INTEGRATING CIVILIAN SYSTEMS WITH NAVY OPERATIONS

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SCRIPPS INSITUTION OF OCEANOGRAPHY

FOREWORD

This report from the Scripps Institution of Oceanography (SIO) is provided in response to a request from the Office of Naval Research to investigate whether data from civilian research systems could be exploited to improve Navy operational missions.

As part of the Scripps' effort, a Panel of Experts was convened with representation from Academia, Industry, Civilian and Defense Agencies. Five of the academic representatives are members of MEDEA, whose mission it is to adapt DOD and Intelligence assets for civilian benefit; our task was the inverse: to adapt civilian assets for Navy benefit. A review was conducted in cooperation with ONR, NRL, SPAWAR and NRO, which was particularly helpful coordinating briefings from NRO, NIMA and NSA technical experts. The review culminated in a meeting, titled the Navy Intelligence Integration Symposium which was held in San Diego, May 27 through May 30, 1997. An initial meeting at SIO and the Cecil H. and Ida M. Green Institute of Geophysics and Planetary Physics (IGPP) was followed by two days at a classified facility at SAIC in San Diego at a security level of TS/SI/TK. Additional discussions were later held with CINCPACFLT and his senior staff regarding current and projected operational requirements, especially in the expanded mission in littoral monitoring and warfare.

Results of the investigation clearly indicate civilian research is a critical asset that can readily be applied to provide information essential to current Navy problems such as characterization of the littoral zone, ship monitoring and tracking. We have coined a phrase to represent the panoply of research assets that could be exploited as Civilian Technical Means (CTM). These CTM are burgeoning and currently or will soon exceed the resources of the National Technical Means in their breadth and spectrum of information particularly for Navy operations. Hence we have titled our Report – Integrating Civilian Systems with Navy Operations.

While there are numerous civilian research activities of potential value to the operational Navy, their appropriate and timely use must be carefully planned to provide immediate access and highly accurate information.

We acknowledge the input and support of the many representatives of the organizations outlined above, ADM Archie Clemins of the CINCPACFLT; RADM George Wagner, COMSPAWAR; and especially the extensive work done by Ms. Ann Kerr, IGPP.

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PREFACE

At the request of the Office of Naval Research an investigation into whether data from civilian research systems could be expanded and exploited to improve Navy operational missions was conducted. This report covers the activities and some results that were observed during the study conducted in 1997 that indicate civil systems are a critical asset that should be applied to provide information essential to current Navy problems such as characterization of the littoral zone, intelligence, surveillance, reconnaissance and tracking.

This study was performed by a panel of experts representing a broad spectrum of expertise. The scientific judgements and conclusions reflected in this report are those of the following individuals:

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EXECUTIVE SUMMARY

The Scripps Institution of Oceanography (SIO) was funded by the Office of Naval Research to investigate whether data from civilian research systems could be exploited to improve Navy operational missions. This report covers the activities and some recent results that indicate civil systems are a critical asset that could readily be applied to provide information essential to current Navy problems such as characterization of the littoral zone, ship monitoring and tracking.

As part of the Scripps' effort, a Panel of Experts was convened with representation from Academia, Industry, Civilian and Defense Agencies. Five of the academic representatives are members of MEDEA, whose mission it is to adapt DOD and Intelligence assets for civilian benefit; our task was the inverse: to adapt civilian assets for Navy benefit. A review was conducted in cooperation with ONR, NRL, SPAWAR and NRO, which was particularly helpful in coordinating briefings from NRO, NIMA and NSA technical experts. The review culminated in a meeting, titled the Navy Intelligence Integration Symposium which was held in San Diego, May 27 through May 30, 1997. An initial meeting at SIO was followed by two days at a classified facility at SAIC in San Diego at a security level of TS/SI/TK.*

The Symposium was aimed at the combined use of data and techniques for naval missions, focusing on three topics:

1. Civil Systems, Surveillance (Acoustics and Space).
2. Use of NTM for operational and tactical problems and recent research results in Acoustics.
3. Propagation modeling.

**A follow-up meeting was held at CINCPACFLT headquarters, Pearl Harbor, Honolulu, Hawaii, to review findings and to acquaint the panel with the needs and methods of a major operational command.*

Briefings on NTM and civil satellite systems as well as DOD acoustics systems such as FDS and SOSUS were provided. The unprecedented participation of NRO was an extremely valuable contribution, providing the Panel with overviews of IMINT, MASINT and SIGINT, as well as briefings on relevant selected technology applications. The discussions between the two communities contributed greatly to establishing an accurate and comprehensive capabilities baseline for our review.

