data in support of shallow water chart production. In the late 1980's the CHS acquired several Simrad EM-100 multibeam sonars, and eventually the newer EM1000 multibeam system, which provided both bathymetry and imagery. As the CHS began to collect data with these systems they quickly realized that they were not able to handle the tremendous increase in data density that these systems produced relative to their conventional single channel echo-sounders. Faced with this problem, the CHS came to the University of New Brunswick's Dept. of Surveying Engineering (now known as Geodesy and Geomatics Engineering) and, with support from the Natural Sciences and Engineering Research Council of Canada, and several industrial sponsors, established a research group (The Ocean Mapping Group) whose mandate was to develop innovative techniques for the processing, management, verification and visualization of high density ocean mapping data.

Multibeam Sonar Software Tools

As with all acoustic systems operating in the ocean, multibeam sonar systems are plagued by serious problems caused by the environment (noise, motion, refraction, etc.). The initial efforts of the Ocean Mapping Group were to develop a series of software tools that would allow the hydrographer to edit and verify the massive amounts of data collected by multibeam systems in order to produce a "clean" data set suitable for incorporation into hydrographic charts. While historically, hydrographers tend to process their data on shore well after the data was collected, our goal in developing new tools was to be able to process and display the cleaned data on board the vessel collecting it, in as close to real-time as possible. What has evolved is a suite of software tools that work in real-time, near-real time and for post-survey analyses. While these tools were originally designed to work specifically with the multibeam sonars used by the CHS, they are general enough to work with most multibeam sonar systems. We will very briefly describe these tools and then look as some example data and potential applications in fisheries research.

Real-Time Tools**:** In order to derive a complete solution for the relative position of each sounding produced by a swath sonar, a multibeam sonar system must also include ancillary sensors for the precise determination of ship's position, ship's heading, vessel motion (heave, pitch and roll) and the sound speed profile in the water column. Most multibeam sonar manufacturers provide some means of integrating the data from these various sensors and then produce a "data telegram" with the information necessary to determine the position of each sounding (or imagery pixel). Our real-time tool strips out the essential features of these telegrams to produce a computer display that shows, in real-time, a color-coded bathymetric map (or imagery mosaic, if selected) of the survey as it progresses. Thus the operator gets to view the data as it is collected in its geographic context. In addition, other displays present waterfall plots (non geographically referenced) of color-coded bathymetry, sun-illuminated bathymetry (ideal for identification of small features), low-resolution and high-resolution imagery. These data are not edited or fully processed, but they do provide an excellent means to monitor the progression of the survey and the quality of the data being collected (problems can be identified immediately rather than days later). In order to aid in quality control, other ancillary information is provided, including tidal correction data, heave, pitch and roll data, and ship's heading and surface current solutions. A final window displays acoustic backscatter as a function of angle of incidence, an experimental tool aimed at developing a seafloor classification capability (see below).

The advantages of real-time display are manifest. Shipboard scientists are instantly provided feedback on data quality and coverage; decisions can be made in real-time as to changes in the survey and sampling programs. Any area on the real-time geographic display can be expanded and, with the click of a mouse button, targets or features on the display selected and interrogated for geographic position. In addition, if historical data exists (e.g., previous swathmap or other digital data or even raster scans of existing charts), these can be loaded into the tool and used as a backdrop upon which real-time navigation and plots can be overlain. Using these tools, a vessel can be instantly and unambiguously directed to a seafloor target for sampling, photography or instrument deployment.

SWATHED, Gridding and Mosaicing**:** Upon completion of a survey line, the data from that line is loaded into the SWATHED toolkit which facilitates the interactive editing of the data on a swath by swath basis. User selectable, automatic filters remove obvious outliers from the data and then the operator interactively selects further points for editing. While this process is subjective (and thus done with great care and scrutiny by hydrographers who have legal obligations about the data included in [or excluded from] their charts), for the purposes of fisheries of geologic research, it can be done with great speed, typically in much less than the time it took to collect the data. Additional tools can be applied at this point that can help resolve problems with sound speed corrections and provide detailed insight into the quality of the sonar data. The final result of this process is a cleaned, tide and refraction-corrected data set that is now suitable for gridding and mosaicing.

One of the greatest advantages of multibeam sonar data is that, if used properly, multibeam systems can provide 100 percent coverage of the seafloor (at a data density that depends on the system, water depth, vessel speed, ping rate, etc.) and thus obviate the need to extrapolate beyond, or interpolate between, sparse soundings. The price we pay for this coverage is massive data rates -- an EM1000 in 100 m of water

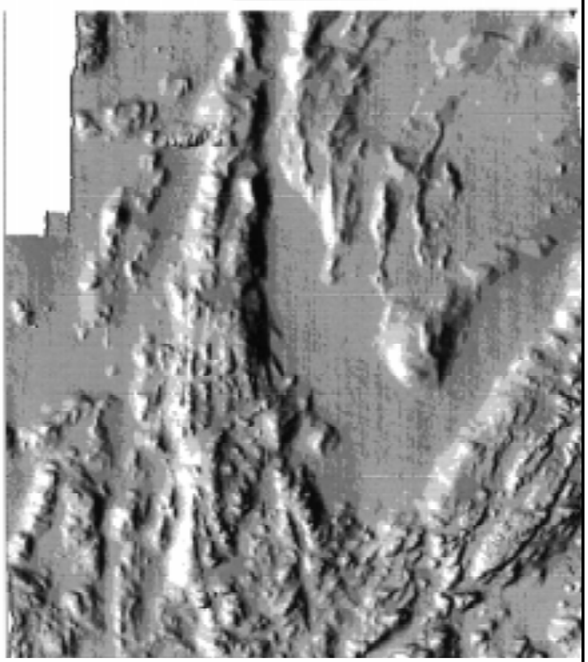

Figure 2a. Sun-illuminated topography for small area of Scotian Shelf. Sun is from 135 degrees and vertical exaggeration is 3 times. Water depths are 80-130 m.

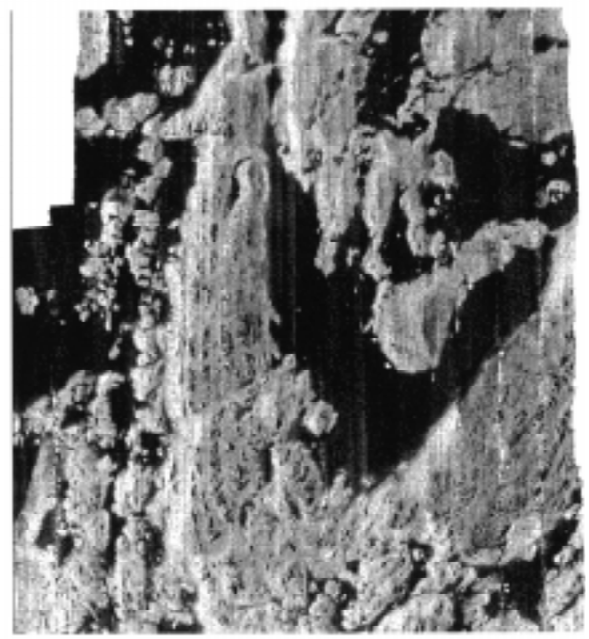

Figure 2b. Multibeam sonar imagery (sidescan sonar) from same area as in Figure 2a. Light areas indicate high backscatter and represent rock outcrops. Dark areas have low backscatter and represent sands and muds.

produces about 28 Mbytes of data per hour, an EM3000 at the same depth about 80 Mbytes of data/hour and EM3000 in 5 m of water produces about 450 Mbytes/hour (including sidescan imagery). The advantage of this dense database is that it can be used to create accurate digital terrain models (DTM's) and imagery mosaics of the seafloor. This is done through a process that grids each new line of data (typically at a scale of about 10% of the water depth) into a growing DTM. At the same time, the imagery from each line is sequentially added (at a pixel resolution that is typically about 5% of the water depth) to a growing sidescan sonar mosaic. This process is done on board the ship and is completed not long after each line is edited. Thus by the end of a survey day, an up-to-date, edited DTM and imagery mosaic can be produced. Depending on the needs of the survey, these products can be displayed as gray-scale or color-coded depth plots (with or without contours superimposed), color or gray-scale sun-illuminated bathymetry (Figure 2a) and color or gray scale sidescan imagery (Figure 2b).

<u>Interactive 3-D Visualization</u>**:** The output products described above provide the shipboard scientist with an accurate depiction of the 2-D bathymetry and areal distribution of backscatter (which is most likely related to seafloor type -- see below). While these same tools can produce static 3-D projections of the seafloor, we have taken 3-D visualization one step further by developing a suite of tools that allow for the interactive exploration of the seafloor data. The gridded and mosaiced products of SWATHED can be imported into another software package "Fledermaus" that uses a 6-degree of freedom mouse ("bat") that turns simple hand motions into a data exploration tool. This step can also be done on the vessel as soon as the data is gridded and mosaiced. A color-coded, sun-illuminated and shaded rendering of the DTM (or the imagery draped on the DTM) can be "flown" around and explored from all angles by simply moving the bat relative to a sensor located on the computer monitor (Figures 3a and 3b); if special LCD glasses are worn, the scene can be seen in true stereo. Data points can be interrogated in the 3-D scene for position, depth and other attributes (3-D GIS)

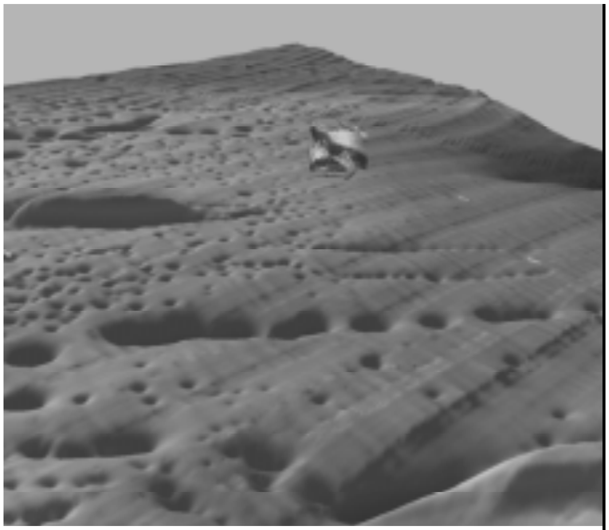

Figure 3a. Scene from interactive exploration of multibeam sonar data from Passamaquoddy Bay, Bay of Fundy. Large holes are pockmarks thought to result from expulsion of gas along fault planes. Object in middle of scene is simulation of volume rendered school of fish.

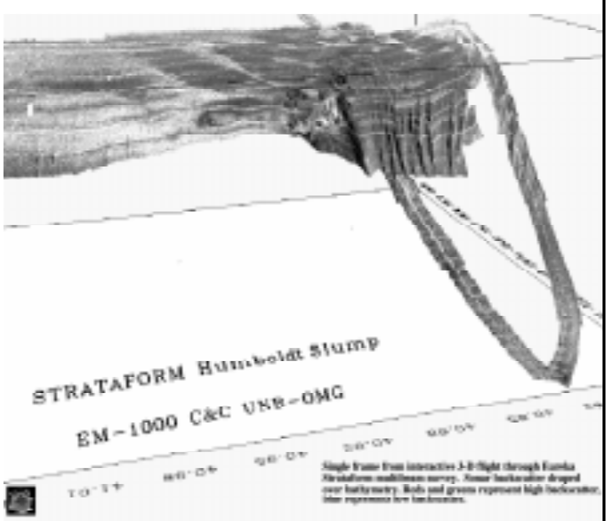

Figure 3b. Single frame from flight around multibeam sonar imagery draped over bathymetry from ONR survey off Eureka Calif. Light colors indicate high backscatter.

and multiple objects loaded into the scene (e.g., seismic records to show subsurface structure, positions of moorings, and other midwater features (see below). Other data sets (e.g., abundance distributions, ecological or other environmental data) can also be loaded and superimposed on the seafloor data. Flights can be saved and rendered to video for later viewing. The resulting image is a realistic rendering of a massive and complex data set that can be explored in an intuitive and natural way.

Midwater visualization**:** While the original focus of the Ocean Mapping Group has been on the interaction of sonars with the seafloor, our recent work in interactive 3-D visualization has led us to apply these techniques to midwater sonar returns with the hope of gaining insight into the density, spatial distribution, and schooling behavior of pelagic fish. While this seems to be a reasonable extension of multibeam sonar capabilities, most multibeam sonar manufacturers work very hard to eliminate midwater returns from their records and modifying these systems is not a trivial matter. In the interim, we have been working with a high-frequency (330 kHz) sector scanning sonar which scans through 180 degrees in 1.9 degree sectors to a range of approximately 100 m to either side of the vessel. While such a sector scanning system does not insonify a complete volume of the water column (gaps are left as the vessel steams ahead), it does provide the opportunity to extract midwater data and explore the feasibility of visualizing school behavior.

Our preliminary work was done on herring schools. A scrolling (as the vessel moves) 3-D display is presented with individual targets clearly defined (they are color coded to represent target strength) and representing the spatial distribution of the school when viewed in 3-D (Figures 3a and 4). As with our other 3-D tools, the scene can be viewed from any viewing angle and targets can be interrogated for position, depth and other attributes. We are now working with the sonar manufacturers in an attempt to use sonars with greater ranges and will hopefully be able to address important questions of school dynamics and particularly vessel avoidance. This work is being conducted as part of the Canadian Dept. of Fisheries and Oceans Hydroacoustics Program; more information about this program can be found on the web at: http://192.139.141.69/hydro.

Example Surveys

Stellwagen Bank National Marine Sanctuary**:** While the impetus for the work of the Ocean Mapping Group came from the Canadian Hydrographic Service, it quickly became clear that the data sets being collected and the images being produced had value far beyond the needs of the hydrographic community. The remarkable

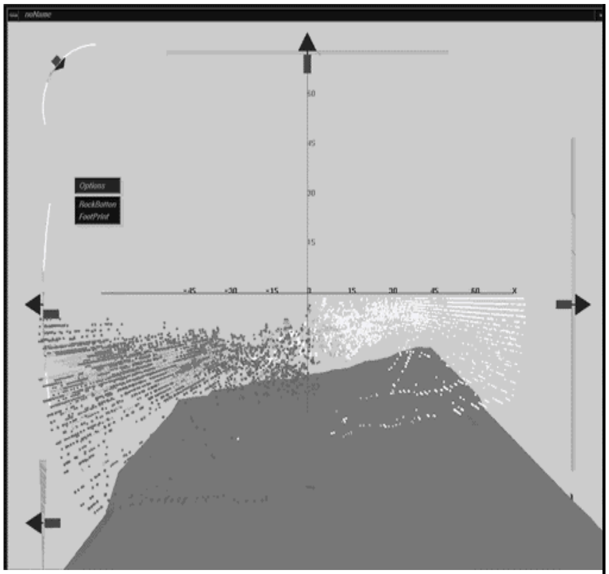

Figure 4. Snapshot of real-time 3-D visualization of herring school.

bathymetric detail provided by properly processed and displayed multibeam sonars (e.g., Figure 2a) allowed the geologic community to produce geologic interpretations of large areas of the offshore that had previously been depicted only as smoothly changing contours. While this level of bathymetric detail provided direct clues as to what the seafloor type was (bedrock outcrop versus flat sands and muds) the addition of directly co-registered sonar imagery provided even further evidence of the hardness or texture of the seafloor (e.g., Figure 2b). This combination, along with the ability to survey at high speed (the CHS has a Small Water Area Twin Hull [SWATH] vessel equipped with a multibeam system that typically surveys at 16 knots though a more typical survey speed for a conventional vessel would be 9 - 11 knots) and wide swathwidths (more than 7 times water depths for some systems in water depths less than about 100 m) makes multibeam a very powerful tool for mapping the detailed seafloor environment.

The value of multibeam for characterization of the seafloor has been recognized by a range of organizations charged with stewardship of the marine environment. For example, the US Geological Survey, along with NOAA-NOS, the CHS and the University of New Brunswick's Ocean Mapping Group have been using multibeam sonar to produce a detailed map of the bathymetry and distribution of seafloor types in the Stellwagen Bank National Marine Sanctuary off Cape Cod, Mass. To date, more than 5000 sq. km of the sanctuary has been mapped providing a detailed depiction of the bathymetry of the bank and clear indication of regions of gravel and boulder fields, sand sheets and mud-filled basins. Also evident in the sonar images are the effects of storms in reshaping the bottom through the generation of sand waves as well as the anthropogenic impacts of dredge spoil dumping and trawling. More information on this program is available via the World Wide Web at http://vineyard.er.usgs.gov.

<u>California and N.J. Margins</u>**:** As part of an ongoing ONR sponsored research program (STRATAFORM) detailed multibeam bathymetry and sonar imagery have been collected on the continental margins off Eureka, California and Atlantic City, N.J. in water depths ranging from 40 to 900 m. Approximately 1000 sq. km was covered off Eureka in less than 10 days and about 3000 sq. km was mapped off New Jersey in slightly more than 14 days. The maps produced in these regions (e.g., Figures 5a and 5b) present a detailed overview (pixel resolution is on the order of 3 to 20 m depending on water depth) of the distribution of both large and small scale geologic features; off Eureka, a relatively boring shelf is shown to be covered by muds and fine sands with the only topographic feature of significance being a dredge-spoil dump that is approximately 5 m in height. The shelf break and slope in this region, however, are punctuated by both small scale gullies, larger canyons and slump deposits as well as large rock outcrops caused by the active tectonics of the regions (Figures 5a, 5b and 3b). During the California margin survey a survey of the deep Eel River Canyon was conducted (in less than 12 hours) in order to evaluate the performance of this type of mapping system in a region known to be a rockfish habitat.

Off New Jersey, multibeam mapping revealed an extremely complex shelf covered by sand ridges with bedforms of various dimensions, rock outcrops and a remarkable terrain of what appear to be relict iceberg scours. The New Jersey survey took place in a region that abuts one of the NURP long-term ecological observatories (LEO-15) and where there is an important scallop and clam fishery. Images of both the California and New Jersey margins are available in the pub/outgoing directory via anonymous ftp to: ftp.omg.unb.ca.

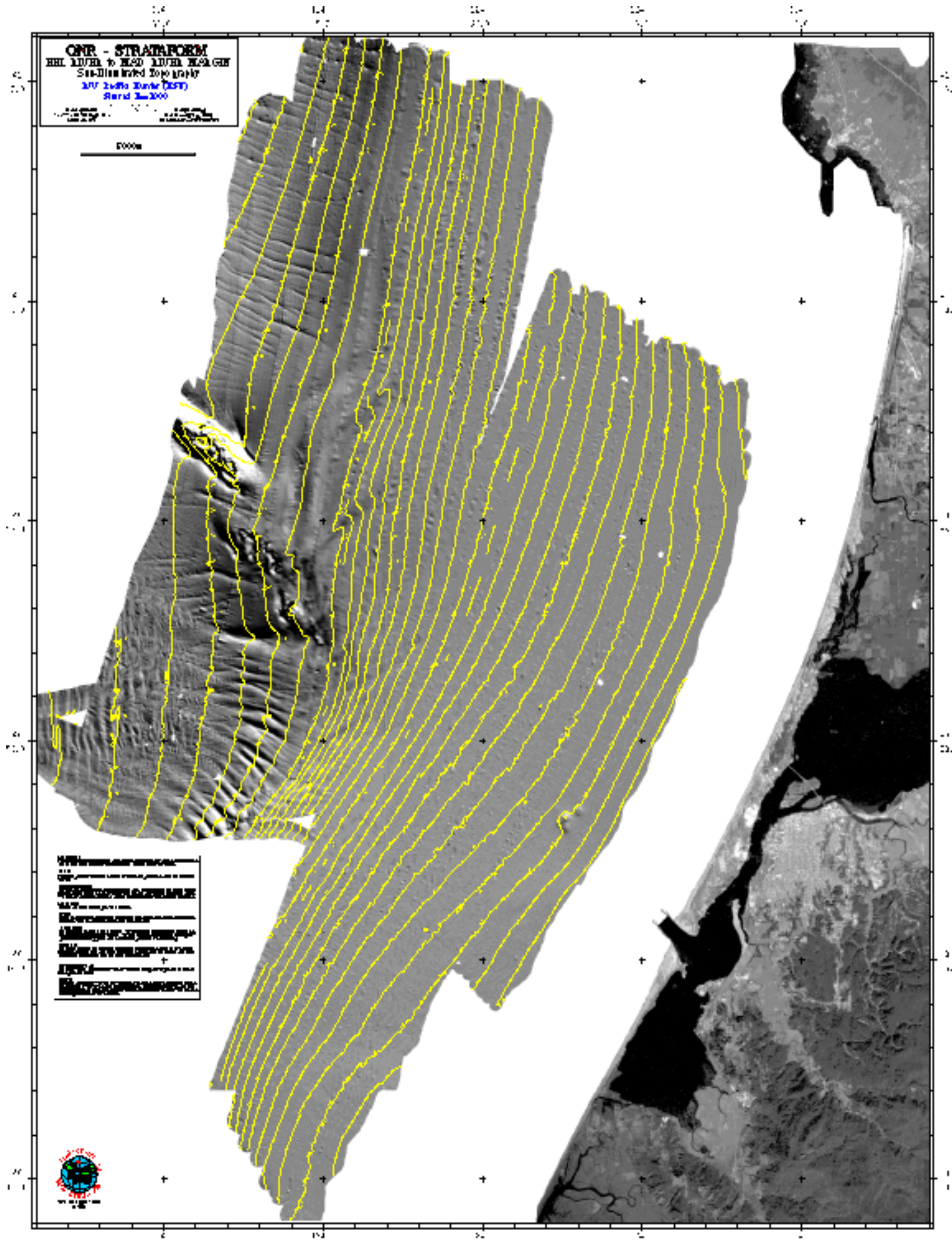

Figure 5a. Sun-illuminated topography of 1000 square km area off Eureka, California.

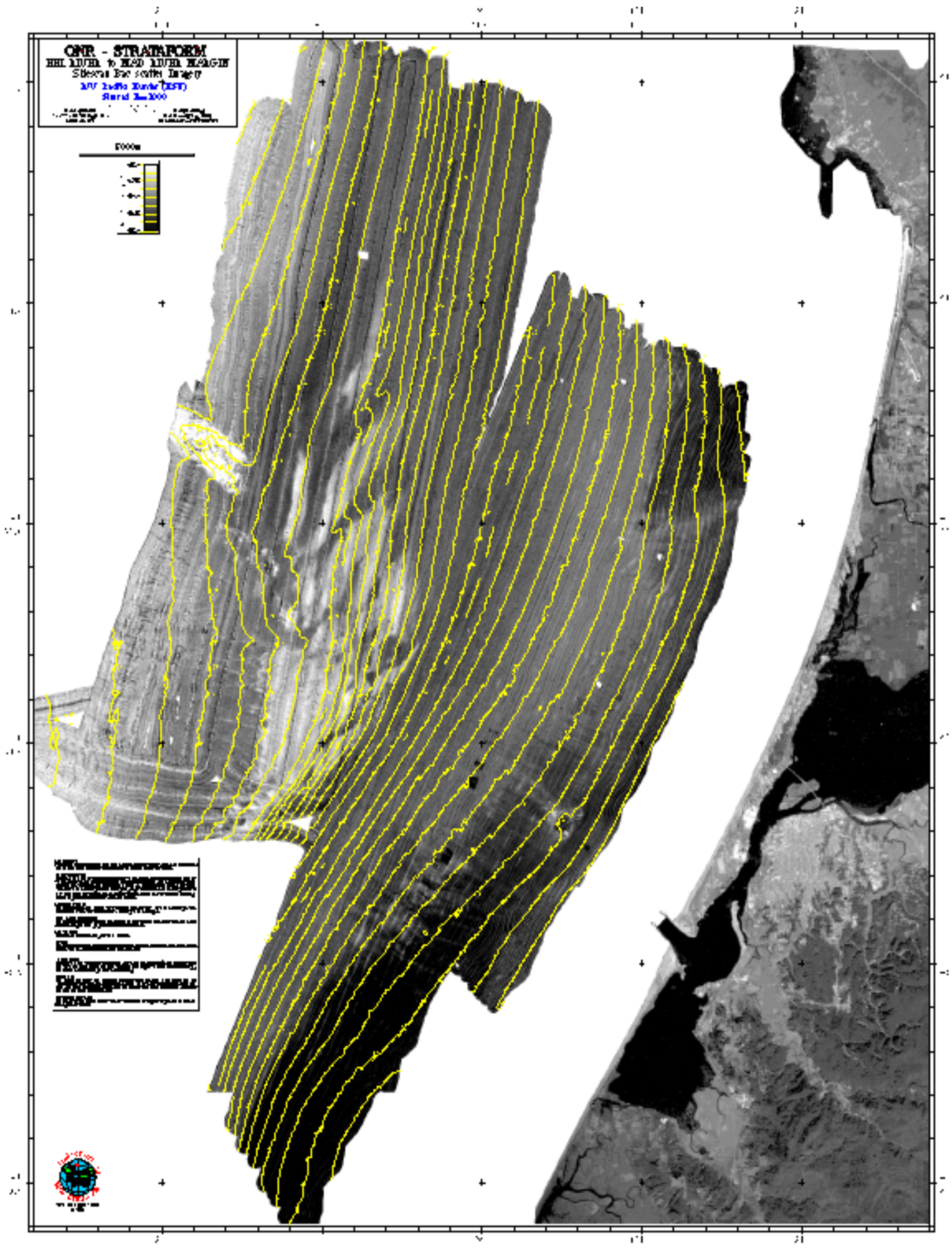

Figure 5b. Multibeam sonar imagery from 1000 square km area off Eureka, California.