Our discussion was aimed at optimizations that could be achieved by the combined use of civilian and military data and techniques for Navy Operations, Surveillance and Coastal Monitoring missions. Several observations can be made at this time:

A panoply of resources at SIO and other research institutions and civil agency programs potentially provide an enormous amount of information on global and coastal ocean environments. On the classified side, it is very likely that the Navy will not be in a financial position to fly Navy-specific satellite missions in the future, for example, although a need for data will increase with time. Planned civil missions can provide much of the data needed to support Navy needs although streamlined access to the data for operational and research purposes must be assured. The Navy is likely to have to argue in the future for rapid and open access to all civil systems as well as for input into mission configurations.

The use of these capabilities in combination with classified assets yields a sum greater than its parts for Navy Surface, Air and Submarine Forces missions as well as Intelligence, Surveillance and Reconnaissance (ISR). The integration of multi-disciplinary tools and techniques from overhead, acoustics, bathymetry, global ocean data and models could provide a unique Navy contribution towards significant improvements in mission forces operational capabilities. For example, independent tracking of surface vessels by overhead assets, when incorporated into acoustic algorithms and overhead reconnaissance observations will allow, in turn, for detection of very quiet submerged targets.

An important obstacle facing the Navy today is the lack of understanding and ability to characterize accurately the 'air/water' and 'water/seafloor' interfaces essential to broad ocean and littoral zone monitoring. Civilian research can now make crucial contributions towards solving these Navy problems. The application of acoustic signal processing optimization algorithms and overhead reconnaissance observations in tracking ships of opportunity is one promising example which would allow for detection of very quiet targets.

Directed experiments in overhead surf region monitoring to establish oceanographic and acoustic ground truth are needed to demonstrate the value of civilian and Navy assets in the characterization of the littoral zone and in monitoring the sea surface and seafloor.

EXPLOITATION OF CIVILIAN TECHNICAL MEANS

Civilian research systems can provide enormous amounts of information on global and ocean environments. Furthermore, commercial systems can also potentially provide much additional information on coastal ocean and inshore environments. Finally, future commercial communication networks can provide the ability to disseminate this information globally, in near real time.

This use of Civilian Technical Means (CTM) for data gathering and transmission may soon exceed the capability of the DOD information systems traditionally used by the U.S. Navy for surveillance of the operating environment. This evolving situation, coupled with changing Navy missions, will pose several challenges and opportunities for the Navy.

First, as the requirements for the Navy to support forces ashore increase, the current meteorological and ocean information gathering needs will increase to include detailed local, timely surveillance of in-shore areas, as far as 50-100 miles inland. This requirement, coupled with decreasing infrastructure resources for broad-area information and reconnaissance will drive the Navy, increasingly, to the use of civil systems for gathering the data.

Second, as the use of civilian systems increases, the Navy will be using data from sources with widely varying levels of reliability, quality and redundancy. This will make the assimilation and conversion of these data into exploitable environmental knowledge more difficult than the exploitation of data whose sources can be controlled (the DOD Information Systems). In particular, the inability of the Navy to guarantee the survivability of any single civil system makes the identification and exploitation of redundant data sources a necessary step in assuring robustness of the information base.

Third, these civilian systems will, potentially, provide data which will be available to many countries besides the U.S. Some of these countries may be able to convert these data to environmental knowledge which could be used against our own forces. We must ensure that we maintain a clear superiority in the timely use of these data.

Given this change in paradigm, there must be a focused effort within the U.S. Navy to:

1. Obtain continuous access to applicable civil overhead data.
2. Continuously identify and qualify these current and evolving civilian research results, civilian and commercial data sources and data bases in terms of militarily significant environmental knowledge, including the development of specialized procedures, as needed. DOD emphasis here should be on reliability and redundancy, to limit vulnerability to uncontrollable developments.
3. Carefully validate the applicable data bases experimentally using DOD and intelligence agency controlled sensing resources as ground truth. This process must also periodically check civilian data bases for corruption (intentional or unintentional).
4. Use these data bases and experiments to develop and validate algorithms, which translate multisource information into

quantitative, timely, environmental knowledge. Assure that the Navy is aware of algorithm developments which might be used by enemies to exploit these same data bases.

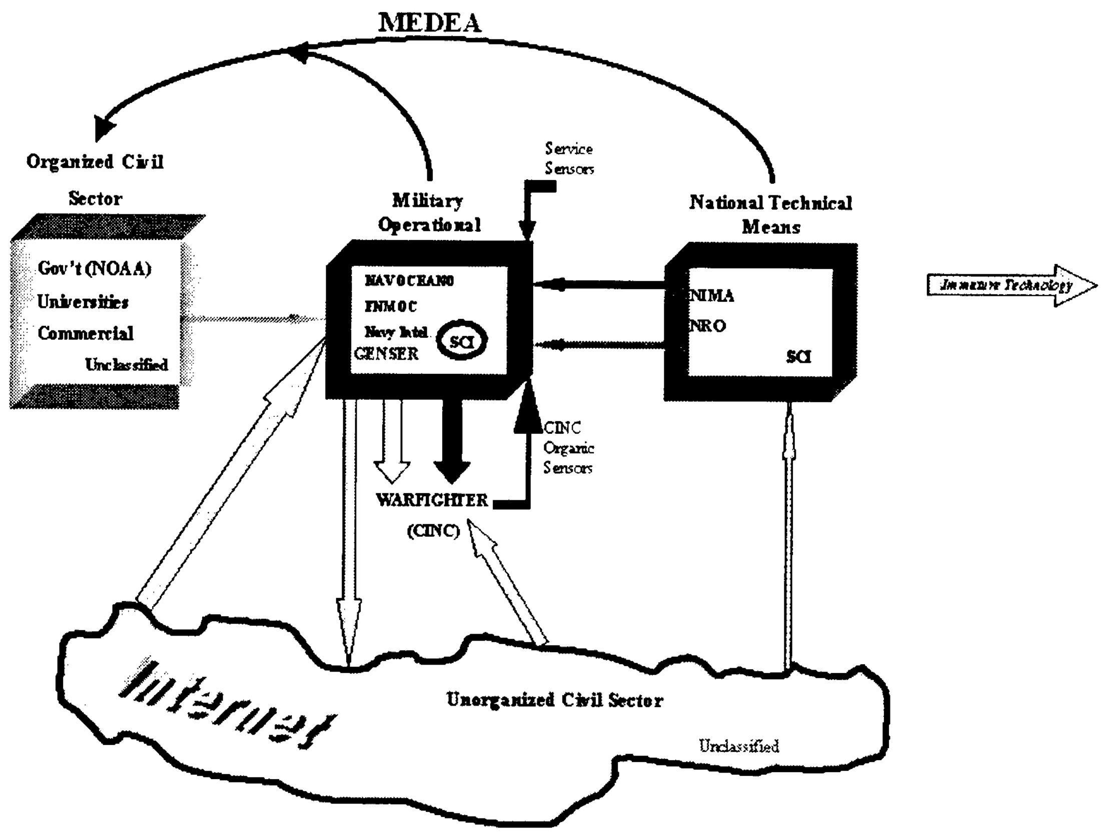
This last step is the relentless effort which is necessary to set the U.S. apart from other countries in the use of Civilian Technical Means (CTM). We must be successful in this effort. U.S. algorithms must be validated with data and limited only by physics, not current implementation capability.*

**This effort will considerably increase opportunity for involving the research community (universities, companies) in the development and of methodologies and algorithms given the emphasis on unclassified, civil data.*

CURRENT STATE

HOW DOES THE NAVY GET INFORMATION NOW?

Both naval intelligence and meteorology and oceanography (METOC) support for joint and naval operations are dependent on access to timely and accurate information. While the Navy intelligence and METOC organizations are separate, there are significant parallels in the collection, exploitation, and dissemination of data and information necessary for the warfighter to be prepared to observe his environment (including enemy forces), analyze the situation, decide on a course of action, and act faster and more intelligently than the enemy. A high level view of the process of data flow (shown below)



demonstrates the present situation. Both naval intelligence and METOC organizations use national technical, organic, and civilian (U.S. and foreign) collection systems to address the warfighter's requirements.

At the theater or CINC level support organizations, such as the Joint Intelligence Center, Pacific (JICPAC) and the Naval Pacific Meteorology and Oceanography Center (NPMOC), these organizations act as clearing houses for the information needs of the CINC, theater, and task force level organizations. These same CINC level organizations translate these needs into tasking of national, service, and force level intelligence and METOC organizations for support. National organizations include the National Imagery and Mapping Agency (NIMA), Central Intelligence Agency, and the National Reconnaissance Office (NRO). Typical service organizations are, for the Navy example, the Office of Naval Intelligence (ONI), the Naval Oceanographic Office (NAVOCEANO), and the Fleet Numerical Meteorology and Oceanography Center (FNMOC). National and service organizations respond to CINC intelligence and METOC requirements by producing standard and special products. Standard products are, for example, ocean climatologies, scheduled weather forecasts, ocean nowcasts, and similar scheduled products. Special products are, for example, environmental support packets, ocean feature analysis, national, theater, and tactical annotated imagery.