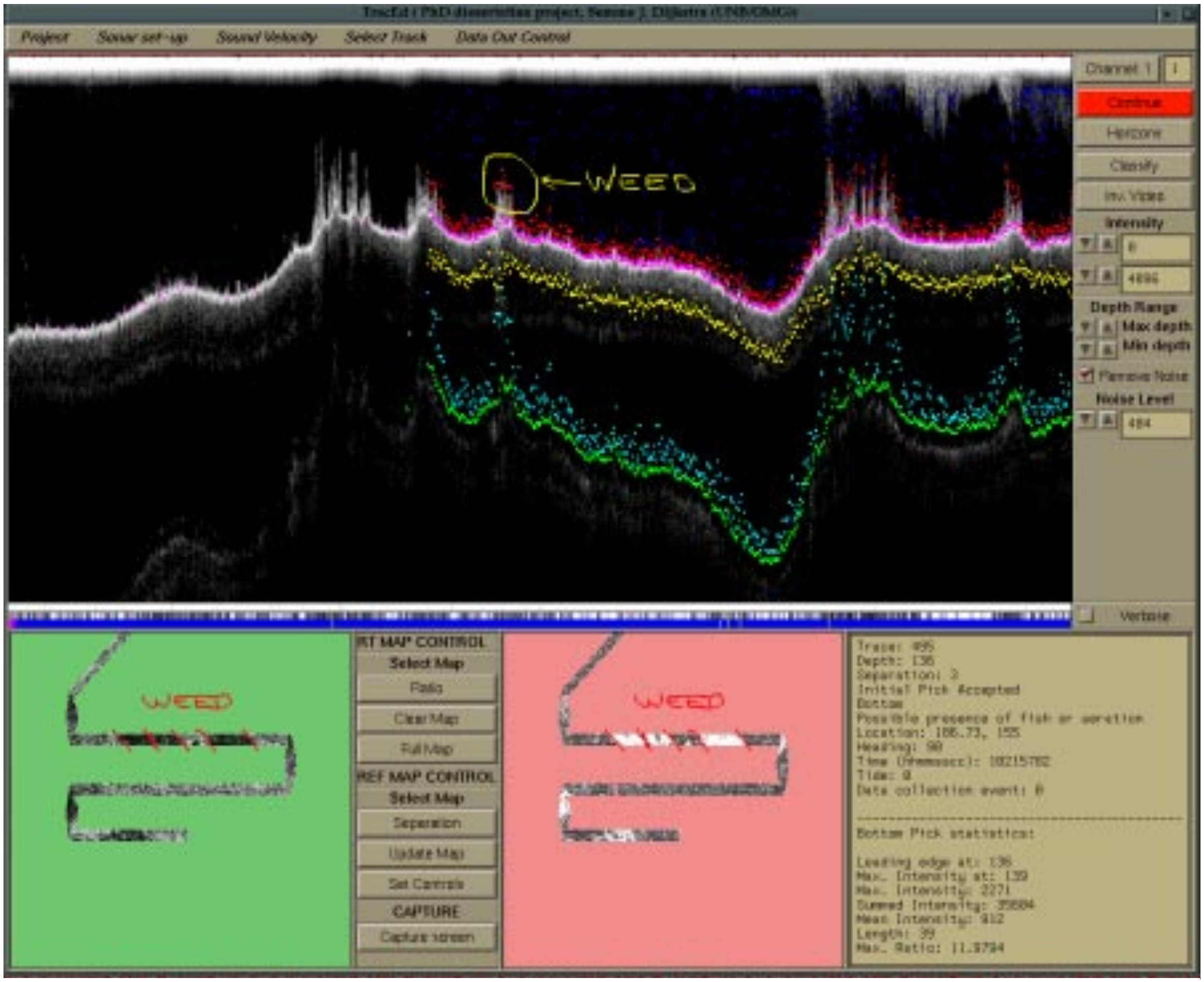

Figure 6. Example of TraceEd tool. Multiple horizons are traced as acoustic returns come in and various parameters used to distinguish characteristic features. Here the separation between bottom pick and earlier arrivals is used to identify seaweed. Distribution is simultaneously plotted in geographic space

Seafloor Classification

The detailed bathymetry and imagery produced by multibeam sonars allow the experienced observer to derive a tremendous amount of information about the seafloor. While the bathymetric data extracted from the multibeam system provides a quantitative depiction of geomorphological relationships (slopes, roughness scales, etc.), the sonar imagery (even if derived from the quantitative measurement of backscatter that some systems provide) can only be interpreted in a qualitative sense. In an effort to turn these qualitative interpretations into quantitative data, the Ocean Mapping Group is also pursing research and developing tools for the remote classification of seafloor material type. Our first approach to this end has been to develop an interactive software tool (TraceEd) that can robustly track the seafloor return (as well as other horizons above or below the seafloor) and then analyzes a number of characteristics of the returned acoustic waveform (e.g., amplitude, rise-time, spectral characteristics, returned pulse length, length of reverberation, separation between layers, etc.) that may be indicative of various seafloor characteristics (e.g., presence of seaweed). Once a useful classifier is selected, the tool will then plot the distribution of this feature (and a second feature if desired) in geographic space providing a derivative map that may well represent a quantitative display of a particular seafloor property or properties (Figure 6).

A second approach that we are using takes advantage of the wide swath over which multibeam sonars insonify the seafloor. Both theoretical and field studies have established the acoustic backscatter from the seafloor should vary in a predictable (Lambertian) fashion as a function of the angle of incidence of sound on the seafloor. If all other factors were held constant, the shape of the backscatter versus angle of angle of incidence curve should vary as a function of seafloor type. Using this approach, we are developing techniques to minimize the instrumental and environmental artifacts in multibeam backscatter data and then extract and display (either in real-time or in post processing) backscatter as a function of angle of incidence across the swath. When these techniques are in place, ground truthing studies will evaluate the usefulness of this approach for remote seafloor classification.

Finally, we have developed another interactive graphical tool (LASSO!) that allows us to display geographically registered backscatter data (e.g., a sidescan sonar image) and then graphically select and outline (i.e., - lasso - with the mouse cursor) any region of interest (Figure 7a). All data points within the lassoed geographic region are then selected and their statistics or other characteristics evaluated (e.g., the statistics of backscatter values in each selected region are determined). The tool can also overlay other data sets (e.g., physical property measurements from samples) and the relationships between properties in bivariate space displayed and color coded based on the selected geographic region (Figures 7a and 7b). The tool can be used in the inverse sense by interactively selecting regions in bivariate space (e.g., select all points with high sand content and/or high organic carbon content) and then instantly viewing the geographic distribution of data points with these sets of characteristics. This tool has proven invaluable in evaluating the viability of numerous approaches towards seafloor classification.

Applications To Fisheries Research

We have described a number of recent developments in multibeam sensors, in 1) our ability to extract quantitative information about both the shape and character of the seafloor from them, 2) our ability to manipulate and overlay multiple geographically-referenced data sets in order to establish derivative relationships, and 3) our ability to visualize and interact with these massive data sets in a natural and

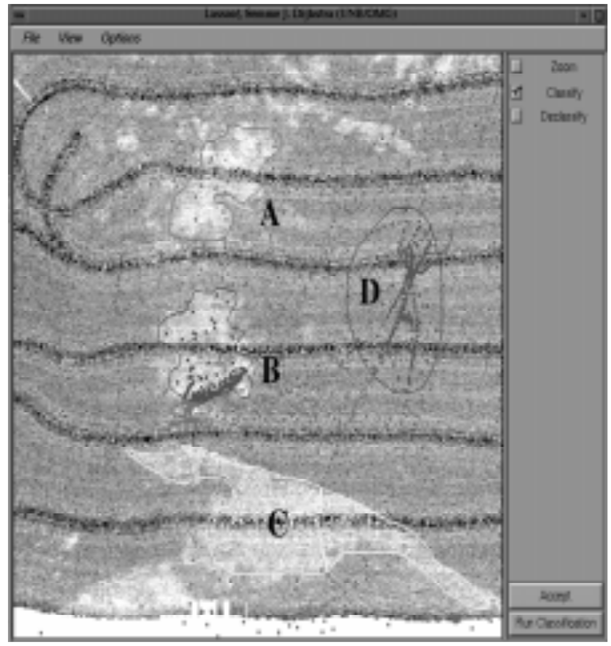

Figure 7a. Selection of areas of interest in geographic space using LASSO tool. Dots represents overlain dataset of seafloor "roughness" and "hardness" values from a RoxAnn system.

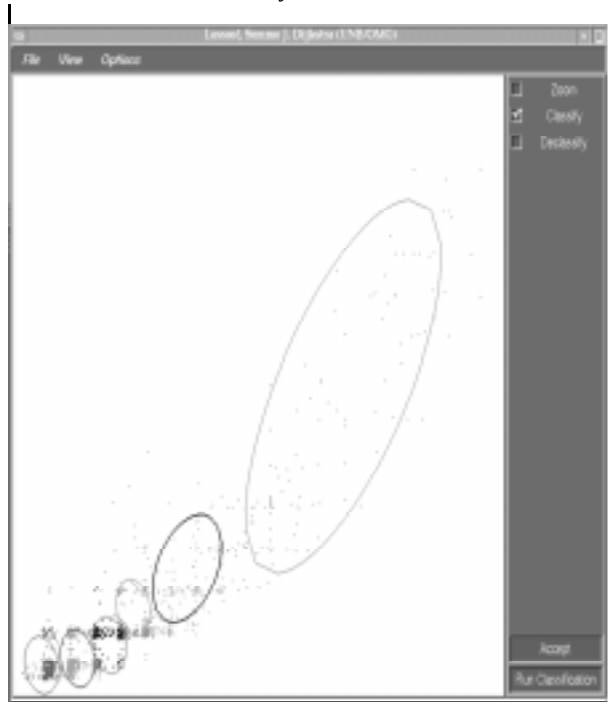

Figure 7b. Bivariate distribution of "roughness" and "hardness" values from areas selected in geographic space shown in 7a.

intuitive manner. While our expertise is not in fisheries research, it seems obvious that the ability to remotely and rapidly characterize bottom shape and potentially bottom type should have important ramifications for several aspects of fisheries research.

One of the most obvious applications of multibeam mapping is in support of habitat studies for invertebrate species. An example of this is a series of recent surveys done around the Magdalen Islands by researchers from the Maurice Lamontagne Institute of the Canadian Dept. of Fisheries and Oceans. These researchers have used the EM1000 multibeam system mounted on the CHS vessel CREED to map an approximately 200 sq. km region in support of long-term studies of lobster abundances. The aim of the research project is to develop abundance indices for lobster at different life stages and design a monitoring program that can be used to link abundance indices and landings. Before such monitoring sites can be selected and the monitoring program planned, suitable lobster habitats must be found.

The multibeam sonar bathymetry and imagery clearly showed the distribution of muddy, sandy and rocky seafloor (Figure 8). From these results a series of Nephrops trawl surveys were planned to assess the abundance of pre-recruit lobster and to do so without risk to the gear. In the short term, these maps will allow determination of the exact distances between trawling stations and rock reefs in order to better interpret the spatial variability in abundance and to determine the proportion of the habitat that can be sampled with a trawl, essential to increasing the accuracy of the abundance estimates. In the long term, these data provide an unprecedented, detailed, digital characterization of the seafloor that can be used, in conjunction with additional environmental data sets, to greatly increase our understanding of the relationship of lobster to their habitat.

The data provided by multibeam sonars is equally critical for understanding the distribution and nature of groundfish habitats and their relationship to commercial fisheries (and other species associations). By taking advantage of the detailed information on seafloor shape and type provided by these systems, fisheries ecologists can begin to relate habitat to ecological patterns (much like terrestrial ecologists have been able to do). While being able to collect and process data in near real-time can be of importance in survey and sampling planning (as illustrated above), it is also important to note that, for the most part, the seafloor is relatively slowly changing and thus, any survey data collected can be archived and used as a base for comparison with retrospective data and for future work. A project of this sort is being planned for the New Jersey margin where a large historical data base of landing records will be superimposed on, and compared with, the newly collected detailed images of the seafloor. In those areas where there are active changes in the seafloor (e.g., areas of sediment transport or bedform migration), repeat surveys can rapidly document and quantify the degree of mobility of the seafloor.

The increased bathymetric detail produced by multibeam sonar may also prove to play a critical role in providing boundary conditions for the ever increasingly high-resolution coupled ocean circulation models that are currently being used to enhance our understanding of biological and fisheries processes. Most models now use the standardly available ETOPO-5 bathymetric data base that is gridded at 5 mile resolution. While this spacing is coincident with the 1/12 degree resolution of some GCM's, higher bathymetric resolution will be needed as higher-resolution regional models are developed. The growing collection of multibeam data is an ideal source for the needed bathymetric data and, in critical regions, new multibeam surveys can be carried out.

Finally, multibeam bathymetry and imagery provide an ideal means of examining the impact of human activities on the seafloor and on the fisheries. Many modern multibeam sonars can easily discern trawl marks and debris or dredge spoils dumped on the seafloor. Multibeam surveys can quickly pinpoint the location and spatial distribution of human activities and help focus the subsequent sampling and monitoring needed to assess the impact of this activity on the fisheries. Repeat surveys provide the opportunity to monitor the fate of feature (i.e., how long do trawl marks last, or how are dredge spoils spatially distributed) and once again allow sampling and monitoring programs to be designed around a clear knowledge of what is on the seafloor rather than a blind guess.

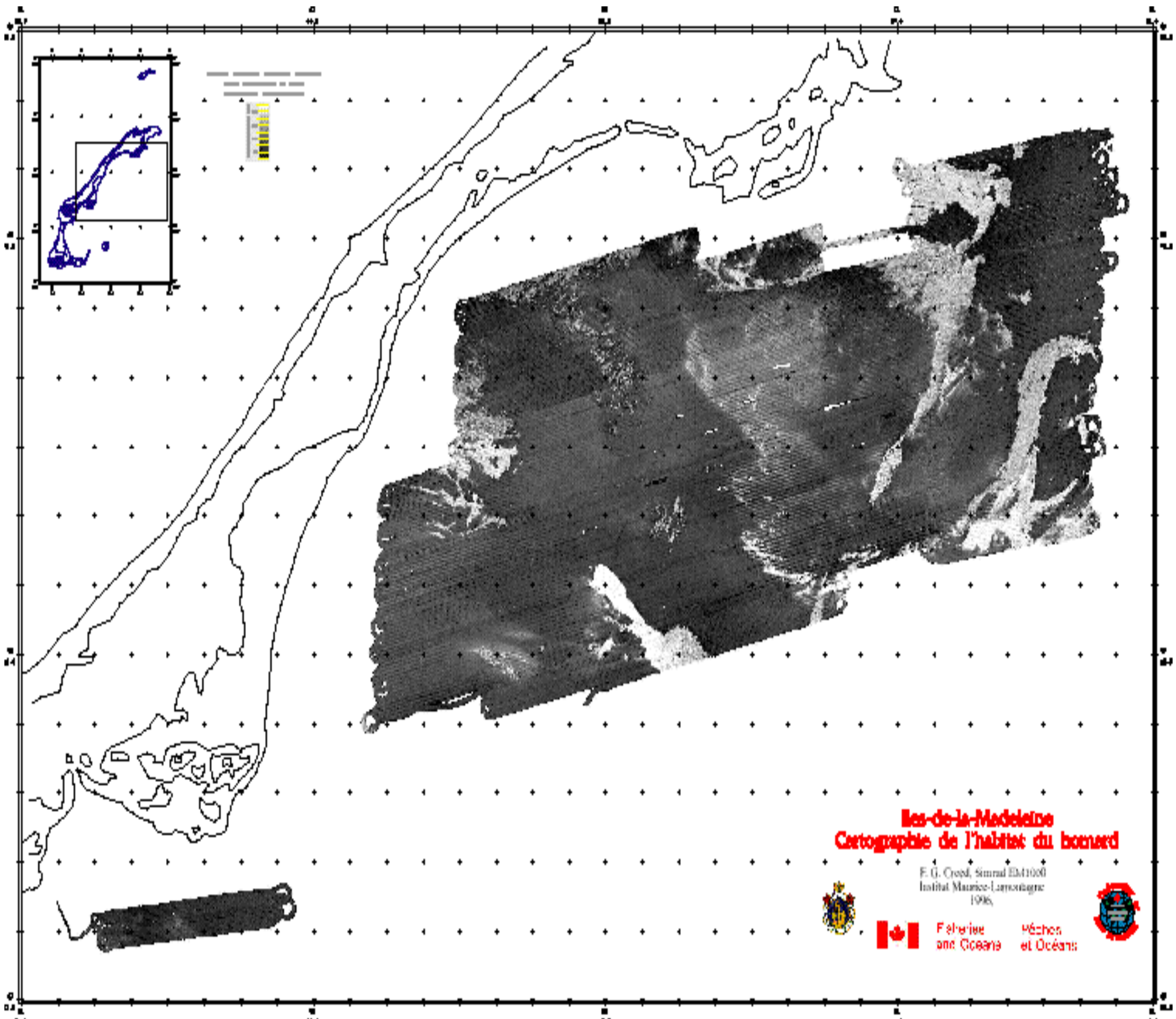

Figure 8. Multibeam sonar imagery from DFO lobster habitat survey. Light areas are rocks and gravels, dark is mud.

Conclusions

Modern multibeam sonars provide the means to map the detailed bathymetry and potentially the distribution of seafloor type over large areas of the seafloor in relatively short periods of time. Typical multibeam sonars can map continental margin areas of several thousand square kilometers on the time scale of weeks, providing 100 per cent coverage of the seafloor with a vertical resolution that is typically less than 1% of the water depth and a lateral resolution that is typically between 5 and 10 percent of the water depth. The Ocean Mapping Group of the University of New Brunswick has been developing software tools that can display the data as it is being collected in map form, in real-time, and produce fully processed images of seafloor on board the research vessel in near real-time. Software has also been developed that allows these massive data sets to be explored simultaneously in both a geographic and bivariate context (to better understand the spatial distribution of seafloor properties) as well as to be brought into an interactive 3-D environment along with ancillary data sets so that the features of, and the relationships amongst, these complex data sets can be explored in a natural and intuitive fashion.

The result of a properly processed multibeam sonar image is a digital depiction of the spatial variability of seafloor shape and type that is analogous to stereo aerial photography. As such it seems well suited for use in a range of fisheries research applications including: 1- real-time use in planning sampling programs dealing with invertebrate and ground fish habitat; 2- use of archival or newly collected data for comparison with retrospective analyses of fisheries survey data in order to identify habitats and species associations; 3- the provision of more detailed boundary condition information to high-resolution ocean circulation models and; 4- the assessment of the impact of human activity (trawling, dredge-spoil dumping) on fisheries. Multibeam data is continuously being collected worldwide, for purposes other than fisheries research (geologic, hydrographic, cable and pipeline route and military surveys). Much of this data is available to the fisheries research community but they need to seek it out and learn how to fully take advantage of it.

Working Groups

Working groups were an important focus of the workshop. Assignments to working groups, including chair and rapporteur, were made prior to the workshop to assure that the appropriate balance of expertise would be represented in each group. Each working group was given a charge to discuss a specific area and to develop the outline of a working paper. Working groups made reports to the plenary session for feedback from the group as a whole and then reconvened to draft papers from their deliberations with recommendations for needed actions. The first four working groups in the list below were proposed, with the fifth an *ad hoc* working group developed to stress the importance of cooperation.

- Real-time or near real-time environmental data needs
- Retrospective environmental data needs
- Physical oceanographic and atmospheric model applications
- Data delivery systems, data accessibility criteria, and formats
- Partnerships in fisheries oceanography

The following section begins with a paper presented by Jim Schumacher describing the FOCI program and the manner in which it uses environmental data in ways that pertain to all of the working groups. This is followed by the working group reports, the consolidated list of recommendations, and a summary of the priority recommendations.

Application of Environmental Data in Fisheries Science: Examples from Fisheries Oceanography Coordinated Investigations (FOCI)

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Introduction

Research in fisheries oceanography examines relationships between production and dynamics of fish populations, and the marine environment. One goal is to understand natural causes of variability in year-class strength of commercially valuable species and apply this knowledge to management. A major challenge is to understand biological processes and interactions of these with the physical environment (Figure 1). Oceanic features that exert a marked influence throughout the ecosystem include transport, temperature and turbulence. Dispersion of heat, salt, nutrients and plankton plays a crucial role in establishing the foundation for productivity at higher trophic levels. At high latitudes, an additional feature of the physical environment is the seasonal sea ice. Sea ice influences population distributions and the timing and extent of ice-edge phytoplankton blooms.

Waters of the Gulf of Alaska and Bering Sea are highly productive. Fish and shellfish from Alaskan waters constitute nearly 5% of the world and 50% of the US harvest. Walleye pollock, salmon, halibut and crab provide an important source of food and generate over 2 billion dollars each year in revenue. Pollock constitute the world's largest single species fishery with catches from Alaskan waters exceeding 1.2 million metric tons each year. Because pollock are prey for numerous fish, marine birds and mammals, they are a nodal species in the Alaskan marine ecosystems.

The combination of large variations (> twenty-fold) in recruitment of pollock and the existence of a basic knowledge of regional physics and biology of Shelikof Strait by NOAA scientists led to the creation of Fisheries-Oceanography Coordinated Investigations (FOCI) in 1984 (Kendall et al. 1996). Some preliminary research began in the Bering Sea in 1986 with a more extensive program starting in 1991 (Schumacher and Kendall 1995). Ongoing research is being conducted in both regions. Our experience in Shelikof Strait is that monitoring basic physical and biological properties provides indices of survival of young pollock (Megrey et al. 1996) while enhancing knowledge of biophysical processes in the region

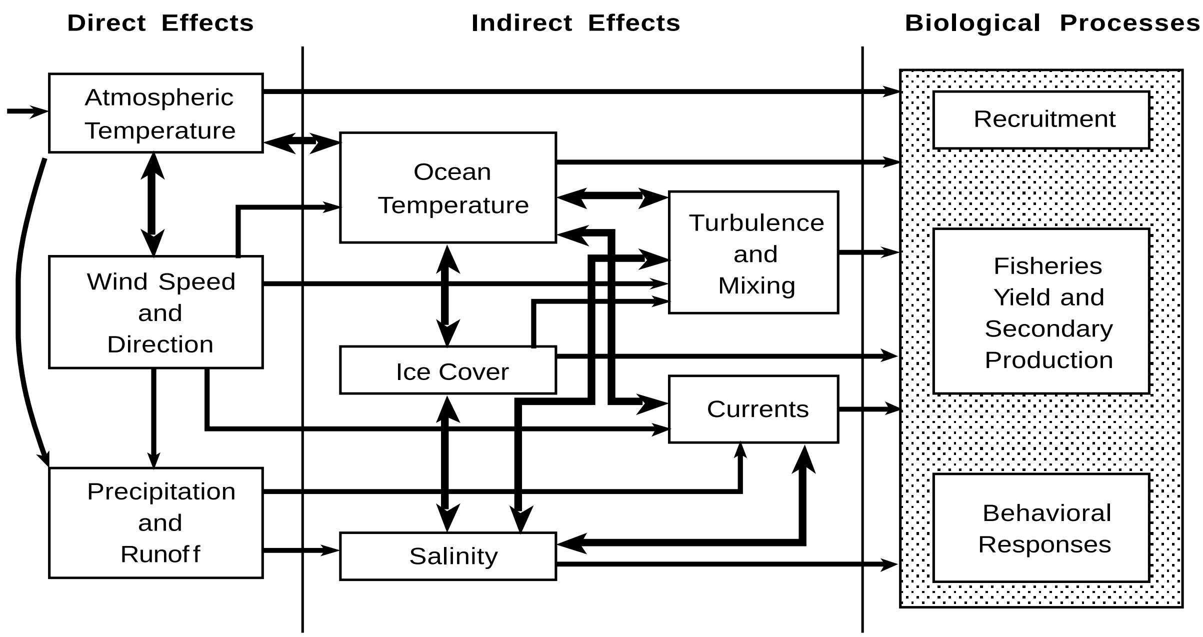

Figure 1. Climate pathways affecting the abiotic environment and biological processes (after Glantz, 1992).