The efficacy of this process depends on the support organization's level of adaptation to changes in information processing and the level of technical inertia extant in the organization's culture. Most of these support organizations at the national and service level are attempting to adapt to the changing world of civil information processing. They are concerned, especially, with the Internet, and commercial exploitation of what was once the realm of the national technical means of the few countries capable of having advanced technologies available only to government organizations. The Naval Oceanographic Office is an example of a service organization working to adjust to the revolutionary changes being made in communications, remote sensing, and information technology. They are tasked with producing accurate and timely oceanographic information to the warfighter. They do this by using a variety of *in situ* data-collection assets, exploiting both DOD civil sector satellites, and by using all-source information. They utilize commercial and research information ranging from library searches (they operate the Maury Oceanographic Library, one of the world's foremost oceanographic libraries) to the Internet. The quality of their products depend on the availability of timely images from satellites (the Naval Oceanographic Office is the national producer of world-wide Multi-channel Sea Surface Temperature fields, for example) and other remote sensing sources, the quality of information residing in the public sector, their own extensive data bases, and ultimately on the experience and knowledge possessed by the analyst preparing the product. The growing relationships between the research community and this organization must be encouraged to ensure naval superiority in an intellectually competitive environment.

BUDGET REALITIES

Budget realities indicate that the availability of dedicated defense observing systems will become significantly reduced in relation to similar systems in government public sector and commercial systems. Furthermore, many Navy needs depend upon broad area search capabilities which are rarely met by intelligence systems.

The planned reductions in U.S. Navy infrastructure will force the U.S. Navy to look for civil (commercial and research) data in lieu of actually developing operating space-based measurement platforms.

The growth of non-government sensors, and commercial and public domain information available on the Internet are already changing the Navy's level of reliance on service and intelligence agency sensors. This dependence on civil systems, while making the job of national and service intelligence METOC support organizations more challenging also presents exciting new opportunities for improved knowledge of the environment and improved products.

SOSUS: A NEW LOOK

The Sound Surveillance System (SOSUS) was designed to exploit the deep sound channel to detect and track Soviet submarines at long open-sea ranges. SOSUS evolved over many years to meet a slowly evolving and well defined need.

Today's global threat demands systems that can operate against deep and shallow water targets ranging from quiet diesel-electric to Russian nuclear submarines. The new threats demand an order of magnitude (at least) better performance. The systems must provide for rapidly changing requirements, a far cry from the traditional acquisition approach of the SOSUS era. The expanded missions include active and passive operation modes, some non-acoustic capabilities, and communications with land, air and sea forces; in short an undersea ISR (UISR).

Finally, these UISR systems must be designed to cost where cost can be traded off against capability and performance.

Ongoing and projected advances in ASW can be associated with three developments: (i) a realistic description of the marine environment (for example, mesoscale variability which contains more than 95% of the ocean kinetic energy was unknown when SOSUS was developed); (ii) the strong interaction of the sound field with the variable ocean environment was only vaguely understood, and poorly, if at all, accommodated; and (iii) new developments in undersea technology and signal processing coupled with advances in computer technology can enable the kind of flexibility, performance and "design-to-need" demanded of UISR. Light weight fiber-optic undersea cabling being developed and deployed for the commercial communication business is being used to link undersea systems to shore, ship and buoy. Hydrophones, oceanographic sensors and acoustic modems can be installed, integrated and multiplexed using COTS ATM/SONET communication protocols. The sensor packages can be configured for tailored acoustic hydrophone array topologies. This includes pop-up vertical arrays from nodes deployed not by cable-laying ships, but by air, submarine, or ship-of-opportunity assets. The systems can be "cut" for specific environments and operational needs.

Local ocean, bathymetry and geo-acoustic properties, and *in situ* measurements can be exploited to tailor not only the wet end but also the signal processing. *In situ* measurements from installed systems can be combined with emerging technologies.

Ocean Acoustic Tomography is being developed by the University community as an "inverse" method using the measured sound propagation to infer the ocean temperature and current field (taking advantage of existing SOSUS assets). When used in conjunction with satellite altimetry, it provides a powerful tool for providing timely information on small scale(>10 km) and larger scale variability. These data can be assimilated into ocean model nowcasting and forecasting for the needed acoustic parameters.

Developments in matched field processing incorporate knowledge of the sound speed structure to exploit the three-dimensional character of the acoustic propagation. This in turn leads to improved detection and tracking by exploiting the depth and range (as well as the more traditional bearing) separation of the submerged target from surface ships and wave noise. Independent positioning of surface ships by civil reconnaissance and through satellite global communication systems can be used directly in the array processing to extract this "noise" coherently.

FUTURE

The reconnaissance satellite programs begun in the late 50's in response to a growing Soviet strategic threat served the nation extremely well throughout the Cold War. Many of the existing systems were planned, and even launched during that period, and the planning for modern problems has resulted in new plans and schedules. During the 80's the Navy planned and launched systems for their specific needs. For example, GEOSAT and GEOSAT Follow-On were launched to map gravitational deflections for ballistic missile launch and targeting, and to monitor changes in ocean circulation. Budget restrictions will no longer support Navy-unique overhead systems. A, at best, stable and more likely decreasing budget for the National Reconnaissance Office, coupled with expanding DOD-wide tasking requirements, will severely limit the needed coverage of ocean targets and phenomena. The same historical chain of events could characterize many systems; for example, the acoustic monitoring of the oceans by IUSS. In general, useful information from NTM (National Technical Means) will be much more limited as the number and breadth of these systems decreases. The Navy of necessity must complement these traditional sources with information from civil systems.

Civilian systems will continue to expand at a rapid rate for sensing the atmosphere, sea surface and undersea environment. While there will continue to be unique capabilities for intelligence systems such as resolution, targeting, security and survivability, the volume of data generated by civilian systems represents an opportunity which the Navy must exploit if simply because budget constraints will not allow duplication. These civil systems will be developed by the U.S. and many other nations; some will be implemented by governments and others by private corporations. Data will both be publicly available for a fee and restricted for profit or proprietary purposes. While the Navy must continue to maintain systems unique to its needs, it will be just another player in the realm of acquiring and using environmental data.

The boundary between NTM and Civil Technical Means (CTM) is rapidly blurring. Meteorological, intelligence, and oceanographic commands throughout the world have begun to take advantage of the vast amounts of data on the World Wide Web (WWW). This is particularly true of meteorological data available from the World Meteorological Organization (WMO), but civilian oceanographic and intelligence data are growing in usefulness, availability and applicability. As observation systems necessarily expand throughout the world, communication bandwidths increase and civilian databases become increasingly accessible through mechanisms such as the WWW, the Navy's differentiation of NTM and CTM sources will continue to blur.

There are several enabling aspects of relevant civilian systems which will grow rapidly in the future in response to both economic forces and scientific initiatives.

- **Sensor Technology.** The technology for sensors is often the most expensive and limiting factor for acquiring environmental data. These sensors and systems are now in the midst of a revolution-miniaturization with microelectronics, micropower technologies, sensing with fibre optical components, on board data storage and data compression, and compact, energy-efficient sources are a few of the driving technologies. Examples now in place include low cost environmental systems (The Earth System Science Pathfinder (ESSP)), very large multi-channel (~ 24,000 channels), multi-line (~ 10 six km) towed arrays for oil exploration, autonomous AUV's fused into sensor networks, and low-cost, long-life remote buoys.
- **Communication Systems.** Wide band digital communications systems using satellites and/or fibre optical cables are responding to the commercial demand for video-level bandwidths. The Navy requirements are relatively modest and will not greatly influence the evolution of these systems. However, their availability enables sensor fusion and data assimilation at unprecedented scales. Command and control considerations will continue to dictate that the Navy use secure military systems for its critical components so it is imperative that it distinguish those data which are needed in the event of the unavailability of civilian systems. There are also some unique Navy requirements – wide band communication with submarines and long range, and high data rate acoustic telemetry. A new consideration is that an adversary potentially can exploit the same data available from civilian systems which was not possible in the past.
- **Computer Networks.** The capabilities of the Internet and the World Wide Web are now well known and the Navy systems are already involved in exploiting this capability in both open and classified contexts. The challenge will be to identify and assimilate them to create a knowledge base which provides an enhanced

capability for the Navy to perform its various missions. The challenge is significant. The amount of data now available world wide is enormous, diffuse and chaotic; the accuracy and reliability of the data are typically unverified; the formats and architectures are not standardized; access is unmonitored; and broad access to important databases is not ensured. There are also robustness to failure and latency issues where the demands for speed and reliability of command could not tolerate the relatively unstructured redundancy and discipline on the WWW. Nevertheless the Navy must develop the capability to address all these issues if it is to exploit the full potential available from civilian sources.

- **Algorithms.** To turn knowledge about an environment into a capability requires dynamical algorithms for interpolation and prediction. The development of these algorithms and, just as importantly, an evaluation of their reliability is a critical issue in exploiting the wealth of data available from civilian sensors. Some of these algorithms, just as some aspects of weather forecasting are symbiotic with civilian needs, will be developed simply because of their economic consequences. Unique Navy needs such as real time prediction of the underwater environment and forecasting in remote areas must be developed and evaluated with the same scrutiny which economic forces impose.