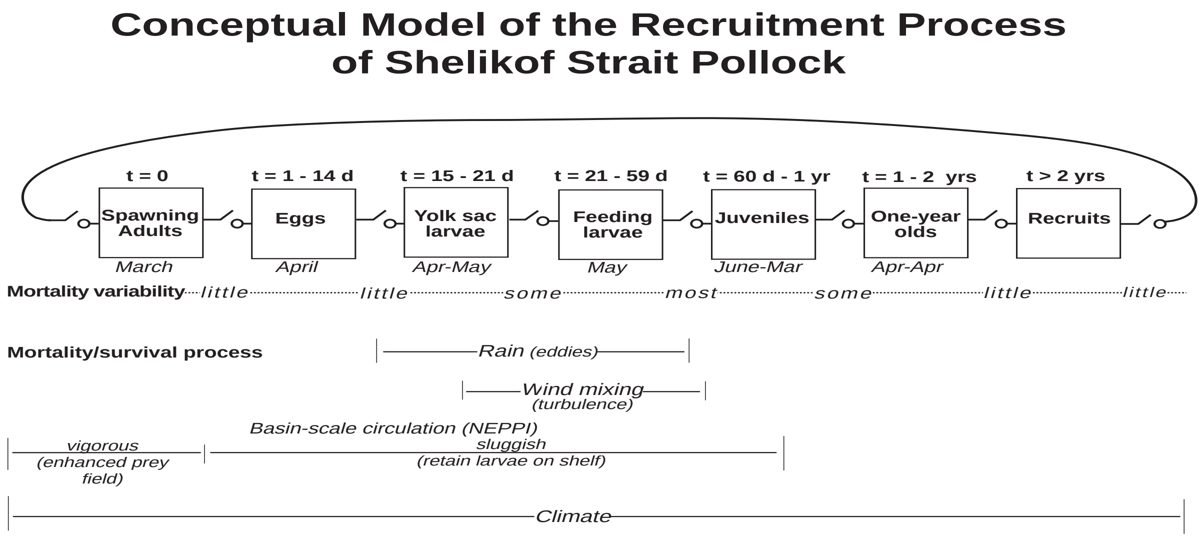

Figure 2. Conceptual model of factors important in determining year-class strength of pollock in Shelikof Strait region. (after Megrey et al. 1996).

(Bailey et al. 1996a,b; Brodeur et al. 1996; Napp et al. 1996; Stabeno et al. 1996) and guiding model studies (Hermann et al. 1996a,b).

In an attempt to understand the large variation in recruitment of pollock, FOCI has made use of real and near real-time observations, retrospective data analysis, and model simulations. In the following sections, I first present the conceptual model used by FOCI to examine how the physical factors influence year-class strength. This is followed by examples of applications of: real and near real-time data, retrospective analysis and modeling studies. Data delivery systems and accessibility are then briefly discussed.

FOCI Conceptual Model: Shelikof Strait

Based on more than a decade of research on pollock in Shelikof Strait (Fisheries Oceanography Vol. 5, Suppl. 1 1996), we have elucidated the features of early life history, found that several environmental factors contribute to interannual variation in survival of eggs, larvae, and juveniles, and determined that recruitment is largely set during these stages (Kendall et al. 1996). This work has led to the development of a conceptual model (Figure 2) of some of the physical factors (Table 1) important to determining year-class strength of pollock in Shelikof Strait. The FOCI model consists of a number of successive switches that indicate the probability of survival to the next stage of development (Megrey et al. 1996). Within a given life stage, physical and biological processes are the determinants of survival. These switches operate on a variety of spatial and temporal scales, and can apply to individuals, cohorts or to the entire year class. Hence, the FOCI model is a regional adaptation of the generic model shown in Figure 1. In an analysis of survival patterns of pollock (Bailey et al. 1996a), it was hypothesized that the level of recruitment can be set at any life stage depending on sufficient supply from prior stages, a type of dynamic that can be termed supply dependent multiple life stage control. To date, results suggest that year-class is most likely set during the larval and/or early juvenile stage, and on average, 77% of the generational mortality occurs in the first 5 months of life (Bailey et al. 1996a, b).

On a global scale, there likely are climatic switches that precondition Shelikof Strait as a favorable region for pollock reproduction. On the scale of the North Pacific Ocean and Gulf of Alaska, a basin-scale switch operates during winter-spring to provide nutrients for eventual production of pollock larval prey and may also affect advection of larvae from the region of hatching either offshore or to their nursery grounds along the Alaska Peninsula. For optimal recruitment, it is suggested (Kendall et al. 1996) that circulation in the Gulf of Alaska would need to be vigorous in winter (to supply nutrients) and then sluggish in spring (to retain

Table 1. Description of environmental data series. (after Megrey et al. 1995).

Data series	Description
	ATMOSPHERIC FEATURES
Rainfall	Monthly average precipitation (dm) at Kodiak, AK
Air temperature	Monthly average air temperature (˚C) at Kodiak Monthly COADS[a] average air temperature (˚C) at 3 sites
Sea level pressure	Monthly COADS sea level pressure (mb) at 3 sites
Wind speed	Monthly COADS average speed (m s^{-1}) at 3 sites Monthly NMC gridpoint average wind speed
Wind direction	Monthly NMC[b] gridpoint average wind direction (degree) at two locations
Wind stress	Monthly NMC gridpoint average wind stress (N m^2) at two locations
Wind mixing	Monthly NMC gridpoint wind mixing averages (W m^2) at two locations
NEPPI[c]	Monthly average sealevel pressure index (mbar). Calculated as SLP(northcentral Pacific)- SLP(Reno)
	ICE FEATURES
Percent ice cover	Percent ice cover in Cook Inlet
Date of last ice	Julian date of last ice cover in Cook Inlet
Maximum ice extent	Julian date of maximum ice cover in Cook Inlet
	OCEANOGRAPHIC FEATURES
Seasurface temperature	Monthly COADS average seasurface temperature (˚C) at three locations
OSCURS[d] model output	An index of Gulf of Alaska circulation. Number of simulated drifters out of six released on Feb 1 at 55˚N between 152˚W and 137˚W that cross 154˚W by April 1.
Freshwater runoff	Index of mean winter coastal freshwater discharge (m^3 s^{-1}) anomaly in the Gulf of Alaska (Royer model)

[a]COADS: Comprehensive Ocean Atmosphere Data Set; [b]NMC = National Meteorological Center;
[c]NEPPI = Northeast Pacific Pressure Index; [d]OSCURS = Ocean Surface Current Simulations.

larvae on the shelf for subsequent transport to their nursery grounds). Since we have found increased early larval condition and survival in eddies, physical conditions related to the development of eddies in springtime provides another switch in the model. The amount of freshwater entering the system likely provides an index of this switch since eddies are generated due to baroclinic instability. Since we have found that increased survival of larvae reaching the first-feeding stage occurs during periods of calm winds (Bailey and Macklin 1995), the final switch is an index of turbulence experienced by these larvae.

Uses Of Real/Near Real-Time Data

One use of real or near real-time data is a requirement to guide field operations. Observations from both Shelikof Strait and the eastern Bering Sea indicate that high abundance of pollock larvae often reside in eddies. An important question raised by this is do eddies provide an environment more conducive to survival than that which occurs in adjacent waters or are the high abundances simply a function of time/space patterns of hatching being coincident with eddy formation? To examine the nature of biophysical processes extant in these features and determine their influence upon survival requires detailed *in situ* observations. Finding a reliable method to locate an eddy for field studies has been a challenge. Remote sensing offers one possible solution. Although infrared imagery has proved useful, cloud cover and generally weak sea surface temperature gradients limits this approach. High resolution ERS-1 Synthetic Aperture Radar (SAR) eliminates both of these constraints. Mesoscale features are imaged by SAR through several possible mechanisms not all well understood, although current-induced wave refraction has been examined in Shelikof Strait (Liu et al. 1994). At present, however, SAR coverage does not provide daily access to images for either the eastern Bering Sea or Gulf of Alaska.

Hydroacoustic techniques provide another means of real time detection of mesoscale features. During April and early May 1992, three eddies were apparent in SAR images of Shelikof Strait. In mid-May a larval survey was conducted and a satellite-tracked buoy deployed in a region of high larval abundance. The buoy made a circular trajectory around a mesoscale feature which likely was one of the eddies observed in the SAR imagery. During this time and on a subsequent cruise, anomalous patterns of backscattering appeared on a 38 kHz acoustic system. A strong scattering layer at the surface and in midwater, with the column in between nearly void of sound scattering organisms characterized the signal (Brodeur et al. 1996). This signal appeared in several sections of data where SAR had indicated the presence of eddy-like features. Analysis of concomitant water property and shipboard acoustic Doppler Current Profiler (150 kHz) observations confirmed the existence of these features. The density of larval pollock in these features was estimated to be an order of magnitude greater than in surrounding waters. FOCI results substantiated that acoustic backscatter signals can sometimes be used to identify and characterize mesoscale biophysical features in the ocean, thereby permitting real-time studies of these features. We are presently using several different acoustic frequencies to detect frontal features in the Bering Sea and thereby direct sampling for juvenile pollock

Another use of real time data has been to recover/replace lost biophysical platforms. As part of a project to develop biophysical indices of the environment of the eastern Bering Sea, two platforms that measure biophysical parameters have been moored over the shelf. While some real-time data (wind, air temperature, water temperature, fluorescence) from the surface waters has been transmitted via ARGOS, the most important observation to date has been location of the platform itself. During winter 1995, extensive sea-ice coverage advanced to and over the platforms. Both of them were dragged many kilometers from their original site. Having the position information allowed us to both stage an emergency recovery cruise and to readily locate the damaged platforms.

The acquisition of real time data generates enthusiasm among researchers. Observations from satellite-tracked buoys has been of great interest for both ongoing field operations and for providing a sense of the present status of the environment. We have not, however, had an occurrence where a buoy was deployed in an eddy and we then had the opportunity to examine biophysical conditions and processes. Finding a high concentration of larvae and then deploying a buoy, however, has been a method for finding eddies. Between 1986 and 1993, 45 buoys were deployed in support of studies of pollock over the slope of the Bering Sea. In three of these years, four regions of high rough counts of pollock larvae were found and buoys deployed in them. In all cases, the trajectories of the buoys defined eddies. Likewise, the buoys (33) which were not deployed in a patch did not indicate eddies. Having the opportunity to watch as buoy trajectories support (or don't support) one's preconceived notions regarding circulation has generated enthusiasm within some of the FOCI team. This year’s results indicate very sluggish circulation existed between April and June in Shelikof Strait and over the eastern shelf of the Bering Sea.

While FOCI has not yet used model simulations in a real time mode, other programs have (e.g., OPEN). In this approach, larval and oceanographic observations are assimilated into a circulation model that forecasts the location of the larvae at a later time. There are also observational and combined observation- model products available, including sea surface temperature and sea surface temperature anomaly fields. This spring over the Gulf of Alaska and Bering Sea shelf very high sea surface temperature fields were shown in the near real-time results from Fleet Numerical Oceanographic Center's Optimum Thermal Interpolation system (OTIS). One possibility is that wind driven circulation, as indicated in buoy trajectories, is weak due to winds being more moderate or calm than is usual. The implication of weak winds is that mixing was minimal so that sea surface temperatures became unusually high.

Retrospective Environmental Data Needs

The most important retrospective data set that FOCI required was a longer recruitment time-series. Megrey et al. (1995) present an extended recruitment series back to 1962 that increased the length of the time series by about 65%. This was accomplished by combining catch biomass and length-frequency data, and applying stock assessment model techniques (Methot 1990). This series, which is updated each year after results are available from the annual hydroacoustic survey of adults in Shelikof Strait, forms the basis for all comparisons and exploratory statistical analyses with environmental processes.

The next environmental data need is for time-series of physical features and/or indices of processes that are important to pollock recruitment. Often an index or proxy for a process is either all that is available or is most useful since our understanding of the process is limited. Wind generated mixing within the water column provides an example of a process where both measurement limitations exist and our understanding is minimal. Direct measurement of turbulence is not practical at this time. While measurements of wind and water column structure are simple to collect, to do this over the entire FOCI study region is not practical. Although our understanding of turbulence is limited, we can still examine how it influences first-feeding pollock larvae and their prey. Results from modeling studies suggest that wind mixing of the upper layer can be either beneficial or detrimental to larval fish survival depending on the intensity of the turbulence (Davis et al. 1991). Clearly, there are aspects of turbulence and its impact on larval survival that are not known. We use wind speed cubed as a proxy for turbulence and examine the influence of this index using observations. The patterns that emerged when larval survival and mixing index were compared show that (1) strong wind mixing events during the first-feeding period were associated with periods of lower than expected survival, and (2) periods of higher than expected survival were associated with calm wind periods often bracketed by strong mixing (Bailey and Macklin 1994). The use of indices also applies to model simulations. Recent results (Anon 1996) note that indices developed from physical circulation models should be used instead of raw environmental descriptors (e.g., depth-averaged water temperature) when conducting exploratory statistical analyses of the effects of such processes on Atlantic cod recruitment.

To provide time-series for exploratory statistical analyses, FOCI has used both direct observations and models to produce retrospective times-series. The northeast Pacific pressure index (NEPPI) is constructed from the sea level pressure difference between the continental US and a position near Unimak Pass. The pressure time- series used here actually is from a model that interpolates point observations. At present, one research component in the Bering Sea is examining sediment cores to determine if fish scales have been retained and can be used to construct historical time series of qualitative abundance similar to those of sardine and anchovy populations off California (Baumgartner et al. 1992).

Applications Of Atmospheric And Oceanic Models

FOCI has made extensive use of several different models of the physical environment, from those that interpolate observations to complex numerical models. Ongoing modeling studies in Shelikof Strait examine the potential impact of interannual changes in circulation on survival of larvae in the western Gulf of Alaska. The physical factors which must be incorporated into the circulation model include: complex bathymetry with many islands, mesoscale (~20 km) meanders and eddies, strong vertical shear (estuarine-like flow), and intense forcing by both wind and freshwater runoff.

The circulation model used is based on the Semispectral Primitive Equation Model (SPEM) modified for this region (Hermann and Stabeno 1996). Thus far, SPEM has reproduced the observed general spatial features of regional circulation (Stabeno and Hermann 1996): model output and measured currents show reasonable agreement and eddies with similar spatial scales to those observed are generated. SPEM has been used in retrospective mode to hindcast circulation and results show that during 1978 (the strongest year-class in the recruitment time-series) larvae were more likely transported into coastal waters along the Alaska Peninsula than in 1990 (a below average year-class) when they remained in the sea valley for an extended period and then where transported offshore and thereby lost to recruitment (Stabeno et al. 1995). An ongoing research topic is the assimilation of moored current observations into SPEM and an

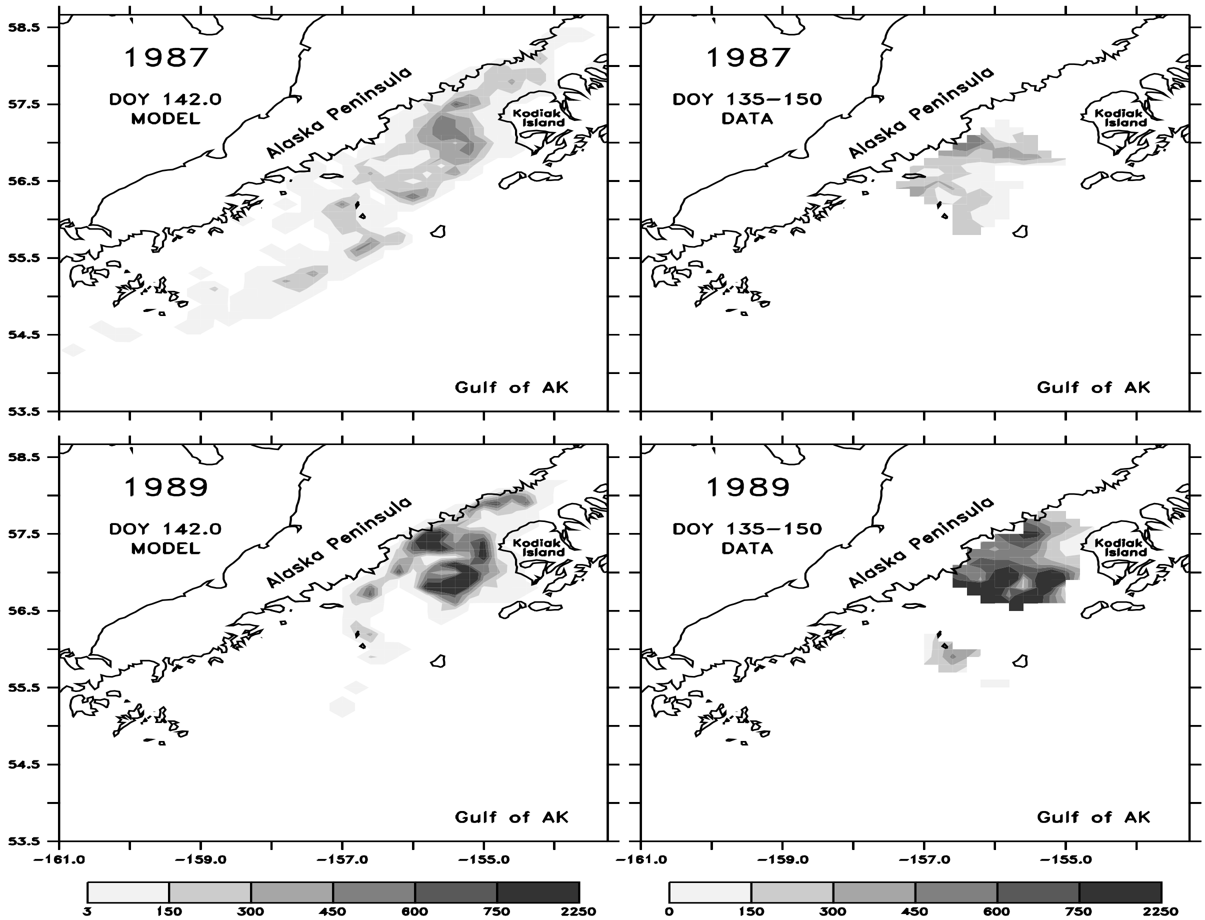

Figure 3. Larval concentrations from the SPEM/IBM model (left column) and from observations (right column), for mid-May 1987 and 1989 (from Hermann et al. 1996a).

examination of how this influences model simulations.

SPEM has been coupled to a spatially-explicit, individual-based, probabilities model (IBM) of egg and larval development (Hinckley et al. 1996). Since it follows the unique life history of individual fish, the IBM approach yields specific information about survivors. The model employs a spatial tracking algorithm for each individual that includes vertical migration according to life stage. Horizontal transport, growth, and behavior are governed by velocity, salinity and temperature fields generated by SPEM. Low-pass filtered velocity and scalar fields from SPEM are stored once per model day, then used as input for multiple runs of the biological model. Interannual differences in wind and freshwater runoff lead to differences in the modeled spatial paths of individuals, and in the distributions of population attributes (e.g., growth). The model-generated spatial distributions qualitatively compare favorably with observed distributions of larvae (Figure 3) and juveniles (Hermann et al. 1996a).

To examine how basin-scale circulation and wind fields might influence physical features in the Shelikof Strait region, FOCI scientists used a linear superposition of geostrophic current and Ekman drift estimates known as OSCURS (Ocean Surface Current Simulations: Ingraham and Miyahara 1988). Results from model simulations showed the marked impact of weak or strong circulation in the Gulf of Alaska (Figure 4) on water properties in Shelikof Strait (Ingraham et al. 1991). For use in correlative model studies, the simulated drifter observations had to be converted from trajectories to an quantified index. This was accomplished by noting the number of drifters out of the six released on February 1 at 55˚N between 152˚W

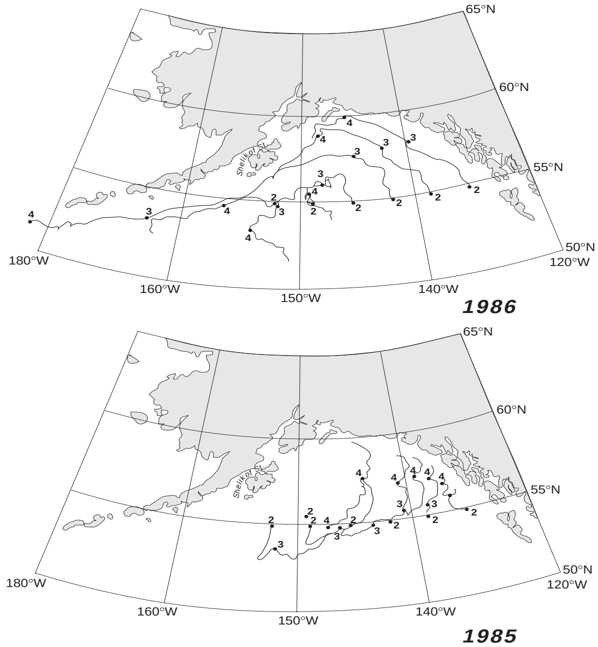

Figure 4. Computer trajectories of the upper ocean during a typical year (1986) and an anomalous year (1985). The numbers represent the first of February, March and April, respectively (from Ingraham et al. 1991).

and 137˚W that crossed 154˚W by April 1 (Megrey et al. 1995). The conversion of numerical model output to simple quantified indices is an integral part of using models in fisheries oceanography. The OSCURS model was also used to characterize regime-scale shifts in transport into the Gulf of Alaska and examine how these shifts might impact zooplankton production (Brodeur et al. 1996).

Data Accessibility and Delivery Systems

FOCI has a home-page on the world-wide web (Figure 5) that provides a basis for interaction between researchers from within and/or outside. Although FOCI does not presently have access to data through this medium, plans are underway to accomplish this. The basis will be the PMEL data and software that is presently being used in conjunction with equatorial oceanographic studies (Figure 6).

In June 1996, discussions were held in Seattle to explore the creation of a useful web tool to support investigators of NOAA's Southeast Bering Sea Carrying Capacity (SEBSCC) program. Issues raised included

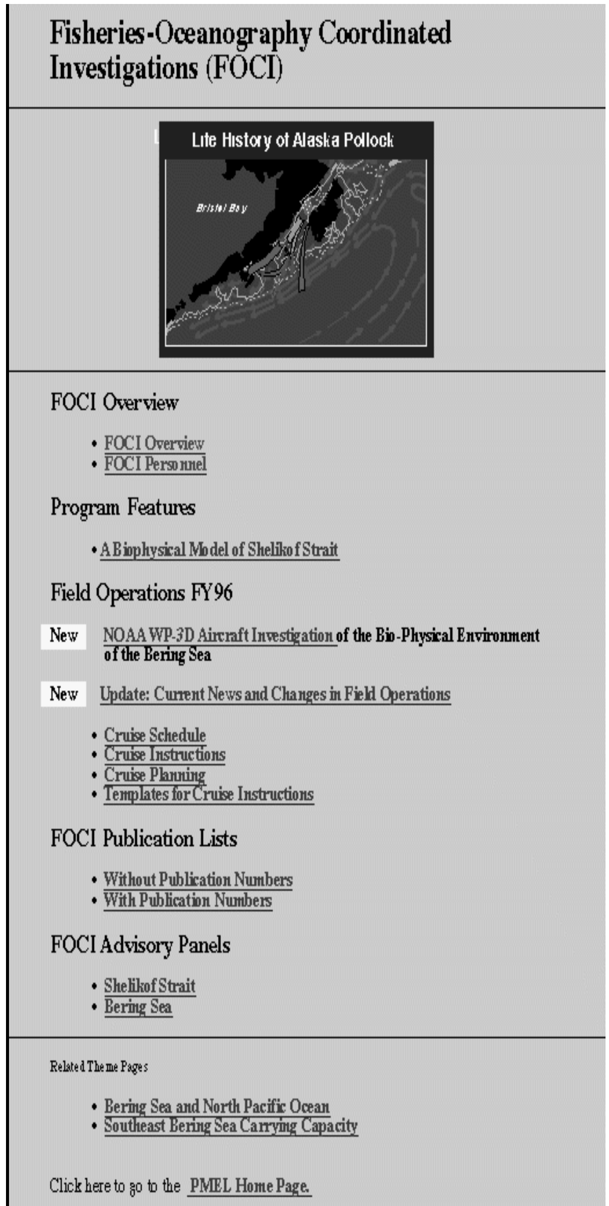

Figure 5. The FOCI Home Page.

data policy and formats, server versus desktop data analysis, the present content of PMEL's Bering Sea theme page, and strategies to complete the goal. Specific recommendations were to: (1) make FOCI data available on the web server by completing processing and making data available for outside users; include links to pre-established data sites for the Bering Sea, e.g., the University of Alaska's Marine Sciences Institute home page, (2) explore the conversion of

Figure 6. The PMEL Home Page showing data and software that presently are available.