Some of the risks and disadvantages associated with the use of civil systems for meteorology, intelligence and oceanography were cited above. While it is essential to exploit civilian systems for providing needed information, the development of a dependence upon these systems brings considerable risks. For example, while the Internet was designed to be highly fault tolerant-point to point communications can be established through nearly an infinite number of pathways – the network is vulnerable to failure of major nodes at critical times as evidenced by the recent partial shutdown of a single server in the Northeast U.S. "Essential" data could become unavailable at critical times. In fact, it is conceivable that a network could be disabled through covert action. Given that other than limited warfare is highly unlikely during the coming decades, the network, including satellite linkages, will not be globally vulnerable, but limited interruptions are possible and can be expected routinely. These network outages may not be very important for several classes of information, but will be problematic for "perishable" data.

While the popularity of the WWW and access through "browsers" have grown greatly in the past five years and many organizations now make data and information available through this medium, there remain vast databases of information which are largely or completely inaccessible through the WWW. Normal practice, for example, shields data collected by civil systems from general use. Data from NASA satellites and spacecraft are made available only to the teams of Principal Investigators; scientists supported by the Office of Naval Research and the National Science Foundation regularly sequester their collected data for two years following collection. A major cultural change is needed within the scientific community to make all these data more available following collection while respecting the rights of the PI's.* The Navy will likely find itself in the unusual position of recommending an "open skies" access to data collected globally!

Many government agencies, particularly abroad, have elected to recover the costs of data collection by charging for the data. Everyone is familiar with the costs of accessing LandSat, RadarSat and SPOT data, but future and current plans include charging for SAR data from ERS-1/2 and even meteorological data previously freely available through the WMO. If this benighted approach continues unabated, the costs of accessing CTM data will escalate and, conceivably, substantial budgets will be required to access the needed data.

The capabilities for potential adversaries to acquire ISR data is also increasing at a rapid rate. Some of the data can be acquired on the WWW; however, critical data can be purchased from commercial systems while several nations are launching their own capabilities. This raises the specter of intelligence warfare with a significant civilian component

**The academic community must adapt to the use of expensive, large-scale observatories.*

RECOMMENDATIONS

WE RECOMMEND THAT:

1. SPAWAR should act as the Navy focus for exploitation of CTM for operational purposes.

2. A dedicated civil organization such as CORE should maintain an ongoing assessment of civil data sources for potential use in operations. This would require periodic assessments of civil capabilities similar to those presented in this report and an evaluation of success in access and use of such data.

3. SPAWAR and the Oceanographer's Office should identify and, with fleet commands, sponsor several experiments which compare environmental assessment capabilities within the Navy with independent approaches that would be used in the civil community. These assessments would be directed to the support of land operations, e.g.,
   - Covert SOF ops
   - Marine incursions in local crises

4. ONR should sponsor scientific investigations, algorithm development, instrument development and testing, and communications methodologies to fill information deficits either to search the civil data bases identified in (3) for militarily relevant information, or through innovative use of civilian sensors. The use of civil sensors (e.g. satellites, buoys, acoustic arrays) in this work would encourage the full participation of the university research community.

5. ONR and SPAWAR should establish a program to determine the limits of acoustic processing gain which can be achieved through the incorporation of overhead-derived knowledge.

- SPAWAR and the Oceanographer's Office should evaluate the use of civilian overhead systems as long term observational tools.

Overview of the Meeting

Dr. Edward A. Frieman

Overview

Origin

- Discussions with Jim DeCorpo re potential Navy uses of upcoming civil systems

Trends

- Concern for environment on global scales growing
- Growing capability-sensors, high speed comms
- Internet, database management, computing

General Plans

- Variety of systems, no coherence
- Separate international observing systems for oceans, land, climate, atmosphere, etc.
- Investigate strategy for integrating these

U.S. Monitoring Plan-Integrated Observing Capability

- National Environmental Monitoring Initiative – $650 million spent now, V.P. Gore wants report card on state of U.S. environment
- NASA Earth Observing System/Mission to Planet Earth/cooperative satellite programs with France, Japan, etc.
- NPOESS-convergence of DoD-NOAA metsats with NASA help
- MEDEA-use of classified assets for environmental issues
- International Research Institute – El Niño related long-range climate prediction
- Integrated Global Observing Strategy, IGOS-link GOOS, GCOS, GTOS, CEOS, others

Navy Grand Challenges/ONR

- Environmental adaptability
- Wave front coherence
- Adaptive environmental assessment
- Downward extrapolation
- Targeted observations
- Predictability extensions
- Knowledge synthesis

SYNTHETIC APERTURE RADAR INTERFEROMETRY

Bernard Minster

This summary is extracted in large part from the LightSAR Science requirement document prepared by the Light SAR Science working Group, and from the ECHO proposal.