AFSC's data bases to WWW (perhaps EPIC-compatible) format, (3) encourage inter-line-organization cooperation, (4) communicate with PICES, GLOBEC, and ESDIM groups attempting similar projects, and (5) reexamine strategies after the ESDIM and GLOBEC workshops are completed.

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Working Groups Reports

Working Group 1: Real-Time or Near Real-Time Environmental Data Needs

Participants: Ken Frank (Chair), Tom Leming (Rapporteur), Janice Boyd, Ernie Daddio, Larry Mayer, Rick Methot, Dave Mountain, Bill Peterson, Bill Pichel, and Jim Simpson.

Real-time or near real-time environmental data have numerous uses in both applied and operational fisheries oceanography. Some examples of the former applications include directing process oriented experiments and monitoring the status of biophysical platforms (e.g., Schumacher, this volume). Operationally, real-time or near real-time environmental data can be used to guide fishing activities and provide information on location of fishing fleets for enforcement activities (e.g., Merriner et al., this Report) .

Members of the working group concluded that the types of questions requiring real-time data needs could be categorized into three groups:

- those associated with hypothesis testing,
- those dealing with exploratory data analysis, and
- those with proven or established needs.

It was also noted that in much of the discussion there was a bias towards the application of environmental data to pelagic fisheries. It is well known, however, that a majority of the commercial fisheries in the US and Canada are exploiting so-called groundfish (or bottom dwelling species) such as walleye pollock, cod and flatfishes.

Fisheries management is a multiple step procedure involving research vessel surveys, compilation of catch statistics, quantitative analyses using models, provision of information on safe harvest levels, the allocation of quotas to various fleet sectors, and so on. The fundamental biological concern in the process involves determining the abundance and age composition of the population in the current year, a form of nowcasting. This is accomplished, in part, through the use of research vessel surveys which at present do not use environmental data to direct the survey in terms of its timing or location (see Frank, this report). There have been, however, *a posteriori* attempts to use environmental data to interpret the survey estimates.

Applications of real-time data to fisheries problems can be enhanced by: i) using the historic data to estimate climatological reference fields to serve as a baseline for identifying anomalies in real-time data, and ii) analysis of historic data to develop relationships between biological and physical parameters which can then be applied to real time data. We emphasized that to achieve these ends due care must be paid to appropriate inter-calibration of data sets.

Given this background we made the following recommendations:

Determine the degree to which surface data may be used to characterize internal ocean structure (e.g., determine de-correlation scales between satellite SST and internal thermal fields). This could result in a wider application of data derived from remote sensing instrumentation.

Utilization of operational, high spatial resolution, multi-layer, regional circulation model imbedded in a larger scale general circulation model may prove beneficial to integrate the diversity of physical data now being collected (both *in situ* and satellite data). Currents, mixed layer depths and other quantities derived from this model may enhance our current understanding of biological and fisheries processes. While our gut feeling is that such a model is needed, the specifics of its application remain to be determined. The initial application of such a model may be as a research tool only and will require validation against historical data. Important characteristics of the physical model might include nesting of regional models within basin-scale models of ocean circulation implying higher resolution in those areas of fisheries interests and having data assimilation capabilities.

Real-time resource survey data in general are not easily accessible to outside users. Cruise reports and pamphlets are frequently distributed to fishermen reporting the results of the most recent surveys soon after their completion, suggesting that the information could be made available electronically and distributed via Internet. This improved accessibility of near real-time fisheries data would complement the growing number of physical data products now available and could stimulate new analyses.

One potential use of real-time environmental data is the adaptation of survey designs to expected changes in the distribution of the target species. This will depend on an underlying knowledge of the reaction of fishes to the physical environment and the degree to which the distribution of fish can be predicted from these physical factors. While such changes could improve the precision of survey results it is important to recognize that many of these surveys have been in existence for decades and their value depends on comparability over time. A potential case study is the hydroacoustic line transect survey of Pacific whiting. Interannual variability in the northward distribution of this species appears to be related to the temperature conditions in the California current.

In the case of the groundfish fisheries, a detailed knowledge of the bathymetry and distribution of bottom types is a critical component of identifying habitat and designing proper surveys. Newly developed multibeam sonar technology has the ability to provide the fisheries scientist with a near real time, detailed 3-D picture of seafloor characteristics, and the use of these systems in support of fisheries surveys is strongly recommended. Given the relatively invariant nature of most seafloor characteristics, real time mapping in support of survey design also provides a critical archive of seafloor data that can, and should, be made available to retrospective surveys.

Because real-time environmental data may be used to predict fish distributions, it follows that prediction of the distribution of fishing vessels may be feasible. This can lead to improvements in management practices as it relates to minimizing by-catch and aiding enforcement.

Satellite data are being underutilized. Three ways to correct this situation are:

- i) use of secondary derived products, e.g., simulated Lagrangian drifters applied to studies of larval fish transport,
- ii) use of new satellite technologies, e.g., use of NOAA-K data which combine visible, thermal and microwave and hence can provide coverage during cloudy periods, and
- iii) use of new satellite technologies such as SAR, which provides all weather measurements and ADEOS OCTS and/or SeaWifs which provide ocean color information.

We strongly recommend that, at a minimum, the following Level 2 mapped ocean color products be made available to researchers in near real time (24 hours):

- water leaving radiances;
- CZCS type pigment, chlorophyll-a;
- diffuse attenuation coefficient;
- suspended solids, and;
- coincident sea surface temperature.

Moreover, we recognize that algorithm development and implementation is necessary and should be encouraged in order to i) develop optimal products for fishery applications from new types of remote sensing data, and ii) to improve calibration, atmospheric correction, and cloud detection in existing satellite products. Potential uses of ocean color data include making estimates of transport, water optical clarity, phytoplankton biomass, and primary productivity. Potential uses of synthetic aperture radar (SAR) data include improved ice edge detection (available in the near future from the National Ice Center products), coastal wind vectors, vessel surveillance for enforcement, and detection of ocean fronts and slicks. These remote sensing capabilities should be included in planned demonstration experiments for a variety of pelagic fish stock assessments and associated research. In addition certain forms of airborne remote sensing (LIDAR) have potential use in the estimation of fish stock abundance.

Make available to the civilian community to the greatest extent possible classified near real time data such as in GOODS (NAVOOCEANO) and BATHY (FNMOC).

Examine means to promote the near-real time delivery of environmental data from fishing vessels, including both surface data and bottom temperature data from trawling vessels.

Working Group 2: Retrospective Environmental Data Needs

Participants: Dan Ware (Chair), Michael Fogarty (Rapporteur), Ned Cyr, Tim Gerrodette, Anne Hallowed, Alec MacCall, Richard Parrish, Clay Porch, Chris Reid, and Tom Royer.

Retrospective studies play a central role in determining relationships between environmental forcing and dynamics of living marine resources. This approach is a valuable adjunct to process-oriented and model-based approaches. The principal objective of retrospective studies is to provide a guide to future responses of living marine resources to environmental variation based on past responses.

In accordance with the terms of reference for the working group, several general issues were addressed, including:

- identification of the factors driving data needs
- specification of the variables that are employed in retrospective studies;
- consideration of the types of environmental time series that are needed to meet current research needs;
- archiving and accessibility requirements for data, and;
- the development of recommendations for future work.

We address each of these in turn below.

A. Identification of the factors driving data needs: The working group identified four principal factors shaping data needs, including requirements for: (1) resource management, (2) economic planning, (3) advancement of ocean science and (4) multinational agreements. The first factor can be further partitioned into several distinct components such as the need for information on stock abundance and distribution; estimates of stock production (particularly recruitment); requirements for coastal habitat assessments (including issues as diverse as determining habitat distribution and quality and identifying illegal dump sites); assessment of climate change; and assessing impacts on threatened and endangered species.

The development of predictive indices of stock abundance and productivity can be an important guide to investment decisions in a particular fishery based on medium and longer term prognoses for the stock.

The working group noted that advancements in ocean science depend on the pursuit of a spectrum of research strategies. Examination of empirical relationships between environmental factors and measures of stock productivity can be particularly important in cases where experimental and other approaches are not possible.

Finally, we note that meeting responsibilities of multilateral agreements often entails the development of stock assessments which provide the basis for allocation decisions. These analyses often involve examination and interpretation of time series of biological and physical variables for calibration of assessment models.

B. Specification of the variables that are employed in retrospective studies: Retrospective analyses typically involve exploratory examination of the relationship(s) between measures of biological productivity or abundance (dependent variables) and physical environmental variables (independent variables). Other approaches include the use of models with initial conditions defined by past observations in an attempt to hindcast historical patterns. This approach plays a critical role in model validation. The physical factors which have been used in this context include

- (a) air-sea fluxes (heat, salt, momentum) with particular emphasis on solar radiation and measures of cloud cover;
- (b) atmospheric forcing with reference to sealevel pressure fields (derived indices such as NEPPI, SOI, NAOI, APLI etc.), storm frequency and intensity, and freshwater input (e.g., precipitation, runoff);
- (c) vertical velocity (upwelling/downwelling) based on well established measures such as the Bakun upwelling index and the current velocity index (Thomson index);
- (d) turbulence;
- (e) horizontal flow (current speed and direction);
- (f) mesoscale features and their variability including eddies and rings, fronts, jets, squirts, filaments;
- (g) mixed layer depth and temperature;
- (h) measures related to seasonality (e.g., spring or fall transitions, ice cover, etc);
- (i) coastal sea level; and
- (j) water properties (e.g., salinity, nutrients etc).

The biological variables most often considered in relation to environmental factors include distribution patterns in space and time, trends in biomass, and production (including considerations of individual growth, reproduction and mortality). The working group noted that all trophic levels including phytoplankton, zooplankton, benthos, nektonic organisms (e.g., fish and squid), marine mammals, and sea birds are critical in these analyses. Components of production which have been examined in previous retrospective studies include individual growth, maturation schedules, fecundity, and mortality (natural and fishing). Changes in demographic parameters such as growth rates and reproductive output can be important indicators of changes in basic production processes. With respect to mortality-related issues, the working group focused on catches as indicators of removals from the system as a critical element. Diets and daily rations of predators serve as important components in estimating predation mortality and as indicators of change in system structure.

The working group also addressed the issue of 'reconstructed' indices derived from a number of sources in geological records and elsewhere. For example, long term precipitation patterns can be reconstructed from tree rings and a further translation to temperature can be made. Similarly, long term temperature indices can be derived from ice cores, isotope ratios from foram shells and other sources, and changes in species composition of foraminfera. Growth patterns can be derived from examination of hard structures which retain annual (or other periodic) markings for fish, shellfish, and marine mammals. Indices of primary production can be derived from sedimentation rates. Fish abundance has been indexed using scale deposition rates in anoxic basins where biogenic disturbance is low. Finally, the group noted that information on distribution and abundance of exploited resources can be derived from the archeological record (e.g., excavation of middens etc.) and from anecdotal reports (historical writings, newspaper accounts etc.).

C. <u>Types of environmental time series needed to meet current research needs</u>: The group again partitioned its consideration of requirements for retrospective analyses into physical and biological data needs. We identified several indices which can now be derived from model outputs including surface and subsurface transport (Lagrangian and Eulerian) and its variability; mixed layer depth, temperature, and salinity; and Ekman dynamic indices covering the entire water column including the bottom layer. We also noted the utility of having long term measures of ice cover in arctic and subarctic regions. Finally, the importance of having model-derived indices of nutrients was emphasized.

With respect to biological indices that are needed, the group recognized that advances in technology have opened avenues for enhanced indices of production. For example, measures of sedimentation rates, phytoplankton biomass and production from drifting buoys and stationary moorings, and ocean color derived from satellite imagery have allowed recent advances in developing indices of primary production at a range of spatial and temporal scales. Alan Longhurst and colleagues have recently defined over 50 oceanic provinces throughout the world ocean based on ocean color measures. In contrast, instrumentation attached to buoys and mooring arrays can provide fine scale measurements in space and time.

The need for zooplankton biomass indices was also seen to be critical in monitoring events at secondary trophic levels. Again, advances in instrumentation (e.g Video Plankton Recorder; automated identification (pattern recognition) tools etc.) have opened new possibilities for data acquisition and analysis for zooplankton. The working group identified alternative indices derived from model outputs that could be used to complement the 'direct' measurements identified above, including measures of zooplankton biomass and production, and indices derived from measured light, nutrients, temperature and turbidity data.

It was noted that advances in fine-scale sea floor mapping using side scan sonar and dual-beam echo sounders have allowed important characterizations of habitat types (including sediment types and structural complexity). Coupled with new approaches to graphical visualization, the links between distribution patterns of marine resources and habitat types are now being explored. The group noted that understanding the relationship between habitat and resource productivity is essential. Changes in habitat monitored using satellite imagery (e.g., wetlands) or in habitats potentially disturbed by fishing gear monitored by advanced echosounder technology was viewed as particularly important in recognition of the dynamic nature of the habitat in response to natural and anthropogenic perturbations. Spawning locations and nursery sites were thought to be particularly important in this regard.

Hard structures (e.g scales and otoliths in fish;

statoliths in squids; shells in gastropods and bivalves, teeth and ear plugs in some marine mammals) provide important records of the growth history of the individual which can be examined in the context of environmental change. These structures also can, in many cases, be examined in greater detail to extract information on past environmental events. For example, isotopes of oxygen have been used to examine temperature trends while isotopes of nitrogen and carbon can be linked to trophic level of the individual. The working group noted that the rich store of information in these sources should be explored in greater detail.

The extent to which these and other measures of physical and biological variation could be assembled to provide 'leading indicators of climate change' was discussed and it was considered useful to develop such integrative indices (e.g., Ebbesmeyer et al.). Further research on climate variability and fisheries is needed.

D. Archiving and accessibility requirements for data: The group noted the importance of archiving environmental measurements and in ensuring ready access to these data. With respect to satellite data, it was noted that these objectives are being met. For example, NOAA plans to continue to archive the AVHRR data, Japan plans to archive the ADEOS data, NASA is archiving scatterometer, altimeter, radiometric, and ocean color data, and NOAA plans to continue archiving derived products from satellites (e.g., CoastWatch products). Advances in computing power have facilitated access to these data. The group noted that the production of browse files in video format would facilitate access by permitting potential users to know where to seek data.

With respect to the critical issue of data continuity, the working group emphasized the importance of continuing to collect and archive core data sets (e.g COADS), to identify and archive key baseline intercalibration data sets, and to ensure continuous biological monitoring. In an age of retrenchment in government activities, it is essential that the continuity of critical monitoring programs be maintained.

The group noted that the sheer volume of information now available from diverse sources raises the issue of what data products should be accorded highest priority for saving and maintenance. This topic could easily require a workshop of its own.

E. Recommendations: See listing of Consolidated Recommendations, page 116.

Working Group 3: Oceanographic and Atmospheric Model Applications

Participants: Frank Schwing (Chair), Jim Ingraham (Rapporteur), Loo Botsford, Larry Breaker, Ron Fauquet, Dave Johnson, Val Loeb, Dave Mountain, Bill Peterson, Bert Semtner, and Robin Tokmakian.

The modeling Working Group agreed that existing numerical circulation models provide physical environmental fields that can be applied to important fisheries research and management issues. It is important that these models and their output be made known to potential users of this output in the fisheries science community, and that there be communication between modelers and the users. Efforts should be focused on incorporating biological modules into physical models, and working toward coupled physical-chemical-biological models. Oceanographers are needed as "translators" between modelers and fisheries biologists. Scientists must develop synthesized model products that will benefit management plans now and in the long-term.

There is a need to distinguish between ocean models that provide simulations (diagnostic models) versus those that provide forecasts (prognostic models). Real ocean conditions can only be provided with models driven by the real atmosphere (i.e., atmospheric forecast models) and that have ocean data assimilation capabilities. Without these crucial elements, ocean models do not truly represent with the actual atmosphere or ocean.

A number of "trade-off" issues were discussed, in part because the Working Group included modelers and users of model output (principally researchers). These issues must be considered when using output to address fisheries problems, and many require further discussion, possibly at future workshops, to ensure model results are appropriately accessed and applied. An alternative is to evaluate "trade-off" issues by individual cases or by being model specific.

Simple vs. complex models**:** Complex models may provide a more accurate solution. Simple, or mechanistic, models may be easier to understand and operate, provide results sooner, and may be more enlightening, but may miss important details.

Application of output for research, management or industry needs**:** The Working Group focused on application of model output for research issues, but acknowledged that very different models and products are probably required by management and industry. It was suggested that forecast models could be applied now to ensure safety of vessels in derby-type fisheries.

Operational status of models: An interesting paradox in our discussions was that the researchers were more confident that models are fully credible and operational than were the modelers. Modelers expressed concern about credibility, while researchers believed it is important to get output to them for validation. The general question of when a model is fully developed requires careful consideration and input from both model developers and researchers using model products.

Memory vs. CPU: Computational power and data storage are both becoming large and inexpensive. For a particular case, it is important to address the question of which is more cost-effective: storing all model fields and derivatives or storing the basic fields and recomputing derivatives later?

2-D, 3-D or 4-D: While most models provide 3- and 4-dimensional fields, reducing output to 2 dimensions makes it simpler for researchers to store, graph, etc.

Domain of interest: Researchers may have different requirements for lateral and horizontal domains, and desire different levels of resolution. For example, stock habitat studies may focus on the surface layer, while a study of nutrient circulation must consider deeper flows as well.

Definition and parameterization of variables: Mixed layer depth, for example, has numerous definitions, and can be evaluated in several ways. The Working Group felt that modelers must make a first choice, and allow researchers to evaluate that definition and provide feedback as to its applicability. Researchers may be better qualified to decide the best alternative. The appropriateness of a particular definition may be region- or problem-specific.

Higher resolution vs. longer time series: As computational power increases, models can be run with higher spatial and temporal resolution, or to extend retrospective simulations back further in time. For a specific application, one of these may be preferable.

The Working Group identified several important specific issues:

1. Communication and Information Exchange

Cross-discipline communication between modelers, fisheries scientists and managers is essential.

- Models are now available that could be used by the fisheries community.
- Users of model products (primarily researchers) and modelers must together identify what model products are to be saved, and modelers must make those products accessible.
- Only a few variables are initially of importance. To economize on storage, the Working Group identified four basic parameters: i) upper ocean temperature, ii) salinity, iii) lateral and vertical currents, and iv) sea level. Other products can be derived from these by their users, or requested specifically.
- Oceanographers are needed as "translators", to evaluate model capabilities and limits for fishery biologists.

2. Model Validation and Credibility

- Credibility, defendability and potential liability of model output is an important issue.
- An important research activity is validating model output basic fields and products (e.g., mixed layer depth, drifter tracks).
- A numerically straightforward test of models that would also be of great use to fisheries scientists is the *a posteriori* application of individual-based models (IBMs), using output from the physical model.
- Modelers need to add data assimilation to their models, and need independent data to validate output.

- Surveys will take on an increasing role in groundtruthing bio-physical model output.

3. Model Products for Fisheries Management
- Researchers must consider how to use output for management issues besides stock assessment.
- Most models are not sufficiently developed (i.e., operational) to impact real-time management and enforcement.
- Climate change models can be used to identify environmental variability (anthropogenic and natural) of use to long-term fisheries management.

4. Physical-Chemical-Biological Modeling
- Empirical relationships allow chemical fields (e.g., O_2, nutrients) to be derived by scientists from basic physical model output.
- Coupling physical and biological models, or at least using physical model output to drive biological models, is necessary to correctly represent conditions in areas of interest to fisheries researchers.

5. Appropriate Model Domains
- Physical models of use to fisheries research must have a variety of scales and types -- global, regional, estuarine, nearshore, plume.
- The depth range of output of interest to researchers or managers will vary with the problem, but coastal regions are of most significance to fisheries problems.
- For some applications, vertical resolution of model fields is needed, while vertically averaged transports are preferable in others.

6. Availability of Model Output
- Model output should have different degrees of accessibility, with more commonly used or requested data being easily accessed by researchers.
- Reanalysis products are the most desirable products to be used from forecast models.
- Model forcing fields, at least surface wind stress and heat flux, must be made available to researchers.
- NODC, or a similar agency, should permanently store output from selected models for future analysis in fisheries problems. These should include basic model fields, climatologies derived from models, and initial forcing fields.
- NOS is working to develop site-specific models of many US estuaries and bays, whose output will have fisheries applications.

7. Model Improvements
- Models should use observation forcing fields and data assimilation methods, rather than climatologies (annual cycles), to capture episodic events and interannual variability of importance to fisheries.
- Human activities (e.g., habitat alteration, streamflow modification) must be incorporated into models.
- The topic of data assimilation includes several important issues that merit further discussion and consideration, including credibility of and access to output, the need for independent data to validate output, and feedback from researchers to modelers.
- Computer resources are expanding rapidly; large models will eventually be run on desktop computers.

The following sections respond to specific questions asked of the Working Group:

A. Identify what drives the data need.

The need for model data in the next five years is driven more by fisheries oceanography research than management or enforcement at this time. Models should be developed to solve problems, a hypothesis driven approach to modeling. Fisheries researchers need to develop products from the models for use by managers. The long-term goal of applying model output is to improve predictions of stock fluctuations and assessments of stocks. Specific key issues require model output to describe environmental variability: during early life history of stocks; in terms of how it may affect prey; and how it limits or enhances movement of populations. Using climate change model output to address long-term scenarios of stock variability is another important issue. In the case of an unexpected fisheries event (e.g., PSP outbreak, fish die-off, marine mammal strandings), short-term retrospective models can be used to determine if the physical environment may have changed.

B. What types of data or model output are required?

Model output can be thought of as synthetic data to interpolate between observations, or extend observations in time. Fisheries scientists need a suite of physical models at a range of scales from global to regional. Regional models generally need global model output for their open boundary conditions. Physical domains, and time and space scales appropriate for fisheries questions must be defined. Initially, focus should be on retrospective models rather than real-time. The former are needed to build confidence in the output, through validation with data independent to any data assimilated into the model. Bio-geo-chemical models (e.g., NPZ models) that incorporate biotic parameters should be developed. The specific model parameters of use to fisheries research should be discussed by the entire community, perhaps in another workshop. However it is important to get some output to scientists now. As a first step, we recommend a focus on basic upper ocean fields -- temperature, salinity, density, lateral and vertical velocity -- that can be used by researchers to develop other products, and validate model utility (e.g., transport trajectories). Other model parameters of importance are mixed layer depth and some parameters of ice. The Working Group recognized that both of these items have regional differences that limit their effective derivation with global models. We also acknowledge there may be additional model output of use to fisheries that were not identified. In addition, fisheries scientists may not be aware of community physical models, and the potential access to their output. Model data are now available in acceptable format. While model fields are usually Eulerian based, fisheries researchers think in a Lagrangian framework. Interactive conversion and 3-D visualization packages are available on the Internet to generate Lagrangian products from basic model output. The need to make model output available in a retrospective sense, particularly for fisheries management applications, was noted. As a result of this workshop, procedures for transferring and archiving model output at NODC are being established.

C. <u>What is the present status of these data, model applications or output accessibility delivery systems</u>?

The Working Group felt that some model products are readily available via overnight mail, Internet, or web, and researchers can obtain model output quickly. Delivery of operational (regularly run) models, with perishable data, is best by a regular posting of the output. Other model output should be specifically requested by the researcher. Data transmission should be via reliable communication modes. Efforts should be made to ensure continuity and coordination of model output storage by some agencies.

D. <u>What are key issues of saving and storing model output</u>?

Technological improvements are making storage less of an issue, but it is still a long-term concern since increasingly higher resolution models produce massive volumes of output. On a case-by-case basis, the fisheries scientist and modeler must consider the trade-offs between archiving all model forcing and output fields and their derived products, versus limited capability available to the researcher for recalculating parameters from basic fields. Fisheries researchers probably need only a small portion of most model output; researchers should identify their data needs on an individual basis. Communication between fisheries scientists and modelers is crucial to identifying what model output must be saved. The Working Group felt that basic model reanalysis fields, model climatologies, and initial forcing fields should be saved permanently for future use.

E. <u>What steps should be taken to enhance the use of atmospheric and oceanographic model output to fisheries problems</u>?

Two-way communication between the modelers and fisheries researchers is necessary. Modelers must demonstrate reliability, usability and accessibility of model output, get information to the research community, and make data available quickly. Users must work closely with modelers, gain awareness of what output is available, and communicate this information to colleagues. Both groups must have a willingness to work outside of their disciplines, collaborate with each other, and emphasize cross-discipline communication. Researchers must also develop products from model data that are of utility to managers, thus serving as meta-users of output.

F. <u>What are the highest priority actions to be taken?</u>

The Working Group identified these items to be greatest priority:

Cross-discipline communication -- The highest priority item is two-way communication between modelers and fisheries scientists, and between the scientists and NMFS managers. Researchers must let modelers know what is needed to address fisheries issues. Modelers must communicate model availability and reliability, as well as technical details related to the proper interpretation of output.

Definition of domains appropriate for fisheries research -- Fisheries researchers must specify domains and parameters needed to address fisheries issues, and communicate them to modelers.

Model validation and credibility -- Model credibility is a trade off between getting a fully developed model, and the timeliness of using its output for fisheries issues. Models must be tested with independent data. Testing should focus on recently improved models and reanalysis products. Comparisons should consider not only validation of basic physical parameters, but how well model derivatives represent patterns in nature (e.g., larval movement and retention). One way of testing models is to use output to run IBMs, and compare these results with expected motions. Model output must be validated before a model can be considered fully developed (e.g., operational); this can be done best by applying the model to real fisheries problems. The Working Group felt the best way to uphold the credibility of models is to limit access to the output to knowledgeable researchers qualified to test and apply model results within the operational constraints of that model. Active communication between these researchers and the modelers will result in improved model capabilities and a better realization of its limits.

From model output, the research community must develop products that management will need and use. Researchers are responsible for making managers aware of products derived from model output. Management needs to get results they can use to address critical issues now, but also be shown the long-term utility of model products. The Working Group recommended that some dramatic events (e.g., crashes in populations of California sardine, Georges Bank cod) be shown as retrospective examples of how model output can be incorporated in management plans for responding to environmental changes that impact fishery populations.

Proceed with full bio-chemo-physical coupling of models-- Although empirical relationships now allow nutrient and O_2 fields to be derived by researchers from basic model fields, coupling is necessary to accurately represent the distributions and dynamics of these variables in areas of biologically dynamic activity of interest to fisheries researchers.

Identification of useful model parameters-- While the Working Group defined some basic model output variables of need, fisheries scientists must identify an expanded list of important parameters, possibly in a future workshop. Fisheries scientists must also follow-up with modelers regarding utility of output, additional needs, etc.

The Working Group identified these items to be high priority:

NOAA should permanently store output from selected models (including model climatologies, forcing fields) for future applications. NODC is a possible agency for archiving model output. NOAA-based models are a good first candidate.

Coupling models of different scales. Small spatial-scale models must be nested within larger domain models, for prescribing forcing or open boundary conditions.

Apply output from estuarine, plume, and nearshore models to fisheries issues. NOS is working to develop site-specific models of many US estuaries and bays. NMFS should take advantage of these models for fisheries applications, particularly since a majority of commercial stocks use estuaries and nearshore habitats during some part of their life cycle.

Incorporate human activities in models (e.g., habitat alteration, streamflow modification). Human-induced changes in environmental conditions and habitat contribute to fisheries variability, and must be considered in modeling activity.

Working Group 4: Data Delivery Systems, Data Accessibility Criteria, and Formats

Participants: Jim Holbrook (Chair), Bob Gelfeld (Rapporteur), Robin Brown, Ernest Daddio, Bob Groman, Doug McLain, Nancy Maynard, Roy Mendelssohn, Jerry Norton, Chuck Stein, Art Stroud, and Scott Woodruff.

A. In the context of fisheries research, surveys, management, or enforcement what are the key attributes desired in systems for data accessibility and how do they differ from existing systems?

The Working Group determined that an ideal data access system should include the following elements:

1. A search engine that supports data discovery through an interactive interface that searches metadata for spatial, temporal, and keyword criteria. The results from this process are provided to users as hyperlinked pointers to national data centers, and other distributed centers of data.
2. A browse capability that enables the user to visualize and further refine the search process initiated in element 1.
3. Theme pages that allow users to easily locate data and information products that relate to a specific topic or subject. Theme pages are generally created and maintained by a team of experts that organize and quality control the content.
4. An ordering and downloading system that is integrated with the above discovery process and enables the user to request data and information products. Generally a number of options will be provided to the user as to data formats and distribution medium.
5. A user reply interface to allow for easy feedback concerning comments, suggestions, and problems.
6. A library of analysis software and utility tools that make it easier for the user to interact with the data and information products that are accessed by the system.

Key Attributes of Data Accessibility Systems

1. easy to use (intuitive)
2. timely delivery
3. inexpensive access costs
4. known quality (homogenous; described in metadata)
5. format friendly
6. expert human support available to users
7. homogenous graphical user interface (GUI)
8. data documented
9. maintained and supported
10. affordable system costs
11. platform independent
12. scalable and extensible
13. web based
14. access limitations allowed
15. reliable
16. compatible with a wide variety of data types
17. simultaneous access to both real-time and retrospective data

B. The Working Group then examined if standard formats are being used for environmental data and models of importance to fisheries by addressing the following questions:

1. What formats should be used for data delivery? (The Group recommended that 2 or more formats be available as appropriate to a given data set for delivery)
   a. ASCII (column, tab or comma delimited)
   b. BINARY (with software)
   c. HDF
   d. MIME extension such as MPEG and GIF
   e. NetCDF
   f. specialized formats (with software), e.g., GRIB and BUFR
   g. SDTS

2. Do current format-related accessibility problems hinder use of selected environmental data in fisheries?
   YES

3. Are there special data formats to which environmental data for fisheries should adhere? Should fisheries be headed towards these standardized formats?
   YES (above list of data exchange formats)
   YES

4. Are these formats consistent with relational database systems?
   Although we feel this issue is unrelated to this question of data accessibility, relational database systems may be an essential element of any back-end solution.

C. The Working Group then addressed the present status of these data, model applications or data accessibility delivery systems.

The data delivery systems that we saw presented at this workshop (and others like them) are strongly endorsed and are encouraged. An effort should be made to increase the inter-compatibility between them. Some specific questions and our answers follow:

1. Are distributed or centralized data systems most appropriate for fisheries applications?

Either decentralized or distributed are appropriate, but we recognize the importance of a limited number of archival centers.

2. What is the appropriate role for the Internet (and WWW) in making data available to both the scientific community and the average citizen?

It is an integral part of delivery strategy

3. Is data sharing a problem to deal with? To what extent do providers of data feel a proprietary hold on data?

Yes, limited use and controlled use should be recognized as an important part of the research process, but should be restricted to not more than two years. To a great extent, there does exist a proprietary hold on data.

D. What steps and in what priority order should be taken, regarding formats, data accessibility, and delivery systems to enhance the application of environmental data to fisheries problems?

See listing of Consolidated Recommendations, page 116.

Working Group 5: Partnerships in Fisheries Oceanography

Participants: Ron Fauquet (Chair), Ned Cyr (Rapporteur), George Boehlert, Janice Boyd, Larry Breaker, Robin Brown, Bob Gelfeld, Jim Holbrook, Ben Holt, Jim Ingraham, Dave Johnson, Larry Mayer, Nancy Maynard, Michael Reeve, Chris Reid, Jim Schumacher, and Jim Simpson.

This ad hoc working group was formed to address questions of communication and cooperation. Originally termed the "inter-agency working group," it was noted that the terminology excluded academic participants. Hence, the first order of business was to change the name to reflect the nature of fisheries oceanography which blends many disciplines and institutions. This Working Group was open to all and attendance was high, with representation from four line offices of NOAA, Navy, NASA, NSF, Canada, and the academic community.

A variety of questions were posed for the group, but the discussions were not constrained by them. The discussion is summarized below under the most pertinent questions posed by the conveners, followed by the recommendations deemed of highest importance by the group.

1. <u>What benefits can accrue from developing partnerships in fisheries oceanography</u>?

This question led to a spirited discussion, both of success stories and ideas about how cooperation could be improved. Some of the key topics discussed included how partnerships can:

a. leverage funds not available to a single agency or group; often, programs in one agency can benefit another with only minor changes and such changes in emphasis can be mutually beneficial to both groups or agencies.

b. generate different viewpoints on problems; by its nature, NMFS or other resource management agencies are typically constrained by both total personnel and the types of expertise on the staff. Applying a narrow range of expertise to problems often results in a myopic view of the range of solutions. Bringing different disciplines and insights to the same problems through cooperation, whether short term assignments or other approaches, is clearly beneficial.

c. access data and resources not readily available in a single agency (financial, "brainpower"); several participants noted that this workshop was the first time that they became aware of how fisheries problems with environmental data are framed in the resource agencies. Several fisheries scientists learned of readily available data sources that would be beneficial to their research and potentially to management. These examples relate to the issue of communication discussed in several working groups.

d. increase efficiency through joint planning; all agencies make plans for research programs, data collection or monitoring programs, often years in advance. The utility of the resultant data may be enhanced by including others in the planning stage. In many cases, the improvements in data utility can occur with only a little more effort.

e. share limited staff resources; downsizing is a fact in the majority of federal (both US and Canada) and state science organizations. It was noted that while many agencies are hesitant to allocate full time effort by key staff to the problems of other agencies or research groups, many are willing to share personnel in a more limited fashion.

f. gain access to academic programs and graduate students; improvement of the ties between agencies and academia should be a high priority. Graduate students provide personnel support for many agencies and also conduct research projects pertinent to the agency mission. Faculty or graduate students can gain access to facilities or resources of agencies. In this way, both gain.

2. What key skills or data access capabilities are lacking in the fisheries sector that may reduce the effectiveness of using environmental data for fisheries applications?

As was evident in discussions held at the workshop, a broad cross-section of expertise is needed to collect environmental data, maintain databases, develop models and evaluate the output, and interpret results as they apply to fishery issues. Agency and academic expertise in these areas were well represented at the workshop, as was the oceanographic expertise from the NMFS Centers. It was generally agreed that key resources to take advantage of available environmental data are lacking in NMFS. This reduces the agency's ability to conduct interdisciplinary research in support of management or, in some cases, to apply environmental data directly to management issues.

Success stories in fisheries do exist, however. The "vessel monitoring system" in the Hawaiian longline fishery used expertise from NMFS, the fisheries Council, Coast Guard, and the private sector. Management of marine turtle and fishery interactions off the North Carolina coast benefitted from the CoastWatch program and efforts of NMFS, NESDIS, and the Coastal Ocean Program. Interdisciplinary research programs such as FOCI, GLOBEC, SABRE have benefitted from cooperation of outside agencies and universities. It was also noted that international organizations, particularly ICES and PICES, are doing an excellent job of coordinating similar work.

Working Group participants agreed that there are many more opportunities to improve the use of environmental data and models in NMFS fisheries science, including the following:

a. database duplication between agencies is inefficient; several examples of duplication were raised at the meeting and a variety of mechanisms to improve the situation were discussed. Most solutions involve improved communication and collaboration between agencies.

b. central, top-down direction in NOAA would be useful in focusing declining resources; The NOAA Strategic Plan has developed cross-cutting initiatives and several mechanisms exist to foster cross-line office cooperation. As regards fisheries and environmental data, these should be reviewed and enhanced.

c. NMFS strategic planning portfolios separate physics and fisheries; this was considered to be a strong concern by some participants. The best cited example was the lack of linkage between the natural resource stewardship and environmental elements dealing with intermediate to long-term (climate scale) environmental variability. It was noted that climate variability has the potential to create major economic and ecological disruptions to fisheries, not only in the US, but globally. Participants expressed concern that NOAA's Office of Global Programs does very little in the fisheries arena, and that many of the NMFS projects dealing with climate scale variability in fisheries are done in ad hoc, piecemeal fashion without dedicated funding. Funding for such problems can lead to enhanced cooperation.

d. NMFS is not always aware of outside resources that could be helpful in addressing its challenges; this is a communication issue. There are simply too many programs and research projects dealing with atmospheric and oceanographic environmental data. Given the limited expertise and manpower in NMFS, it is difficult to be cognizant of all resources.

e. NMFS access to chemical and physical oceanographic and modeling expertise must be improved; physical models are advancing at a much greater pace than biological ones and the potential for "synthetic" or model generated data applications to fisheries are immense. Because NMFS lacks this expertise, partnership mechanisms to promote improved access are crucial.

3. What mechanisms are currently in place to promote partnerships?

The following mechanisms are available and should continue to be used to encourage cooperation:

a. NOAA-University Cooperative Institutes; Cooperative institutes provide a mechanism promoting strong academic ties to NOAA research programs. It was noted that the strongest development of cooperative institutes is in OAR. NMFS does not take adequate advantage of these programs. Exceptions exist, however, for example at the Joint Institute for Marine and Atmospheric Research in Hawaii and the Cooperative Institute for Fisheries Oceanography in North Carolina.

b. Cooperative Marine Education and Research (CMER); This is an innovative program of the Northeast Fisheries Science Center that is modeled after the Fish and Wildlife Service's University Cooperative program. It promotes cooperation with the academic community and has been highly effective in supporting graduate student research on problems important to NMFS.

c. Cross-cutting NOAA programs; Certain existing programs are useful for improving research in fisheries oceanography. The Coastal Ocean Program (COP) funds several interdisciplinary research programs on fisheries oceanography, but many fisheries extend to the open ocean and many of the problems identified at this workshop extend beyond the scope of the COP's mission. Although NOAA's ESDIM program does not specifically address fisheries oceanography, it makes environmental data more available to fisheries scientists and also funded this workshop. It was suggested that NOAA's Office of Global Programs should re-examine the importance of fisheries problems within its program.

d. US GLOBEC Program; Collaboration among many NMFS scientists, academia, and other agencies has been stimulated by this program and research activities on Georges Bank provide a good example. NMFS scientists have been involved in a variety of planning committees and the Scientific Steering Committee as well.

e. NMFS/OAR/COP Fisheries Oceanography Steering Committee; Although this planned committee was described only briefly at the working group, it may be able to serve an important advisory and coordinating role to address issues such as those noted in this workshop report.

f. PFEG; The Pacific Fisheries Environmental Group serves as an important link between the environmental data resources of the US Navy and NOAA. It specializes in environmental data for fisheries and provides raw data, index products, special data requests, and periodic reports to all NMFS Science Centers, throughout NOAA, and to state agencies, academic researchers, and international scientists. Despite declining budgets, the Southwest Fisheries Science Center has maintained PFEG and assured that PFEG's research addresses fundamental problems of interest to fisheries as well as maintaining its role in providing products.

g. interdisciplinary workshops such as this one; Participants felt that the present workshop served an important purpose and that follow-on workshops, if properly focused and organized, could stimulate further cooperation.

Participants also discussed new ways to promote partnerships, including the following:

a. the National Oceanographic Partnership Act; This act, approved as part of the Defense appropriations bill for FY97, would create mechanisms to develop partnerships among agencies as well as the private sector in ocean science research and education. For topics such as the application of environmental data to fisheries, this may present an excellent opportunity for support.

b. the Committee on Environment and Natural Resources (CENR); The CENR is part of the Executive Branch's efforts to promote scientific cooperation. Fisheries is a part of several subcommittees within the CENR, but has no focused subcommittee to address important issues. Establishment of a subcommittee on fisheries or even higher visibility for fisheries in existing subcommittees would encourage interagency cooperation.

c. rotational programs to stimulate cooperation; The NMFS Rotational Program, wherein staff can be temporarily assigned to another location to address important problems, was described. It was suggested that intermediate-term (6 months to 2 years) rotational programs, modeled after the one in NMFS, be established. This could bring other agency expertise to address specific problems of high priority to NMFS. Such a program would require support at higher levels.

4. <u>What steps should be taken to improve interagency cooperation and what are the highest priority recommendations for action</u>?	See listing of Consolidated Recommendations, below.

Consolidated Recommendations by Working Group

The recommendations from all working groups are listed here. From this list, voting for priorities was conducted, leading to the priority recommendations in the following section.

1. <u>**Real-time or near real-time environmental data needs**</u>

1.1. Enhance applications of real-time data to fisheries problems by:

- i) using the historic data to estimate climatological reference fields to serve as a baseline for identifying anomalies in real-time data, and
- ii) analysis of historic data to develop relationships between biological and physical parameters which can then be applied to real time data.

1.2. Determine the degree to which surface data are representative of internal ocean structure (e.g., determine de-correlation scales between satellite SST and internal thermal fields), resulting in a wider application of data derived from remote sensing instrumentation.

1.3. Develop an operational, high spatial resolution, multi-layer, regional circulation model imbedded in a larger scale general circulation model to integrate the diversity of physical data now being collected and enhance our current understanding of biological and fisheries processes.

1.4. Improve the accessibility of near real-time fisheries and resource survey data to complement the growing number of physical data products now available and stimulate new analyses.

1.5. Apply real-time environmental data to adapt survey designs to expected changes in the distribution of the target species and also for adapting real-time management of fisheries.

1.6. Use newly developed multibeam sonar technology in support of fisheries surveys with a near real time, detailed 3-D picture of seafloor characteristics.

1.7. Because real-time environmental data may be used to predict fish distributions, it follows that prediction of the distribution of fishing vessels may be feasible. This can lead to improvements in management practices as it relates to minimizing by-catch and aiding enforcement.

1.8. Develop secondary derived products (e.g., simulated Lagrangian drifters applied to studies of larval fish transport) from satellite data tailored to fisheries needs.

1.9. Use new satellite technologies (e.g., NOAA-K data which combines visible, thermal and microwave and hence can provide coverage during cloudy periods; SAR, which provides all weather measurements; and ADEOS OCTS which provide ocean color information) to develop products for fisheries use.

1.10. Make available to the civilian community to the greatest extent possible classified near real time data such as in GOODS (NAVOOCEANO) and BATHY (FNMOC).

1.11. Develop a pilot project to promote the near-real time delivery of environmental data from fishing vessels, including both surface weather and marine data and from fishing gear-mounted sensors where feasible.

1.12. Develop capability for real-time access to oceanographic data or processed products (COADS, MOODS, remote sensing) for fisheries management or recruitment prediction purposes.

2. <u>**Retrospective working group**</u>

2.1. Develop long-term baseline indices that describe the range of natural variability; extend key time series (sea level pressure, wind fields, temperature, salinity, abundance indices) back to 1900 or earlier.

2.2. Inter-calibrate different sampling systems and models.

2.3. Promote efforts for verification and validation of models; use key "Pulse Points" and transects as reference points.

2.4. Provide users with measures of uncertainty in model output variables.

2.5. Improve physical model accuracy of circulation and variability in Arctic, Subarctic, and North Atlantic regions.

2.6. Conduct comparative retrospective analyses at the regional to global scale; this will require southern hemisphere plankton time series.

2.7. Continue atmospheric, oceanographic and biological data rescue and preservation.

2.8. Promote projects for fisheries scientists to work with physical modelers to produce focused model output.

2.9. Create meta-data base to facilitate user accessibility to data.

2.10. Expand use of archival tags and drifting and moored sensors.

2.11. Provide quality control flags to minimize misuse and misinterpretation of data.

2.12. Convene a workshop to address which environmental data products should be accorded highest priority for saving and maintenance relative to applications to fisheries.

2.13. Develop an archive of detailed seafloor data that can be used for retrospective analyses of fishery survey data to identify habitats and species associations.

3. **Oceanographic and atmospheric model applications**

Note: The working group identified recommendations 3.1-3.5 as highest priority and 3.6-3.10 as high priority.

3.1. Cross-discipline communication -- improve two-way communication between modelers and fisheries scientists, and between the scientists and NMFS managers.

3.2. Model validation and credibility. Input fields improved by reanalysis should be used in all models when available, and data assimilation models must be tested with independent data.

3.3. From model output, the research community must develop products that management will need and use. The WG recommended that some dramatic events (e.g., the California sardine crash) be shown as retrospective examples of how model output can be incorporated in management plans for responding to environmental changes that impact fishery populations.

3.4. Proceed with full bio-chemo-physical coupling of models to accurately represent the distributions and dynamics of these variables in areas of biologically dynamic activity of interest to fisheries researchers.

3.5. Identification of useful model parameters; fisheries scientists (in conjunction with modelers) must identify an expanded list of important parameters, possibly in a future workshop.

3.6. NOAA should permanently store output from selected models (including model climatologies, forcing fields) for future applications.

3.7. Define domains appropriate for fisheries research; fisheries researchers must specify space-time domains and parameters needed to address fisheries issues, and communicate them to modelers.

3.8. Coupling models of different scales; small spatial-scale models must be nested within larger domain models, for prescribing forcing or open boundary conditions.

3.9. Apply output from estuarine, plume, and nearshore models to fisheries issues; NOS is tasked to develop site-specific models of many US estuaries and bays. NMFS should take advantage of these models for fisheries applications, particularly since many commercial stocks use estuaries and nearshore habitats during some part of their life cycle.

3.10. Incorporate human activities in models (e.g., habitat alteration, streamflow modification); human-induced changes in environmental conditions and habitat contribute to fisheries variability, and must be considered in modeling activity.

4. Data delivery systems, data accessibility criteria, and formats

4.1. Increase the inter-operability among existing environmental data access systems such as MEL, NOAAServer, JGOFS, etc. to allow for cross-organizational searches and data access.

4.2. Distribute inexpensive, easy to use software tools for analyzing, extracting, and manipulating important data sets (e.g., COADS, World Ocean Atlas).

4.3. Develop theme pages that focus on issues that fisheries scientists can recognize (e.g., El Niño Theme Page).

4.4. Enforce a proactive data archival policy to insure that new data are made available to the widest community. Data may be stored and supported locally for project or program use, but must be contributed in a timely manner to a permanent national archive for long-term safe keeping.

4.5. Establish as a high priority that all fisheries relevant data can be accessed through on-line system that enables users to search, browse, order, and receive data and information identified through a user defined discovery process.

4.6. Provide a high band width connection to the Internet for all fisheries users to ensure on-line network access.

5. Partnerships for Fisheries Oceanography

5.1. Establish a rotational program for shared expertise at two levels:

- across NOAA line offices to allow an exchange of scientists and expertise, focusing on specific cross-cutting problems where cross-LO cooperation can more rapidly solve the problem.
- crossing agency boundaries (defined broadly, to include NSF and the academic community) to allow an exchange of scientists between labs and agencies, focusing on problems of national importance where enhanced interagency cooperation can more rapidly solve the problem.

5.2. Establish a fisheries working group under the auspices of the Committee on Environment and Natural Resources (CENR) to encourage interagency cooperation.

5.3. Take advantage of increasing cooperation in remote sensing between NOAA and NASA as an opportunity to raise fisheries/environmental cooperation issues.

5.4. Utilize existing programs (COP, NOAA Cooperative Institutes, NOAA-Navy MOA, etc.) to raise the visibility of issues related to the use of environmental data in fisheries.

5.5. Improve NMFS access to outside experts for modeling and chemical and physical oceanographic expertise.

5.6. Stimulate research on the effects of climate-scale variability on fisheries through existing cross-cutting programs.

5.7. Form an ad hoc or steering committee for environmental data for fisheries science that crosses NOAA line offices and agency boundaries to continue efforts initiated at this workshop.

Workshop Priority Recommendations

The 48 recommendations generated by the five working groups were further evaluated to develop a set of priority recommendations. After the workshop, all participants were given the opportunity to vote for five recommendations, and 34 did so. Votes were tallied in two ways. First, 5 points were assigned to each first place vote, four for the second place votes, and so forth to one point for a fifth place vote; the sum of these scores are referred to as "rank total". We also summed raw votes, listed as "vote total." Included below are twelve "priority recommendations" which received 10 or more rank points and at least 5 votes.