INTRODUCTION

Over the past two decades, space geodetic techniques, in particular GPS, have proved a powerful way to study movements and deformations of the surface of the Earth, leading to major advances in quantitative modeling capability. But these measurements lack spatial continuity and require field equipment at each study site. Recent technological advances in spaceborne radar interferometry permit observation of mm-level surface deformation at 25 m resolution with worldwide accessibility. Derivation of the first differential interferometric maps of the co-seismic displacement of the June 28, 1992 Landers earthquake (Massonnet *et al.*, 1993; Zebker *et al.* 1994) has arguably been the most exciting recent result in earthquake geodesy. Nevertheless, at the present time, civilian spaceborne differential interferometry remains primarily a demonstration tool, because no mission dedicated to that purpose exists.

In the past two years, two civilian US SAR missions have been proposed:

1. The Earth Change and Hazard Observatory (ECHO) has been proposed to the NASA Earth System Science Pathfinder program (ESSP). It involves a Synthetic Aperture Radar satellite dedicated to a single measurement: repeat pass radar interferometry. ECHO's mission to map Earth's tectonically active areas and cryosphere to mm displacement accuracy is unlike that of any past, existing, and planned sensors. By focusing on a single measurement by a radar instrument with considerable design heritage, the mission will be low cost and low risk, yet will provide wide-area maps of vector deformation and ice motion that can lead to new discoveries in earthquake and volcano boundary physics for hazard research, and in ice dynamics and mass balance for longterm climate variability studies. Innovations in orbit control and ground system design will lead to efficient, timely data distribution and usage. ECHO will pave the way for future low cost SAR missions for Earth studies.
2. A high technology, low cost Spaceborne Synthetic Aperture Radar (LightSAR) Mission. In addition to being a technology demonstration mission, LightSAR is intended to be accomplished by a partnership of Government, Industry, and the scientific community. The LightSAR Science Working Group (LSWG) has analyzed the science requirements of such a mission, and its recommendations will be presented here. These incorporate previous recommendations and take into account more recent scientific results and emerging applications. Recommendations are made in the context of key science questions within NASA's Office of Mission to Planet Earth (OMPTE) that can be addressed with SAR data. They also take into account the existing and currently planned SAR systems shown in Table 1.

BACKGROUND

SAR data provide unique information about Earth's surface and biodiversity, including critical data for natural hazards and resource assessments. Unique SAR interferometric measurement capabilities, predominantly large scale surface change at

Table 1: Current and Planned SAR Systems

PARAMETER	ERS-1	ERS-2	SIR-C	X-SAR (FLOWN WITH SIR-C)	RADARAT	ENVISAT (ASAR)	JERS-1	PALSAR	MIR-PRIRODA	ALMAZ-1	MITTI SAR-2
Radar Band	C	C	C,L	X	C	C	L	L	L,S	S	L
Polarization	VV	VV	ALL	VV	HH	HH/VV/HV	HH	HH or VV HV or VH	*	HH	HH
Incidence Angle (deg.)	24	24	17 - 60	17 - 60	17 - 50	20 - 45	35	20 - 55	35	30 - 60	20 - 45
Resolution (km)	25	25	25	25	10 - 100	30	18	10 - 100	*	15	10 - 100
Swath Width (km)	100	100	15 - 100	15 - 40	50 - 170 (5 km in scansar)	50 - 400	76	70 - 250	120	20 - 45	50 - 500
System Sensitivity (dB)	-25	-25	-50	-22	-23	*	-20	-25	*	*	-25
Altitude (km)	790	785	225	225	790	800	568	700	394	300	700
Simultaneous Frequencies	1	1	3	3	1	1	1	1	2	1	1
Simultaneous Polarizations	1	1	4	4	1	2	1	2	*	1	1
Orbit Inclination (deg.)	97.7	97.7	57	57	9.6	100	97.7	98	51.6	72.7	97.7
Bandwidth (MHz)	13.5	13.5'	10,20	10,20	12 - 30	14	15	30	*	*	50
Data Rate (Mbps)	165	165	90 or 46/channel	45	110	100	60	240	*	*	240
Launch Date	July 1991	April 1995	April/Oct. 1994	April/Oct. 1994	Fall 1995	Late 1998	February 1992	August 2002	1995	March 1991	2001
Lifetime (years)	3	3	11 days	11 days	5	5	2 minimum	3 - 5	2	2.5	3 - 5

fine resolution, are required to monitor surfaceto-pographic change, to monitor glacier ice velocity, and in many instances to generate critical topographic datasets. Recent publications have documented the contributions of interferometric radar to studies of earthquake mechanisms, volcanological-hazard assessment, and refined measurements of the global ice mass balance upon which an understanding of climate change depend. These interferometric observations form the core operational priorities of the proposed mission.Analysis of data from the Spaceborne Imaging Radar and X-band Synthetic Aperture Radar (SIR-C/X-SAR) indicate that multiparameter (wavelength and polarization) SAR data can provide accurate land-cover classification and forest growth estimates, biomass estimation, mapping of wetlands, measurement of snow density, soil moisture, and surface roughness, characterization of oil slicks, and monitoring of sea ice thickness. While optimal frequencies and polarizations for these measurements depend on the specific application and, in some cases environmental conditions, the more limited multiparameter data set provided by LightSAR should nonetheless contribute to research in this area.