1. Develop long-term baseline indices that describe the range of natural variability; extend key time series (sea level pressure, wind fields, temperature, salinity, abundance indices) back to 1900 or earlier. (Recommendation 2.1; rank total 61, vote total 15)

2. Enhance applications of real-time data to fisheries problems by:
   - i) using the historic data to estimate climatological reference fields to serve as a baseline for identifying anomalies in real-time data, and
   - ii) analysis of historic data to develop relationships between biological and physical parameters which can then be applied to real time data.

(Recommendation 1.1; rank total 44, vote total 12)

3. Establish a rotational program for shared expertise at two levels:
   - across NOAA line offices to allow an exchange of scientists and expertise, focusing on specific cross-cutting problems where cross-LO cooperation can more rapidly solve the problem.
   - crossing agency boundaries (defined broadly, to include NSF and the academic community) to allow an exchange of scientists between labs and agencies, focusing on problems of national importance where enhanced interagency cooperation can more rapidly solve the problem.

(Recommendation 5.1; rank total 28, vote total 12)

4. From model output, the research community must develop products that management will need and use. The WG recommended that some dramatic events (e.g., the California sardine crash) be shown as retrospective examples of how model output can be incorporated in management plans for responding to environmental changes that impact fishery populations. (Recommendation 3.3; rank total 28, vote total 10)

5. Develop an operational, high spatial resolution, multi-layer, regional circulation model imbedded in a larger scale general circulation model to integrate the diversity of physical data now being collected and enhance our current understanding of biological and fisheries processes. (Recommendation 1.3; rank total 28, vote total 7)

6. Develop capability for real-time access to oceanographic data or processed products (COADS, MOODS, remote sensing) for fisheries management or recruitment prediction purposes. (Recommendation 1.12; rank total 28, vote total 7)

7. Use new satellite technologies (e.g., NOAA-K data which combines visible, thermal and microwave and hence can provide coverage during cloudy periods; SAR, which provides all weather measurements; and ADEOS OCTS which provide ocean color information) to develop products for fisheries use. (Recommendation 1.9; rank total 21, vote total 7)

8. Use newly developed multi-beam sonar technology in support of fisheries surveys with a near real time, detailed 3-D picture of seafloor characteristics. (Recommendation 1.6; rank total 19, vote total 5)

9. Determine the degree to which surface data are representative of internal ocean structure (e.g., determine de-correlation scales between satellite SST and internal thermal fields), resulting in a wider application of data derived from remote sensing instrumentation. (Recommendation 1.2; rank total 18, vote total 7)

10. Cross-discipline communication -- improve two-way communication between modelers and fisheries scientists, and between the scientists and NMFS managers. (Recommendation 3.1; rank total 16, vote total 7)

11. Establish as a high priority that all fisheries relevant data can be accessed through on-line system that enables users to search, browse, order, and receive data and information identified through a user defined discovery process. (Recommendation 4.5; rank total 12, vote total 5)

12. Form an ad hoc or steering committee for environmental data for fisheries science that crosses NOAA line offices and agency boundaries to continue efforts initiated at this workshop. (Recommendation 5.7; rank total 10, vote total 5)

Priority recommendations came from all five working groups, with most from Working Group 1. The priorities arrived at here are affected by the nature of the individuals voting, but an analysis of expertise and interests of the participants is beyond the scope of this report. Several interesting patterns, however, emerged from those recommendations deemed as high priority by the participants.

Develop baseline time series of the most important parameters: (1, 2). The two highest priority recommendations are relatively similar but apply across real-time and retrospective working groups; they were referred to by some participants as "motherhood" recommendations. The priority given these recommendations points out the importance of i) developing the baseline against which perturbations are evaluated for both real-time and retrospective aspects of environmental data use and ii) the importance of extending time series of important parameters back in time to evaluate resource fluctuations.

Apply new environmental data technologies to fisheries problems: (5, 7, 8, 9). New and emerging technologies have the potential to change the way in which environmental data are applied to fisheries, but require further evaluation. Remote sensing, multi-beam sonar, numerical models, and other techniques are expanding more rapidly than the fisheries community can assimilate them into their approaches.

Improve communication and sharing of expertise among disciplines and agencies: (3, 10, 12). Fisheries research and management agencies are under pressure to conduct surveys, produce stock assessments, and conserve resources and habitats with often inadequate staffing. The levels of expertise required to incorporate the new technology into fisheries may need to come from other line offices of NOAA, from other agencies, and from the academic community. Mechanisms should be developed which will promote such collaboration to solve high priority problems.

Demonstration of the benefits of applied environmental data in fisheries: (4, 9). Projects demonstrating how environmental data, model output, or new environmental technologies can be applied to marine fisheries are required in order to promote their future use in the community. Past examples of crises in fisheries exist where environmental data or model output can be made available. In a retrospective fashion, the scientific community should be able to show how prudent use of these environmental data could have helped understand or predict the situation, thereby assisting in management decisions.

Data accessibility for fisheries scientists: (6, 11). Fisheries scientists are not always able to readily access the data required for their research. More appropriate data bases and integrative time series, available on-line and in near real-time, must be developed.

Appendix 1
Data access and application: Demonstrations and Visualization

Abstracts

During the workshop, video and internet demonstrations were presented on accessing oceanographic data from CDs on a microcomputer, on internet-based data distribution systems, and on oceanographic model output useful to fisheries researchers. The abstracts of those demonstrations follow.

COADS on a Microcomputer: An Example of the Differing Needs of Fisheries Science in the Organization and Format of Environmental Data

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The Comprehensive Ocean Atmosphere Data Set (COADS) represents one of the most significant environmental datasets for fisheries research, given the long time span of the dataset, the quality control of the dataset, and the relative completeness of the dataset. However, the cooperative effort that produces the dataset has been primarily funded by agencies that need synoptic data. The organization of data is such that extracting time series from the data set at a relatively few locations can be a daunting task.

The microcomputer version of COADS is the original dataset organized in a fashion that makes it easier to retrieve time series. At the workshop, the structure presently used and software that can extract data from the COADS using this structure were demonstrated. Future plans to take advantage of some standardized, public scientific libraries to provide even more ready access were also described. More information is available at www.pfeg.noaa.gov/products/code_extraction.html.

The U.S. Navy's Master Environmental Library

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The Master Environmental Library (MEL) is an Internet based data discovery and retrieval system providing access to geographically distributed oceanographic, meteorological, terrain, and near space databases. The MEL is sponsored by the Defense Modeling and Simulation Office for the purpose of providing realtime, scenario, historical, and climatological datasets for simulations, mission planning, scene modeling, etc. Existing data centers can become a MEL regional site without changing their current data management methods or architecture.

At a high level the MEL is based on the library paradigm. Users query the card catalogue, referred to as the master site, an Internet HTTP server with supporting HTML and Java interfaces. The cards in the card catalogue are the common denominator among all datasets in the library. These cards are metadata records compliant with the US Federal Geographic Data Committee's (FGDC) Content Standards for Digital Geospatial Metadata. Using either the HTML or Java interface, users with a WWW browser interactively create a query made up of region of interest, time range, category, keyword, and data center elements. A WAIS query is run against metadata records for all the data centers specified in the query. Query results are

presented to the user who can then examine the full text of the metadata record or generate an order form customized for the chosen dataset. The Java query results interface provides a unique interactive information visualization and comparison capability that helps the user navigate to the datasets of interest from a potentially large result set.

Orders for data are transferred to the regional site via electronic mail and processed by the MEL regional site software (RSS). This software is customizable and performs the functions of order parsing, access control, scheduling, data extraction, formatting, compression, encryption, delivery and notification. Regional sites specify in the metadata if the data is subsettable and how. These specifications are reflected on the customized order form generated by the master site. Data can be delivered via ftp, email, put on tape and mailed or it can be picked up via anonymous ftp at the regional site. Soon functionality for realtime HTTP ordering and delivery will be added for datasets that are not too large.

The MEL design is based on a three tier architecture that allows for scalability, load managing, and replacement of functional parts as the appropriate technologies advance and become mature. The first tier consists of a user, a WWW browser, and a delivery site (optional). The master site query, results, and order interface along with the regional site's order parser, access control, and job scheduler make up the middle tier. The third tier is made up of regional site databases, extraction and delivery processes. Unlike a two tier client/server architecture that can bog down as the number of clients increases, the three tier architecture has a middleware tier that can balance the load by sending jobs to different servers.

At present, we have a working prototype system on the WWW and will be releasing version 1.0 of our software soon. The URL is: http://www-mel.nrlmry.navy.mil/. Users can find and order or subscribe to oceanographic, meteorological, terrain, and near-space data and products. The MEL currently has two regional sites installed with many more to come in the near future. Access to the MEL is available to the public.

NOAAServer: A WWW-based NOAA Information Discovery and Retrieval System

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and
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Project Objectives

The NOAA Data and Information Server (NOAAServer) project was initiated in FY95 under the sponsorship of the ESDIM Program to address the technical and organizational issues associated with WWW-based on-line data and information access. This project is a demonstration effort with several major goals: (1) develop and implement an intuitive and unified information discovery and retrieval mechanism across NOAA environmental information systems, (2) implement a common "look and feel" across information servers to establish a corporate NOAA presence on the Internet, (3) leverage the agency's expertise and investment in WWW technologies to develop a virtual "one-stop shopping" capability for environmental information discovery and retrieval, (4) promote the development and implementation of on-line, Internet-based information services, (5) promote the use of standards in the dissemination of metadata and data products. Server participation includes ten organizational elements of NOAA distributed nationally.

What is NOAAServer?

The NOAAServer concept is to guide the Internet-connected user to discovery and retrieval of NOAA environmental data and information through a process that takes him from a broad and potentially non-specific information request, to a series of information discovery and refinement steps, to previewing or browsing of data and information, and finally to retrieval or ordering of the information product. The operational scenario is as follows: the user enters the NOAAServer set of information systems initially through a keyword and geographic and time domain query directed at a distributed database of metadata. The result of the query is a group of data set titles displayed for him with hypertext links to the remote servers containing the desired data or information. The user may choose the appropriate data set to explore by clicking on the data set title. He is then presented with a screen generated by the remote server servicing that data set. This screen provides a summary description of the data and presents the user with three additional choices to refine his search or to acquire the data. The three selections "Preview Data," "More Information," and "Obtain Data," are hyper-linked within the server to additional screens that allow the user to browse graphical data products, obtain more detailed text information on the data, or be linked to the database for subsetting or data delivery, respectively.

The networked system that has been implemented to date relies on the WWW http protocol in a client-server model. Text searches are built on a Wide Area Information Server (WAIS) search engine utilizing the WWW forms capability to allow user entry of search parameters. A key feature of the implementation is that the metadata database is distributed across servers. This requires each of the participants to establish and maintain an indexed WAIS database on their local server. An important feature of the metadata search and retrieval is that information may be displayed by the user in any of several standard formats generated "on the fly," including those prescribed by Federal mandate, i.e., Federal Geographic Data Committee (FGDC) and Government Information Locator Service (GILS); the stored format is transparent to the user. To link the data set names to the providers' servers, Universal Resource Locators (URL) are generated "on the fly" to allow the user to point and click and to open a connection to the remote data provider's server. Once connected to the provider's server the user may browse a set of data products delivered to him in WWW standard image format, such as GIF. Alternatively, the user may click on the "Obtain Data" selection and be connected to a detailed inventory of the server's data. Within this screen, the user may subset the data by time and geographic domain (within servers that provide subsetting) through a WWW form and then retrieve the data on-line or have it staged to a directory for FTP downloading. The user requiring more details on the data prior to downloading or ordering, may click on the "More Information" selection to view detailed text information on the data set.

Plans for 1996

The initial implementation of the prototype NOAAServer system integrates 10 servers located in 5 cities and includes elements of each of NOAA's three National Data Centers. The goal in the coming year is to expand this number at least to 15 or 20 and to move the system toward an operational status. This will include implementation of the basic search engine software at least to two additional sites: Asheville, NC and Boulder, CO. It is anticipated that this will provide fault tolerance to ensure user access in the event of a server failure and it will enhance overall system performance by distributing both the communications load and the server load.

The effort will also focus on expanded functionality including the implementation of visualization tools to enable rapid subsetting and previewing (browsing) of data on-line. An important exciting and new technology that will be explored by the developers is Java, which promises to provide a much richer level of interactivity than today's Web browsers.

A set of so-called "Web Theme Pages" that will provide multimedia descriptions of major NOAA strategic programs, e.g., weather warning and forecast services, will be integrated into the existing system. Electronic links to data and information relating to the strategic programs will provide the NOAA user community with expanded discovery capability and will help to integrate information for the user.

To further enhance its descriptions of data holdings, NOAA will be converting its metadata descriptions to conform with Federal Geographic Data Committee (FGDC) metadata standard. The data descriptions, currently held centrally in the NOAA Data Directory, will be distributed to and maintained by the data providers. It is anticipated that this will result in more accurate, up to date, and comprehensive information to the user.

An area of exploration will be the development of capabilities to enable users to perform data fusion, i.e., the overlaying and integration of diverse parameters obtained from diverse sources. A major underpinning of this enabling functionality will be development of tools to convert to a common data transfer standard, Spatial Data Transfer Standard (SDTS), a standard adopted by the Federal government and increasingly being adopted by GIS commercial vendors in their product lines.

Guiding Principles for Development

A number of guiding principles have been adopted to facilitate user access and minimize future software support requirements. (1) The on-line information must be accessible by users via Internet with standard, off-the-shelf equipment. (2) The user should experience a single information system and not be forced to learn to navigate several. (3) The system will be geographically distributed allowing data providers to control the content of their information offerings and to update and expand their offerings as they deem appropriate. (4) The system will conform to standards including those mandated by the Federal government for on-line transfer of metadata and data.

You may access the NOAAServer system on the World Wide Web at the following URL: http://www.esdim.noaa.gov/NOAAServer

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U.S. GLOBEC Georges Bank Data Management System: A Demonstration

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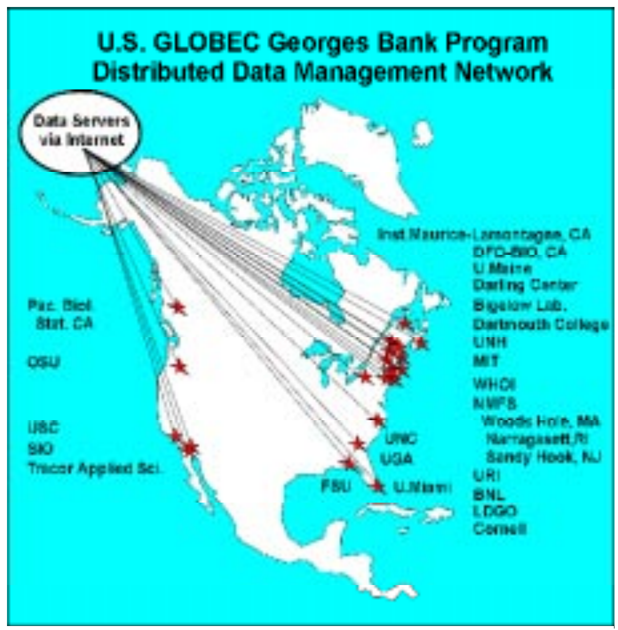
The US GLOBEC (**GLOB**al Ocean **EC**osystems Dynamics) Program is designed to address the question of how global climate change may affect the distribution, abundance, and production of animals in the sea. The US GLOBEC Georges Bank Program uses the US Joint Global Ocean Flux Study (JGOFS) data management system to support our data management needs. We require physical and biological data and information to be made available to our distributed scientific investigators in a timely basis. These investigators are currently located in 24 different institutions, throughout Canada and the United States (see Figure 1). The JGOFS Data Management System uses standard World Wide Web (WWW) clients (such as Netscape, Mosaic, and Internet Explorer) and the hypertext transmission protocol (http) to serve data and information to all types of computing platforms. The JGOFS system uses a data object paradigm to allow numeric, image, video, and text-based data to be accessed over the Internet. A standard set of plotting tools is available for basic x-y and map plots. Also, the system can reformat and download the numerical data into "flat files" for subsequent analysis by other tools such as Matlab. The system is currently serving the following types of data: along track (sea surface sensors); biological sample counts; modeling results; drifter images and movies; digital values and 3-D perspective curtain plot of acoustic volume back scattering; and images of analyzed results.



Location of Phase I GLOBEC Participants

The JGOFS software is freely available over the Internet via our home page (see URL: http://globec.whoi.edu/) and has been ported to HP, IBM, IRIX, OSF, Solaris and SunOS Unix-based systems. We will soon have a version for PC/Windows 3.11 as well.

The system is flexible, data driven, extensible and network accessible. It is used by both the JGOFS and US GLOBEC Georges Bank Programs to provide access to our data. We are each able to implement our own data policies using the same JGOFS software. A detailed description of the JGOFS architecture can be found in (JGOFS Data System Overview, Flierl, et. al.) and is available on-line at http://puddle.mit.edu/datasys/jgsys.html. A description of the GLOBEC use of this data management system is available in Groman and Wiebe, in press, and on line at http://globec.whoi.edu/globec-dir/reports/groman/Hamburg1996.talk/hamburg-text.html

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Availability of High-Resolution Model Output for Fisheries Applications

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Over the last five years, a number of simulations of ocean circulation were carried out with 20-level, primitive-equation, active-thermohaline, global ocean models having average horizontal grid sizes of 1/2, 1/4, and 1/6 degree. Geometry and forcing have become increasingly realistic. Presently, ECMWF three-day winds of 1987-95 and monthly climatological heat fluxes are being used. In addition, integrations are planned with reanalyzed fields from 1979-1996 and with time-varying buoyancy fluxes of that entire period. These simulations will use a prognostic-depth mixed layer as an added improvement for upper-ocean physical processes.

The results of the models are illustrated by video animations of surface height, temperature, salinity, and vertically integrated current speed from the 1/6-degree model on a global basis, as well as by North Pacific results that include particles trajectories and three-dimensional views from the 1/2-degree model.

The output from our 1/4-degree model is most readily available by virtue of being archived at the National Center for Atmospheric Research (NCAR), with extraction programs in existence to sample 3-day, monthly, or yearly files of temperature, salinity, and horizontal velocity. The programs and file information are available at the Web site: http://vislab-www.nps.navy.mil/~rtt; and limited computer resources are available from NCAR to extract user-selected subsets of model output. The 1/4-degree model has been favorably evaluated and compared with the TOPEX/POSEIDON satellite data and WOCE in-situ data, as well as with the higher-resolution model in papers that are also located on the Web site. We invite fisheries scientists and physical scientists to examine and utilize the 1/4-degree model output for their chosen applications, with the understanding that we can provide only limited consulting ourselves.

Ocean Surface Current Simulations (OSCURS) Model Shows Five Decades of Surface Current Variability in the North Pacific Ocean and Bering Sea --It's Time for a Lagrangian Index of Surface Currents

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In OSCURS, daily surface current vector fields are computed using daily sea level atmospheric pressures and empirical functions for wind and wind drift currents plus the addition of long-term mean geostrophic currents (0/2000 db) on an ocean-wide (Baha to China; 10˚ N to Bering Strait) 90 km subset of the FNMOC grid . The model was tuned to reproduce trajectories of satellite-tracked drifters (drogued at 20 m) from the Gulf of Alaska. Motivation to develop OSCURS grew out of the need in fisheries research for new indices which describe variability in ocean surface currents.

New insight on interannual and decadal variability of winter surface currents is seen in video animations of a time series (1947-95) of drifter tracks starting at 200 points in the North Pacific Ocean and Bering Sea. The benefits gained from modeling with synthetic data far surpasses the concerns over limitations.

The start point for a winter circulation index was chosen at Station PAPA (50˚N, 145˚W), where the 3-month winter trajectories (D-J-F) proceeded toward the northeast into the Gulf of Alaska, but year-by-year the trajectories showed a dominant bimodal character in their north-south and east-west components. The latitude-longitude of trajectory end-points covaried with the Pacific North American (PNA) atmospheric index, the Northern Diversion Rate (NDR) for sockeye salmon, and the Washington State Oyster Condition Index (OCI). The start point for a spring circulation index was chosen in the Bering Sea north of Unimak Pass (55˚N,165˚W) to investigate the variability of currents that advect walleye pollock eggs and larvae northeastward to their summer nursery grounds on the eastern Bering Sea Shelf.

OSCURS provides a tool for defining candidates for indices of surface current drift. Time scales are selectable as week, month, or season. Spatial resolution is selectable as fields of start-points, lines of points, or diffusion of many drifters from a single point. It even works well in showing the dispersion of thousands of high windage objects which float away from accidental container spills (80k Nike Shoes, 1990; 29k bathtub toys, 1992; and 34k hockey gloves and Avia lady's aerobic shoes, 1994).

Appendix 2
Poster Abstracts

The following five abstracts were displayed as poster presentations during the workshop.

The Comprehensive Ocean-Atmosphere Data Set (COADS): Project Status and Data Availability

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Project Overview: The Comprehensive Ocean-Atmosphere Data Set (COADS) is widely recognized as the most extensive set of surface marine (primarily ship and buoy) data available for the World Ocean over the past 140 years. COADS data are extensively used for national and international scientific research, e.g., in areas of climate and global change, model forcing and validation, weather, and fisheries science.

COADS is the result of a continuing cooperative project between NOAA--its Environmental Research Laboratories (ERL), Cooperative Institute for Research in Environmental Sciences (CIRES; joint with the University of Colorado), and NESDIS/National Climatic Data Center (NCDC)--and the National Center for Atmospheric Research (NCAR).

COADS Processing and Update Status: The basic observational data (individual marine reports from ships, buoys, and surface-level oceanographic data) are first quality controlled. Then, monthly statistics (including the median and mean) are calculated for each of eight "observed" variables (sea surface and air temperatures, wind, pressure, humidity, and cloudiness), plus 11 derived variables. The monthly summaries are calculated for each year of the period-of-record, currently 1854-1993, using 2-degree latitude x 2-degree longitude boxes.

The original COADS Release 1 (made available in 1985) has been extended now through 1995 by Release 1a. Release 1b, an update of the 1950-79 period completed in 1996, provides individual observations in support of the NCEP/NCAR Global Reanalysis Project plus 2-degree monthly summaries. Also completed in 1996 was a set of monthly summary data in support of NOAA's Pan-American Climate Studies (PACS) Program, based on Release 1a and 1b data for 1960-93. These are 1-degree latitude x 1-degree longitude summaries for an expanded set of 23 variables, including the cube of wind speed.

Data Availability: COADS data products are available in different formats and via different media to meet a wide variety of user capabilities and requirements. The full suite of observational and statistical products can be ordered from NCAR's Data Support Section (http://www.scd.ucar.edu). These are simple packed binary products, with Fortran software access. NCAR offers ftp transfer for suitable data volumes, or a variety of tape media.

Alternatively, the NOAA/ERL Climate Diagnostics Center (CDC) provides access to selected 2-degree statistics in the netCDF format, using metadata conventions developed at CDC. The netCDF files can be accessed via anonymous ftp or by following Web hyperlinks (http://www.cdc.noaa.gov/coads/). Also, NCDC provides individual observations in an ASCII format (http://www.ncdc.noaa.gov/). Other "value added" products based on COADS data should also be noted. These include Roy Mendelssohn's CD-ROM data plus software, and analyzed fields such as the Reynolds et al. Reconstructed Sea Surface Temperatures (1950-92), and the da Silva et al. Atlas of Surface Marine Data (1945-89).

Environmental Data from Fishing Fleets; the Potential of Vessel Monitoring Systems

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The widespread distribution of fishing fleets in the world ocean make them excellent candidates for transmission of real-time sea surface environmental information. Many large, open ocean fishing vessels routinely provide surface ship reports and these represent an important source of data in certain regions. Elsewhere, however, many fishing fleets have been hesitant to provide such data either because of the difficulty of data transmission or because of issues related to the confidentiality of fishing locations. While the latter issue remains a difficult and often contentious one, new technology in fisheries management and regulation called the “Vessel Monitoring System” (VMS) holds the potential to provide an uplink with a great deal of real-time surface data at modest cost.

The VMS was pioneered in a pilot project on the Hawaiian longline fleet in a cooperative venture between the Western Pacific Fisheries Management Council (Council), the Coast Guard, and the National Marine Fisheries Service. The longline fleet is regulated by the Council under the Pelagics Fishery Management Plan. It has some 166 permits outstanding under a management scheme that limits the number of vessels allowed to fish; presently 110 vessels are actively fishing, and 130 VMS units are in place. The fleet ranges from relatively small vessels fishing primarily for tuna and billfish in waters surrounding the Hawaiian Islands to larger vessels fishing more distant waters, often for swordfish. In 1991, the Council designated a no-fishing zone in the area around the Northwestern Hawaiian Islands (NWHI) to prevent interactions between the fishing fleet and the endangered Hawaiian monk seal. Because of the great geographic extent of the NWHI, enforcement was deemed a problem and a cost-effective system to monitor vessel locations was explored. Alternative system designs were investigated and the decision was made to procure a commercially available system (Trimble Galaxy tranceiver), which sends information on vessel position (GPS), speed, and course through Inmarsat-C. These confidential data are recorded on a secure computer system at the Coast Guard facility in Honolulu. Cost for each position record is approximately $0.06. Many vessel owners also use the system for text messaging and fax services.

The system has been operating since December, 1994. Position locations are sent every hour for vessels at sea. Examination of the data for April and May 1996 showed 79,185 observations ranging from 38° S to 64° N latitude and 144° E to 118° W longitude. Plots of daily mean position by month demonstrate the concentration of the vessel locations in an area approximately 20° latitude by 25° longitude. These bounds are subject to shift seasonally, however, as the fish move with environmental conditions.

The VMS system may provide an excellent mechanism to piggyback environmental data sensors for surface ship reports and deserves further evaluation. Fisheries frequently operate in ocean regions with very few surface ship reports and in fact pelagic fisheries for tuna or billfish frequently congregate (as do the fish) near frontal regions where ocean conditions are dynamic. Regulatory requirements for VMS systems will also expand in the future as scrutiny of fisheries in international waters increases. The next candidate fishery may be the Western Pacific tuna fleet, which operates in the tropical and South Pacific.

Environmental Data In Marine Mammal Studies

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As part of its basic mission of managing marine resources, the National Marine Fisheries Service studies the biology and ecology of marine mammals. Environmental data can be used to interpret changes in distribution, diet, behavior, and movement of marine mammals. The example presented here is drawn from work on dolphins in the eastern tropical Pacific, and shows how environmental data have been used (1) to describe dolphin habitat quantitatively, and (2) to improve estimates of population size.

From 1986-90, line-transect surveys were carried out in the eastern tropical Pacific to estimate dolphin abundance. Oceanographic variables were measured concurrently with cetacean sightings. A canonical correspondence analysis of dolphin sightings and environmental conditions showed that the first canonical axis, associated with cooler, denser, higher chlorophyll water, separated sightings of common dolphins from spotted and spinner dolphins. Habitat scores based on this analysis indicated that favorable habitat for spotted dolphins expanded in the moderate El Niño year of 1987, and contracted in the strong anti-El Niño year of 1988. The opposite was true for common dolphins, which prefer upwelling-modified water. Such interannual changes in the amount of “good” habitat may cause short-term changes in the apparent abundance of dolphins, and programs to monitor population size should take account of this. Several abundance response indices are suggested, and adjusted indices of abundance, based on weighted combinations of the original line-transect estimates and the environmental information are computed. We conclude that some of the interannual variability in estimated population sizes can be explained by environmental variability.

Remotely Sensed Ocean Surface Currents: Agreement with Satellite Observations of Coastal Upwelling and Ecological Implications

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Remote sensing is an increasingly important tool in ecology. High Frequency (HF) radar is a relatively new remote sensing technology capable of providing synoptic observations of surface currents in the coastal ocean. These currents supply nutrients and recruits to biological populations, but are difficult and expensive to measure by conventional means, such as subsurface moored instruments and drifters. Here we provide vector fields of surface currents synthesized from HF radar observations, and compare these vector fields with maps of sea surface temperature derived from satellite-based Advanced Very High Resolution Radiometer (AVHRR) sensors to show that HF radar successfully detects and tracks coastal upwelling processes. Data from field surveys show correlation between oceanographic structures observed by HF radar and the distribution of planktonic fish and invertebrate larvae. Larval fish, in particular, are abundant in convergence zones detected by HF radar. Also, the single major recruitment event of barnacles to a rocky intertidal habitat near the HF radar observation range was linked to a relaxation and reversal of upwelling currents detected with the HF radar. These results demonstrate that data from HF radar can support improved prediction of ecological population dynamics and other coastal processes.

The Use of Near Real Time AVHRR Satellite Imagery to Direct Fisheries Research Vessel Sampling Operations

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Near real time AVHRR sea surface temperature satellite images were utilized to direct the NOAA Ship David Starr Jordan while sampling for larval Dungeness crab (Cancer magister) and juvenile rockfish (Sebastes spp.) off the central California coast near Point Reyes during June, 1994, 1995, and 1996. AVHRR images with one kilometer resolution were processed, reviewed and transmitted to the ship by the NOAA CoastWatch Group in La Jolla, CA. The images were downloaded directly on to a Personal Computer through a cellular telephone modem interface. Displaying and manipulating the images was accomplished through the use of the NOAA/NASA CCOAST software for PC's as well as the Windows Image Manager (WIM) developed by Scripps Institution of Oceanography. Newly upwelled ocean water and areas of spatially correlated sea surface temperatures were easily discernable. The satellite images used, along with the sampling stations during the 1994 cruise are presented. Mesoscale sampling in specific oceanic temperature regimes and across upwelling fronts based on AVHRR satellite imagery proved successful. Ground truthing of sea surface temperatures via measurements by the ship's thermosalinometer verified the accuracy of the satellite images. Effective downloading of satellite images over the cellular network was easily accomplished and proved to be quicker and much less expensive than other avenues of digital communications while underway, although being within range of a cellular network antennae was necessary. This system of AVHRR data acquisition and display while conducting operations at sea has been subsequently implemented on the NOAA Ship MCARTHUR (April/May 1996).

Appendix 3
Contributed Abstracts

The following nine abstracts were contributed by scientists not present at the workshop. The content of each is pertinent to the objectives of the workshop and ranges from applications of environmental data to fisheries problems to data distribution systems.

Environmental Indices for Predicting Fraser River Sockeye Salmon Return Times

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and
David J. Blackbourn, Department of Fisheries and Oceans, Pacific Biological Station, Nanaimo, BC, Canada V9R 5K6

Sockeye salmon (Oncorhynchus nerka) return to their natal streams to spawn in the Fraser River basin after completing a remarkable migration of thousands of kilometres from their foraging grounds in the northeast Pacific Ocean. The harvest of these fish in the coastal fisheries, are managed by stock group. Pre-season abundance estimates are adjusted in-season, using commercial catch data, test-fishing data, and predictions of return times. The principal stock groups return to the mouth of the Fraser at different times: the early Stuart stock arrives first, the Horsefly and Chilko stocks are mid-summer runs, and the Adams stocks are late summer runs. The return times of a given stock may vary by as much as three weeks between years. We have undertaken an extensive examination of hypotheses which attempt to explain this variability and developed several new environmental and biological indices for possible use in multiple linear regression models for return time forecasts.

The indices examined (all of which are available in near real-time for pre-season or in-season forecasts) were: 1) for the temperature displacement hypothesis, sea surface temperatures and thermal limits (i.e., the latitudes of surface isotherms along specified meridians and the distances of isotherms from Vancouver Island); 2) for the surface advection hypothesis, eastward and northward currents imputed by the Ocean Surface Current Simulation (OSCURS) model of J. Ingraham (NMFS, Seattle, USA); 3) for the fish length hypothesis, female length of each stock; 4) for the fish abundance hypothesis, return abundances of BC sockeye and total Alaska salmon catch; 5) for the return time hypothesis, stock-specific return times; and 6) for the full moon hypothesis, the day-of-year of the first full moon of the year and the full moons in June and July. For hypotheses numbers 3 to 5, the variables were lagged by one year, lagged by four years, averaged over the last four years to obtain useful forecast variables (rather than having to use a forecasted variable within a forecast model), which also accounted for the time history of these quantities. The full moon hypothesis was suggested by Bill Proctor, a very experienced sockeye salmon fisherman, who stated that he has been predicting return times by the timing of the full moons.

We identified candidate predictor variables for each hypothesis and stock using correlation coefficients and Bonferroni probabilities. Alternative multiple linear regression models were compared to obtain the forecast models that would be the least likely to fail due to changes in the marine climate. Our approach can allow tests of the above hypotheses and potential forecast indices. We have developed forecast models in light of these hypothesis, and suggest that several of the new indices that we used would also be of value for studying climatic effects on salmon.

Ocean Surface Currents Mapped with Two Over-the-Horizon HF Radars

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Ocean surface currents are now routinely mapped with HF radars, such as the commercially available CODAR and OSCR systems. The nominal range of these radars is limited by groundwave attenuation to about 50 km. To extend the range of current-mapping radars, it is necessary to use ionospheric reflections, with the attendant need for large-aperture antenna arrays and special processing to deal with ionospheric contamination of the sea echoes. We have obtained permission from the US Navy to use their Relocatable Over-the-Horizon Radars (ROTHR) in Texas and Virginia for the first tests of current mapping at ranges greater then 1,500 km, using two OTH radars. The results of this test are described in *Nature* (vol. 379, Feb 1, 1996, pp. 434-436). Figure 1 shows the map of vector surface currents in the Florida Straits. Nominal resolution is 10-15 km, which resolves many previously unseen mesoscale features, including bathymetric effects on the Caribbean Western Boundary Current. Results of other current-mapping tests using single ROTHR radars, as well as the Air Force OTH-B radars, are described on the World Wide Web site of the Environmental Technology Laboratory: *http://www.etl.noaa.gov*, which also contains references to recent publications on the subject.

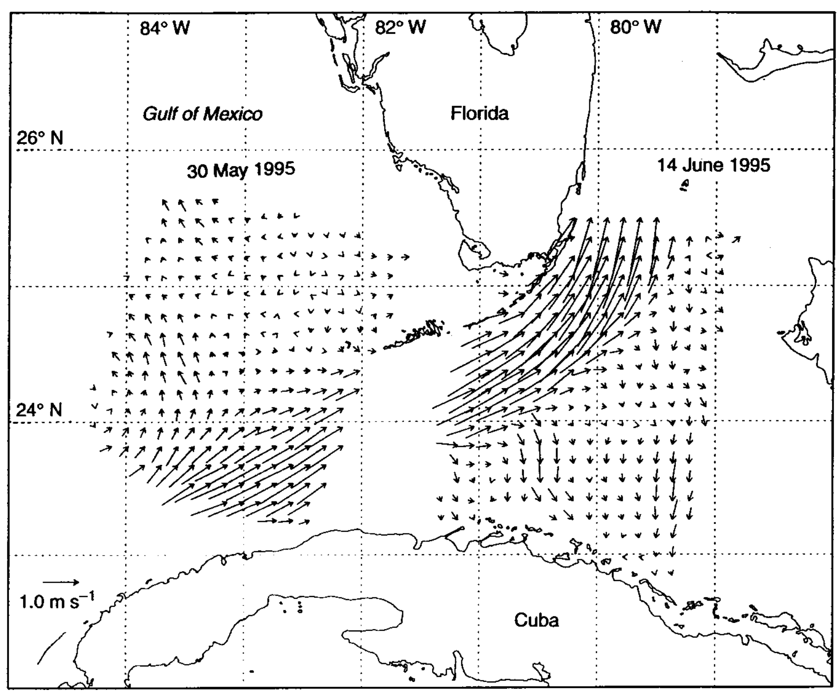

Figure 1. Results of the first attempt to map ocean currents using two over-the-horizon (OTH) radars. The two US Navy ROTHR radars, one in Virginia and the other in Texas, reflected decametric radio waves off the ionosphere to illuminate these two 70,000 km^2 ocean regions in the Straits of Florida. The two regions were mapped 15 days apart. Each radar mapped radial current components, and the two measurements were combined to form current vectors. The arrows show the direction of surface flow, and their lengths are proportional to the magnitude of the surface current (averaged over 2-m depth) at the arrow tip. A maximum current of 2.0 ms^{-1} is present just off the east coast of Florida. The areas illuminated for this test are ~2% of the ocean area covered by the radars, which includes the entire Caribbean Sea and the southern Gulf of Mexico.

Use of AVHRR (SST) Imagery to Benefit U.S. Summer Flounder Fishery Management and Conservation of Sea Turtles

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A trawl fishery for summer flounder (Paralichthys dentatus) intensifies off Virginia and North Carolina during fall and winter on the continental shelf from Chesapeake Bay south to Cape Hatteras, NC. This narrow area is occupied in the same season by endangered and threatened sea turtles, thus increasing chances of interaction between flounder trawls and sea turtles. Images of surface seawater temperature (SST) from the Advanced Very High Resolution Radiometer (AVHRR) sensor on the NOAA-11 polar orbiting satellite were compiled during the 1991-92 winter fishing season. These were coupled with on-board observer data on fishery bycatch of turtles and aerial surveys of sea turtle distribution (see Bulletin of Marine Science 1995, 56:547-568). We documented increased flounder fishery-sea turtle interactions in waters with temperatures >11˚C. However, location of water masses in the area south of Oregon Inlet, NC, is very dynamic, particularly near Cape Hatteras. SST imagery can provide the knowledge of spatial and temporal dynamics of water masses needed by NMFS for regulatory management of sea turtle-trawl fishery interactions. Since 1992 NMFS has used biological and SST observations made during the 1991-92 flounder fishing season, in conjunction with SST imagery for the area available during Nov-Jan of subsequent years, to determine the need to enact emergency and interim rules under the Endangered Species Act for sea turtle conservation during periods when there is high potential for interaction of the fishery with sea turtles (see Proc. WMO/IOC Tech. Conf. on Space-based Ocean Observations, Bergen, Norway, 9/93, WMO/TD-No. 649, p. 184-189). Also, since 20 October 1993, turtle excluder devices (TEDs) have been required in all ocean flounder trawls, except flynets, used between 37º 05'N (Cape Charles, VA) and 33º 35'N (NC-SC border). By using AVHRR imagery each fall-winter season to locate water masses of <11ºC, NMFS has assessed the potential risk to sea turtles of regulatory relaxation in the flounder trawl fishery, e.g., moving the TED line south from Cape Charles to Oregon Inlet, NC, as requested by the fishing industry.

On 24 January 1996, NMFS published a Final Rule which adopted the above TED requirement with one exception: TEDs will not be required in the area between Cape Charles and Oregon Inlet between 15 January and 15 March, unless monitoring of water temperatures by NMFS indicates turtles likely are present in the area. Thus, NMFS has codified the near-real time capability, through satellite SST imagery, to provide protection to sea turtles, while allowing the flounder fishery to continue using area-appropriate gear limitations. To our knowledge, this represents the first direct application of NOAA's Coastwatch Project SST data for active fishery management and protection of sea turtles.

The NOAA/NOS Biogeography Program: Coupling Species Distributions and Habitats

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Introduction

This paper summarizes the activities of the Office of Ocean Resources Conservation and Assessment Strategic Environmental Assessment (SEA) Division to define and interpret the coupling of species distributions and their habitat requirements in estuarine and coastal environments. The work of the Division's Biogeographic Characterization Branch has been formulated to support the development of assessment tools that support habitat and living resources management. The goal of the Biogeography Program is

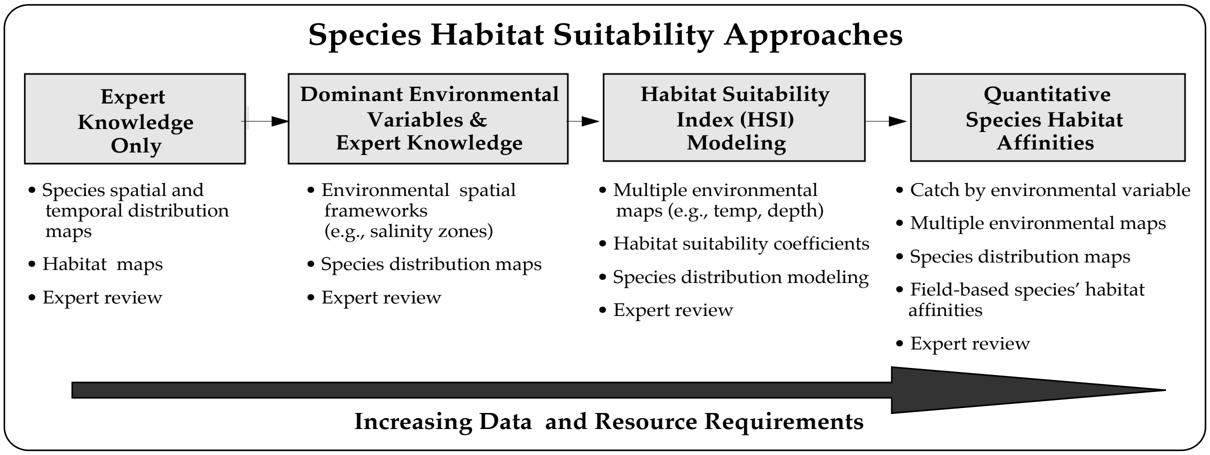

Figure 1. Four approaches to coupling species distribution and habitat.

to develop knowledge of living marine resource distributions and ecology throughout the Nation's marine, coastal, and estuarine environments to provide managers with an improved ecosystem basis for making decisions.

SEA's species/habitat coupling work is addressed through a continuum of approaches to define bio-physical relationships which differ in data content, complexity, and analytical structure. Examples of four approaches are presented below.

1) Expert Review

This approach uses and builds on SEA's development of a series of strategic assessment coastal atlases along the nation's coastlines (Figure 2; NOAA 1986; Strategic Assessment Branch 1989). An important theme in the atlas series is the distribution, relative abundance, and life history function of living marine resources. Species distribution maps are synthesized from a multitude of quantitative and qualitative data sources. The integrated data and maps are peer reviewed by recognized experts on specific species and geographic areas. Where data are available, species are mapped and associated environmental variables are analyzed to interpret species distributions (Brown *et al*. 1996). In areas where data are not available, species distributions are inferred based on knowledge of a species' habitat requirements and the geographic extent of those habitats. This sort of information is developed in expert review meetings and workshops where structured approaches are used to "engineer" our collective knowledge.

2) Controlling Environmental Variables

Estuarine salinity (3-5 zones per estuary) and temperature (monthly) variables provide the spatial and temporal framework to organize species distribution and relative abundance data. The primary data developed for each species include spatial distribution by salinity zone, temporal distribution by month, and relative abundance by life stage (e.g., adult, spawning, juvenile, larva, and egg). These data, along with a series of species life history tables that characterize species habitat requirements, are the major components of SEA's Estuarine Living Marine Resources (ELMR) Program (Jury *et al*. 1994). Over 6,000 species/estuary data sheet combinations have been compiled and peer reviewed for 135 species in 122 continental US estuaries.

3) Habitat Suitability Index (HSI) Modeling

SEA is developing a series of species habitat suitability index (HSI) models to support species/habitat management (Figure 4). The methodologies were developed by the US Fish and Wildlife Service (Soniat and Brody 1988); SEA refined the suitability index coefficients and employed geographic information system (GIS) technology for

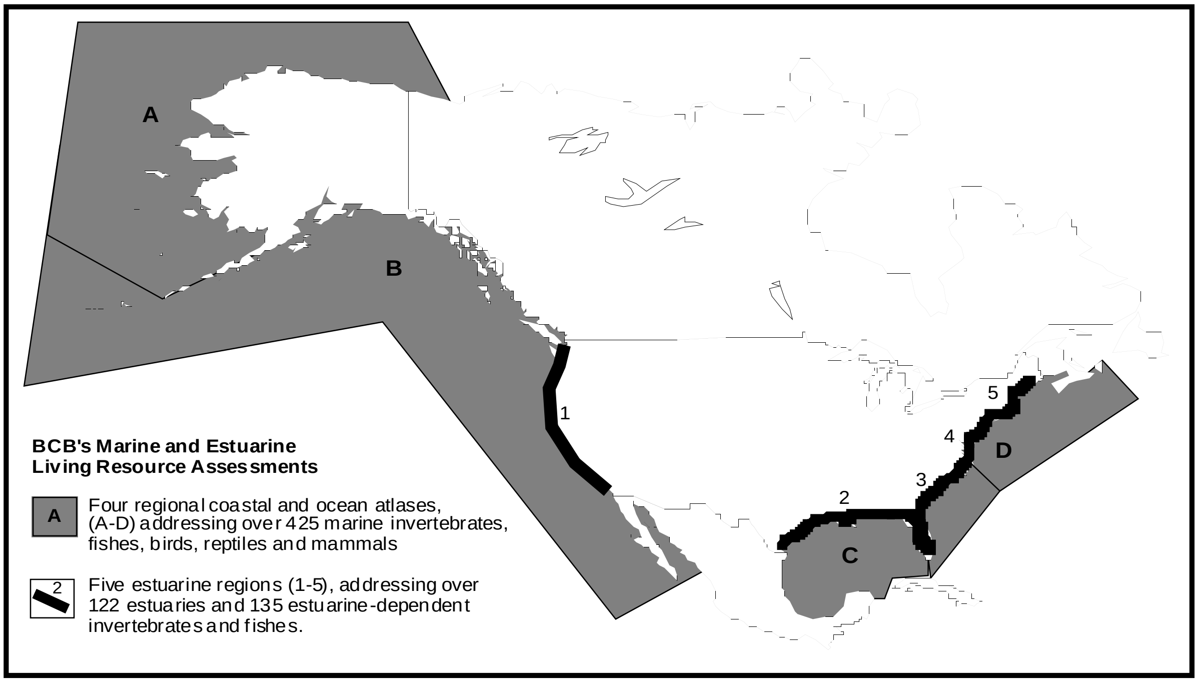

Figure 2. Geographic coverage of SEA's Biogeography Program.

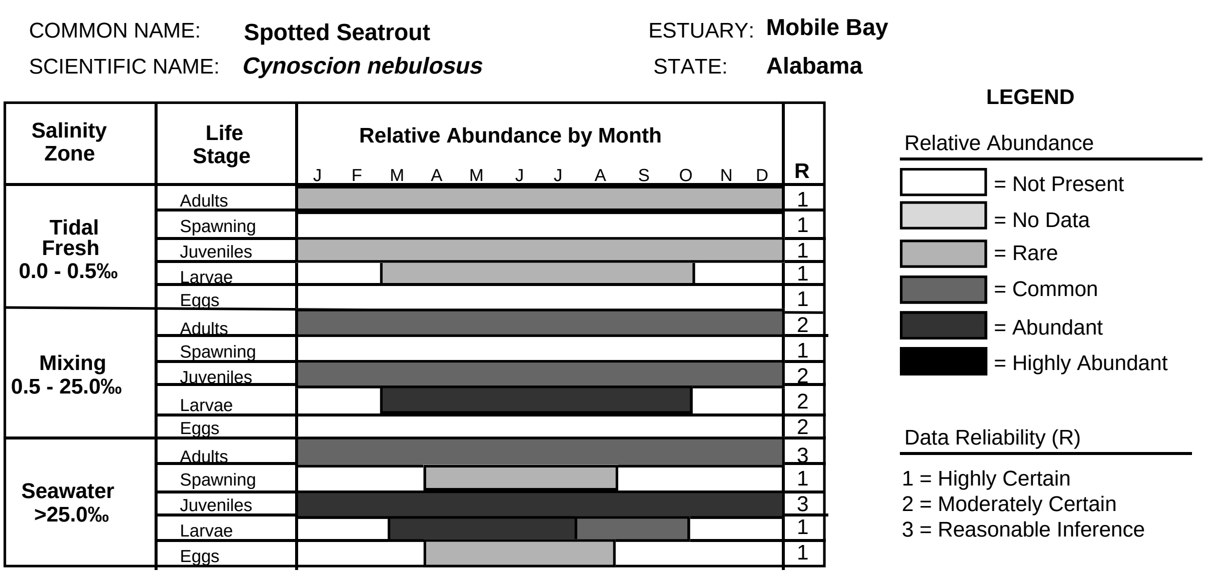

Figure 3. Example ELMR data sheet.

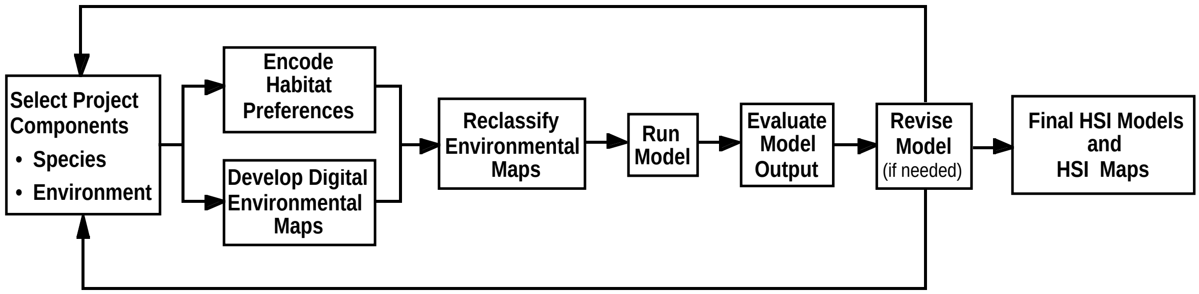

Figure 4. The process of developing and running an HSI model.

map development. The HSI concept centers around the assumption that the "value" or "importance" of a geographic area can be defined by estimating a species' habitat requirements and quantifying habitat availability. A species' habitat affinity (preference) for specific environmental variables (e.g., salinity zones) is encoded to a suitability index (SI) scale ranging from zero (for unsuitable habitat) to one (optimum habitat). SI values are assigned based on the literature or quantitative analyses (see below) to define the strength of species habitat affinities (Monaco *et al.* in press). Digital maps of environmental parameters are developed via GIS technology. A simple model is used to calculate a geometric mean suitability for a specific grid cell (e.g., 100 m X 100 m):

$$HSI = \left[\prod_{i=1}^{n}(SI_i)\right]^{(1/n)}$$

where the SI_i are the suitability indices for environmental variables 1 through n (Figure 5). Model outputs range between zero and one; any grid cell having one or more environmental characteristics in the unsuitable range will have an HSI of zero.

4) Quantitative Habitat Affinity Indices (HAI)

Quantitative analysis to define species habitat affinities depend on having field-based databases that provide species catch rate and simultaneous measurements of habitat/environmental variables. For example, we have analyzed databases on the occurrence of fish and invertebrate species by salinity increment (Figure 6) to determine how species organize themselves across salinity space in East Coast and Gulf of Mexico estuaries (Lowery *et al.* in prep; Bulger *et al.* 1993). In these studies, principal component analysis identified five biologically based salinity zones across the estuarine salinity gradient.

We also analyzed time-series data sets that contained species catch by their habitat variables to measure the repeatability of a species' response to environmental parameters (Monaco *et al.* in press). We quantified species habitat affinities based on the relative concentration of a species in a specific habitat (e.g., depth zone) when compared to the relative availability of that habitat throughout the study area. To quantify species habitat affinities, we developed a habitat affinity index (HAI) based on a modification of the Strauss (1979) electivity index:

$$HAI = (p - r)/\ r, \ \text{if } p \le r$$
or
$$HAI = (p - r)/(1 - r), \ \text{if } p \ge r$$

where p is the proportion of species collected in a specific habitat and r is the proportion of area that habitat comprises in the study area. The HAI has a center point of zero; therefore, the index is scaled so that an HAI of -1 corresponds to non-collection or complete avoidance of an area (Table 1). An HAI of 0 indicates that fish displayed no habitat affinity, and an HAI of +1 indicates an apparent exclusive affinity for a specific habitat zone or area. Negative values (other than -1) are used to define avoidance, and are not equivalent to complete absence; a negative HAI value in the electivity context reflects a lesser concentration of a species in a particular habitat.

Current Applications

SEA's mix of approaches to define bio-physical relationships is currently supporting several joint

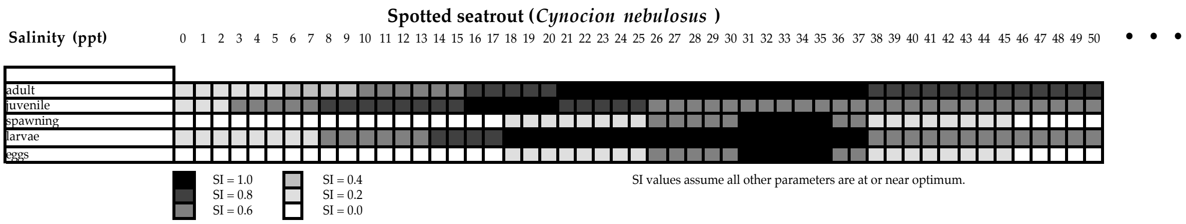

Figure 5. Salinity suitability index coefficients for spotted seatrout.

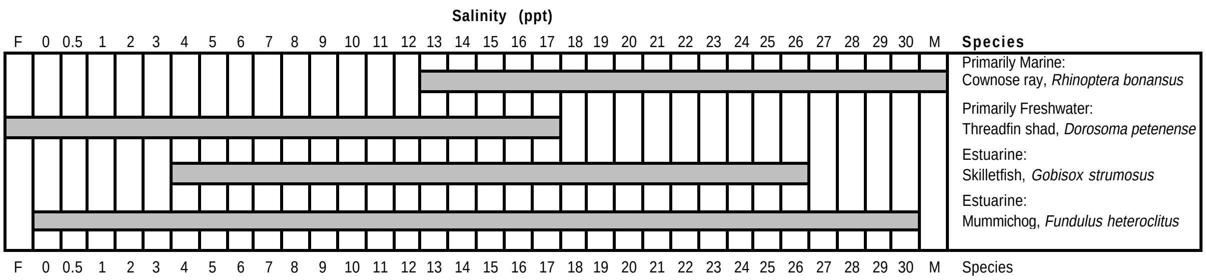

Figure 6. Example of species-salinity data matrix (Bulger et al. 1983).

SPECIES Life stage		SALINITY ZONES (ppt) 0 - 0.5	0.5 - <5	5 - < 15	15 - < 25	> 25	SUBSTRATE (% SILT/CLAY) 0 < 20	20 - ≤ 80	> 80
SPOT	AVG HPI	-0.939	0.012	0.164	0.380	-0.816	-0.577	-0.057	0.304
Juvenile	STD ERROR	0.047	0.006	0.091	0.103	0.059	0.144	0.103	0.191
WEAKFISH	AVG HPI	-1.000	-1.000	-0.792	0.646	-0.542	-0.618	0.220	-0.242
Adult	STD ERROR	0.000	0.000	0.202	0.202	0.325	0.180	0.371	0.377
HOGCHOKER	AVG HPI	-0.014	0.244	0.119	-0.668	-0.898	-0.719	-0.546	0.649
Juvenile	STD ERROR	0.065	0.280	0.406	0.083	0.102	0.133	0.211	0.127

Table 1 . Species Habitat Affinity Index values for two environmental variables in the mid-Atlantic region. Shaded values indicate a statistically significant affinity (+) or avoidance (-) (Monaco et al. in press).

studies and clients. For example, data from the ELMR Program supports mapping products for the National Marine Fisheries Service Office of Habitat Protection by helping define essential fish habitat (Schreiber and Gill 1995), and for the Atlantic States Marine Fisheries Commission's weakfish management plan (Lockhart *et al*. 1996). In addition, ELMR program data are currently being integrated into the next generation of Environmental Sensitivity Index maps under a joint program of NOAA, the Minerals Management Service, and states in the Southeast and Gulf of Mexico regions (Battista *et al.* 1996).

Habitat Suitability Index models for white shrimp, eastern oyster, and spotted seatrout in Pensacola Bay, FL are under development to support the EPA's Gulf of Mexico Freshwater Inflow Committee efforts to assess impacts of changing estuarine salinity regimes (Christensen *et al.* 1997). This pilot study provides an analytical approach to conduct similar investigations across the Gulf of Mexico region. In addition, HSI models have been developed in Maine for Casco and Sheepscott Bays to support the Gulf of Maine Program. This work identifies important areas for management in the Gulf.

Quantitative analysis to define species habitat affinities are underway using the EPA/NOAA Environmental Monitoring and Assessment Program (EMAP) Carolinian Province database. SEA's Habitat Affinity Index will be used to assess whether differences in species' response to their environment can be detected in polluted versus non-polluted areas in the south Atlantic region.

Concluding Comments

Defining quantitative habitat affinities provides new opportunities for aquatic resource management. The identification and protection of species habitat are increasingly recognized as complements to traditional harvest management approaches, and as critical parts of maintaining living resources (Deegan and Day 1984; Funderburke *et al.* 1991; Chambers 1992). A prerequisite for implementing habitat management approaches is an understanding of species habitat requirements. SEA's Biogeography Program will continue to develop and provide information to define the coupling of species to their habitats on national, regional, and local spatial scales.

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Estimation of Pacific Hake Larval Abundance Using Adaptive Sampling

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Adaptive sampling is a sampling design in which the procedure for selecting sample sites and allocating sampling effort depends on data collected during the survey because the spatial distribution is not known *a priori*. In the case of biological sampling in the ocean, modification of the survey can be based upon observed abundance of the animals or on observed environmental variability, which can serve as a proxy for abundance. A stratified adaptive sampling was used to survey Pacific hake larvae during March 9-27, 1995. For Pacific hake larvae, variance among tows is positively correlated with larvae abundance. Adaptive sampling allocates greater sample sizes to strata where larvae are common and thus reduces variance.

The survey was conducted between California Cooperative Oceanic Fisheries Investigation (CalCOFI) lines 66.7 and 90.0. The survey area was divided into 18 strata and each stratum was 40 x 80 nm^2. Various estimates for Pacific hake larval density under adaptive sampling were computed for comparison. A stratified cluster adaptive sample mean corrected for its intersection probability is a modified Horvitz-Thompson (HT) estimator for probability sampling. The intersection probability of a patch is a function of the patch area divided by the stratum area. A stratified two-stage cluster HT was used to estimate mean catch per tow by which we basically subsampled the clusters encountered and the area of a network (a subset of a cluster) was estimated. The variance of the HT estimate included the variance due to subsampling within a cluster. Retrospectively, various estimates for Pacific hake larval density under the adaptive sampling, simple random sampling, and conventional stratified sampling scheme were obtained and their relative efficiencies of estimates were compared. Our results indicated that HT has the lowest variance among all the estimates. Simulation studies are necessary to confirm the variance of these estimators under this survey design. The logistics of survey planning is also a consideration.

Interannual Variability of Mesoscale Eddies and Patchiness of Young Walleye Pollock as Inferred from a Spatially Explicit, Individual-Based Model

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A coupled biophysical model has been used to hindcast the early life history of a population of walleye pollock (<u>Theragra chalcogramma</u>) in the western Gulf of Alaska to assess possible physical causes of interannual variability in recruitment, including the effects of mesoscale eddies. Our modeling approach combines a wind- and runoff-driven, eddy-resolving, primitive equation hydrodynamic model with a probabilistic, individual-based biological model of growth, development, and mortality. Individuals are tracked through space using daily velocity fields generated from the hydrodynamic model, along with self-directed vertical migrations appropriate to each life stage in the biological model. Lacking sufficient data or a lower trophic level model, the prey of larvae and juveniles were assumed in this initial model to be uniformly distributed throughout the model domain. A preliminary spatially explicit model of larval food has also been coupled to this individual based model. Both physical and biological models have been validated with available circulation and larval data. Seasonal trends in Lloyd's patchiness index calculated from model output exhibit similarities to observed patchiness from larval data. Model hindcasts span a wide range of meteorological conditions and recruitment success. Output reveals large interannual differences in the character and extent of larval patchiness, in response to the mesoscale energy of the velocity field. Eddies appear capable of both enhancing patchiness of early larvae (through entrapment), and dissipating patchiness of juveniles (through mesoscale mixing).

Applications of Side-Scan Sonar and In Situ Submersible Survey Techniques to Marine Fisheries Habitat Research

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Interest in the assessment of marine benthic habitats is rapidly growing. As coastal resources are being increasingly modified by combined natural and human disturbances, the direct and indirect impacts on benthic fisheries are of concern and need to be addressed. With the recent reauthorization of the Magnuson Fishery Conservation and Management Act ("Sustainable Fisheries Act"), a congressional mandate now requires identification and implementation of essential habitat for managed fish species. Large concentrations of marine fishes have been associated with banks, seamounts, pinnacles, and other isolated rocky features in deep water. There is relatively little information on the distribution, abundance, and other ecological characteristics of fishes in deepwater rocky habitat.

Rockfishes (Sebastes spp.) are one of the most numerous, diverse, and economically important groups of fishes on rocky outcrops along the west coast from Alaska to California. Diversity, quality, and extent of habitat likely are among the most significant environmental determinants of distribution, abundance, and diversity of adult rockfishes. Because of their close association with rugged heterogeneous bottom substrata of high relief, abundance and use of habitat are difficult to estimate accurately using conventional trawl surveys. Species near deepwater outcrops are particularly inaccessible.

Many species of rockfishes are slow-growing, long-lived, mature at older ages, and have extremely variable recruitment, which leaves them particularly vulnerable to overexploitation. Indeed, declines in abundance and size of economically valuable species now are being noted. Like other coastal fisheries, as local stocks become depleted in shallow water and more effective gear is developed, fishing effort for rockfishes has expanded into deeper and more remote areas. It is now all the more critical to gather information on rockfish populations and the function and value of their habitats in deep coastal waters.

Studies of marine fish assemblages and their habitat requirements are limited by available technology. Mapping habitats and landscape features has been conducted traditionally in either terrestrial or shallow aquatic settings, where sampling and surveying are much easier to perform than in deep ocean environments. Over the past three years, an interdisciplinary team of marine fishery biologists, geologists, and ecologists from federal and state resource management agencies and academic institutes has been pioneering the research on bottom-dwelling rockfishes associated with deepwater shelf and canyon habitats. With funding from NOAA's West Coast National Undersea Research Center, NOS Sanctuary and Reserves Division, and now California Sea Grant, we have combined the use of side-scan sonar, bottom profiling, and manned submersible operations to effectively identify and characterize large- (i.e., 100's of meters to kilometers) and small-scale (i.e., 1 meter to 10's of meters) habitats that support adult rockfishes in deep water (i.e., 50-300 m water depth), and to compare abundance, size, and small-scale distribution and habitat specificity for rockfishes at both lightly- and heavily-fished sites. Because benthic habitats are defined by their geologic attributes, geophysical techniques are critical in determining habitat structure and lithology. These geologic descriptions can be applied to associated biological assemblages.

Side scan sonar is a suitable method for differentiating blocks of hard substrata from surrounding soft sediments based on differences in intensity of reflected sound. Seafloor morphology is imaged on a sonograph that resembles the negative of a black and white photograph. Topographic features such as ledges, vertical walls and boulders produce dark and light images on the records, depending on the orientation of the feature. A strong signal (dark) is received from the side of the feature facing the transducer while a weak signal or shadow (light) is received from the side sloping away from the transducer. The sonographs along each track line are combined with Global Positioning System (GPS) navigational data to form accurate mosaics of benthic habitats. These seafloor mosaics are used to quantify the amount of various hard substrata (e.g., rock ridge, boulder or cobble fields, sand waves, etc.) available at depths suitable to rockfishes.

Interpretations from the remotely sensed sonographs are verified from direct observations made during dives in a manned-submersible. Type, relief, size and depth range of features are described; these field descriptions assist in planning dives at each site and for post-cruise assessment of habitat.

We have successfully used a small manned submersible to groundtruth the remotely-sensed acoustic images, as well as to identify and quantify fish assemblages and associated habitats. Parallel lasers mounted on either side of an external video camera were used to accurately estimate the size of fishes, distance traveled along a transect, and size of habitat patches. These *in situ* observations are especially critical when focusing on benthic habitats of extreme heterogeneity and biological assemblages of high diversity. Much of the biological and habitat information is entered into a Geographic Information System, which is useful to other researchers addressing related topics in spatial management of coastal resources.

We are now applying these techniques to an evaluation of harvest reserves as alternate management tools for marine fisheries. Characterizing and quantifying attributes of available habitat are critical in evaluating the effectiveness of harvest reserves in maintaining regional fish resources. Information on distribution and abundance of fishes living near their maximum depth range should contribute to our understanding of the role that deepwater habitats play in maintaining the health of populations being harvested in more accessible habitats.

Our approach and methodologies are currently being introduced to the South Pacific Applied Geoscience Commission (SOPAC). Using habitat studies in temperate regions as a template, we are suggesting new uses, interpretation, and evaluation of coastal and seafloor geological data in terms of identifying and describing significant fisheries habitats in the SOPAC region. These techniques also are being used successfully by investigators in southeastern Alaska to more accurately estimate densities of commercially important fishes on a habitat-specific basis, thereby improving the management of demersal shelf rockfishes within the region. *In situ* submersible surveys and geophysical remote sensing of the seafloor are a unique combination of techniques that are essential in appraising and managing our deepwater coastal resources.

Ocean Currents and the Distribution of Pacific Whiting (Merluccius productus) along the Pacific Coast during Summer, 1995

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Acoustic-trawl surveys have been conducted triennially since 1977 by the Alaska Fisheries Science Center (AFSC) to assess the abundance and distribution of Pacific whiting (Merluccius productus) along the US and Canadian west coasts. The most recent AFSC acoustic-trawl survey was conducted during 1 July - 1 September 1995 over the continental shelf and upper slope from near Point Conception, California (34˚30'N) to Dixon Entrance, Alaska (54˚30'N).

Because significant interannual differences have been observed between 1977-1992 in the distribution of Pacific whiting based on the AFSC survey results (Dorn 1995, CalCOFI Rep. 36: 97-105), efforts were initiated in 1995 to directly measure several biological and physical processes that likely influence the spatiotemporal distributional patterns of Pacific whiting. Thus, two frequencies (38, 120 kHz) rather than one (38 kHz on earlier surveys) were used to collect echo integration data to describe the biological scattering. Two frequencies can increase the ability to identify different sound scatterers on the basis of their acoustic signatures. The added frequency may enable back-scattering from the principal prey (i.e., euphausiids) of Pacific whiting to be identified. An acoustic Doppler current profiler (ADCP) was also used for the first time in 1995 to describe ocean currents during the entire survey. This work reports on the progress in determining the distributions of Pacific whiting and their principal prey (i.e., euphausiids), as well as a description of the near-surface currents along the Pacific coast based on the 1995 survey data.

Significant quantities of Pacific whiting were detected between about San Francisco, California (38˚N) and the northern tip of Vancouver Island (51˚N). Relatively dense aggregations of fish were located off California near Point Arena and Cape Mendocino, off central Oregon, over Juan de Fuca Canyon near Cape Flattery, and off northern Vancouver Island. As in previous surveys, the size composition of Pacific whiting generally increased with latitude over the study area. Age-1 fish (1994 year class) were found off California, and unlike earlier surveys, were patchily distributed northward to Nootka Sound, British Columbia. The distribution of 2 year olds was more localized, occurring primarily off the California coast. The mean daytime fish depth (MFD) of Pacific whiting was 195 m. However, the MFD decreased with increasing latitude and increased over greater bottom depths.

Work to describe the distribution of euphausiids along regions of the coast is in progress. We intend to identify euphausiid echosign based on net catch data from confirmation hauls, as well as the application of a method (Madureira et al. 1993. J. Plank. Res. 15: 787-802) that utilizes the difference in volume back-scattering between two acoustic frequencies to assist in separating echo returns from different scatterers (e.g., fish versus euphausiids).

Preliminary results based on ADCP measurements show that in addition to surface-intensified mesoscale features, there was nearly continuous evidence of a strong poleward undercurrent on the mid-to-upper slope between 32˚N to at least 47˚N. The undercurrent was characterized by a speed > 5 cm s^{-1}, width > 10 km, and thickness > 100 m centered around 200 m depth, although the velocity core depth increased from about 180 m to greater than 230 m with increasing latitude. The core velocity ranged between about 6-46 cm s^{-1} with a mean of 24 cm s^{-1}.

The combined oceanographic and biological data collected in this study will allow us to examine effects of observed upwelling fronts, associated equatorward surface jets, and the poleward undercurrent on the distribution of Pacific whiting. Although the MFD and the undercurrent core depth varied inversely with latitude, fish were found within poleward flows on 80% of all transects. In addition, the temperature range preferred by most fish over bottom depths > 250 m was about 6.8˚-7.2˚C, which was a narrower range than probably needed to remain in the poleward flowing undercurrent. These results can provide information to evaluate the contribution that bio-physical processes have in determining the distributional patterns of Pacific whiting over different time and space scales.

The Distributed Oceanographic Data System (DODS)

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The advent of the World Wide Web and sophisticated web servers has provided scientists with an increasingly important tool to access data and data archives. However, the very success of the Web is proving to be an obstacle to users of earth science data. The proliferation of Web sites, each with a different "feel" and providing data in a variety of different structures and formats, does little to simplify the basic tasks of finding, accessing and then moving data into an analysis package.

DODS provides a way for researchers to access scientific data anywhere on the Internet from the analysis packages of their choice. This is accomplished by relinking the packages with DODS-provided versions of the packages' data access subroutine libraries (in many cases, to re-link an analysis package is a matter of a few minutes and requires no modification to the researcher's application source code). A program thus modified is then able to read data from any DODS-compliant server on the Internet in addition to being able to read files from a local disk. Data are read into these programs by issuing "load" or "read" commands similar to those issued in the original program but with the data set name replaced by an Internet-standard Uniform Resource Locator (URL), such as: http://dods.gso.uri.edu/cgi-bin/nc/data/fnoc1.nc. The result is that the researcher has effectively converted his or her analysis package into a powerful network client. The analysis programs can be commercially available analysis tools such as IDL, MATLAB or PV-Wave, free-ware such as FERRET or GMT, or an analysis program developed by the user.

The process of analyzing data may be split into two phases: acquisition and visualization. A scientist first retrieves some data set and then uses whatever programs are needed to put the data into a form that will illustrate the question at issue. The visualization phase is often a highly idiosyncratic process -- as it should be. DODS only addresses the data acquisition phase of the process, leaving scientists free to use the analysis programs and methods that best fit their needs and with which they are most familiar. Basically, the steps (which can often be quite tedious) required to acquire the data and prepare it for the analysis program are avoided; the DODS core software does this work automatically.

In addition to providing remote access, DODS offers other important features such as subsetting, format translation and data location:

1) Subsetting --- DODS possesses a sophisticated subsetting mechanism that reduces network traffic as well as the load on a user's system. It accomplishes this with a rich "constraint expression" syntax that allows a user to select virtually any subset from a remote data set. A user can even specify a subset with a conditional data access expression dependent on an entirely distinct data set, stored at another site. The DODS subsetting mechanism can also be used by the researcher to subset his or her own data held locally by simply serving it out via a DODS-compliant server, again requiring only minutes to install in the case of simple data structures or data structures for which DODS-compliant servers have already been developed.

2) Translation --- DODS incorporates a powerful data translation facility, so that data may be stored in a format defined by the provider, but may be accessed by the user in a manner identical to the access of local data files on his or her own system. Furthermore, the translation facility can be extended to data types. If, for example, a user program cannot accommodate a certain data type (a JGOFS program, set up to display sequences, may not be able to read directly an array from a NetCDF archive), it still may be possible to read and display that data by converting ("translating") it to a data type more familiar to the program. For all practical purposes data available from remote machines via DODS-compliant servers look exactly like data that reside locally in the format required by the researcher's analysis program of choice regardless of the format in which they are actually stored.

3) Data Location --- To help users find data on the network, DODS provides a data locator service. Data providers may register their data sets with this service. A remote user may query the data locator for the URLs of any data set satisfying given criteria. With a set of returned URLs, the user can then refine the search by querying the given DODS servers directly.

In addition to the functionality outlined above, DODS contains provisions to increase the amount of data available across the network. The DODS architecture is designed to make it easy for scientists to become their own data providers. Data need not be sent to a central authority nor converted to a standard format in order to make it available to others. Any machine connected to the Internet can host a DODS server, which can make data available to any DODS client.

A small part of the functionality provided by DODS is already available on the Internet. Tools that exist now, such as Netscape and Java, are being used to implement data browsers and catalogs. Netscape, however, is not a data system, and Java is essentially a portable programming language. These tools do not inherently prevent two different developers from creating two completely incompatible data services. The DODS system, on the other hand, is built on a sophisticated and versatile protocol---and the functions to implement it---for data transmission and representation. This ensures that data from any DODS server can be correctly read by any DODS client.

DODS also provides an open-ended environment to scientific data users. For example, a data provider could include a sophisticated Java applet on their site to allow a user to examine their data, and prototypical sites like this already exist. However, the scientist looking at that data with those tools is constrained to look at it in the ways that were anticipated by the applet designer. If a user wants to see the data in ways not accommodated by the site designer, with a contour map, for example, or wants to use some sophisticated curve-fitting algorithm to extrapolate data, there is no recourse. By providing only the data access tools and protocol, DODS allows scientists to use whatever tools they feel are appropriate to the situation, instead of being forced to adapt to the tools provided by others.

Appendix 4
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