For interferometric SAR observations it is necessary to optimize the wavelength of operation against temporal decorrelation, instrumental sensitivity, and radar brightness for many surface terrains. With years of European Remote-sensing Satellite (ERS) and Japanese Earth Resources Satellite (JERS) SAR data acquired, volumes of multi-frequency multi-polarization SIR-C/X-SAR data analyzed, and the prospect of new advances from the multi-mode Radarsat observations, it has become clear that the longer wavelengths such as L-band are best suited to our identified repeat pass interferometry threshold science measurements, where the radar return is relatively insensitive to local changes on the surface. Reduction of SIR-C/X-SAR data show that this wavelength is also a good choice in polarimetric consideration. L-Band multi-temporal and multi-polarization measurements best provide capabilities to monitor changes in i) biomass due to forest regeneration, ii) soil moisture levels, and iii) snow density. Thus the fundamental functional requirements for LightSAR specify L-band as the primary choice of frequency to meet the science objectives.

Threshold science requirements are defined as those which must be met in order to satisfy the needs of a significant segment of the science community. The LSWG recognizes that while SAR can supply valuable information in a broad range of Earth science disciplines, it is impossible to satisfy all science disciplines with the resources of a single affordable spaceborne platform. We have therefore selected a few key measurements which can provide the best scientific payoff. They take into account mission relevance, maturity of the derived data products, uniqueness of the measurements relative to other sensors that could provide equivalent information, and cost and complexity of the mission.

The LSWG concludes that the highest priority science objectives, balancing scientific need and relevance against cost and complexity, are those that can be accomplished by repeat pass interferometry with a single polarization, L-band (24 cm wavelength) SAR. These objectives include seismic and volcanic deformation mapping, vector ice sheet and glacier velocity mapping, topographic mapping and surface characterization, and hazard monitoring and assessment. The LSWG also finds that for the LightSAR mission to provide data to scientists studying the Earth's carbon and hydrologic cycles, a polarimetric capability is required. Specific objectives to be met here include monitoring forest regrowth, estimating soil moisture, and estimating snow density. Finally, a wide swath mode (250-500 km) is required for oceanographic applications- they would also benefit from dual polarization capabilities (HH and VV).

Finally, we characterize the science strategy for this mission by distinguishing between Research Science for which there exists a significant risk that success is elusive; Demonstrated Science for which there exists at least one instance of successful application of the method and the technology; Validated Science, for which results have been independently shown to be correct, qualitatively and quantitatively; and Operational Science, for which a systematic application can be contemplated. The strategy is then simply to seek to upgrade any scientific application to the next level of maturity.

SCIENCE OBJECTIVES

The science objectives for the LightSAR mission are grouped into a broad range of scientific disciplines. These groups are by no means encompassing but represent specific areas where there is an immediate and obvious need for data. These disciplines are listed below in approximate priority order according to the principles discussed above.

The coverage requirements for the science targets relying on repeat pass interferometry as the technique of choice involve approximately 10% of the emerged land area. This generates a duty cycle requirement of 5-10 minutes (average) per orbit, resulting in a few 100 Tbytes of data over the duration of a 3-5 year mission.

NATURAL HAZARDS

Over the past two decades, space geodetic techniques, in particular GPS, have proved a powerful way to study movements and deformations of the surface of the Earth, leading to major advances in understanding. But these measurements lack spatial continuity and require field equipment at each study site. Recent technological advances in spaceborne radar interferometry permit observation of mm-level surface deformation at 25 m resolution with worldwide accessibility. Derivation of the first differential interferometric maps of the co-seismic displacement of the June 28, 1992 Landers was arguably the most exciting recent result in earthquake geodesy. Nevertheless, at the present time, civilian spaceborne differential interferometry remains primarily a demonstration tool, because no mission dedicated to that purpose exists. High-priority scientific goals of LightSAR are, 1) to refine our understanding of the earthquake cycle through mm-level interseismic and coseismic vector deformation maps along faults and plate boundaries, 2) to monitor volcanoes for new activity and potential eruptions through mm-level deformation maps, 3) to support additional natural hazards research using SAR as a rapid and weather-independent monitoring tool.

Crustal Deformation

The most challenging scientific goal for LightSAR is mapping slow Earth deformations. This includes the interseismic accumulation of strain leading up to earthquakes, as well as transient post-seismic strain relaxation following earthquakes. The main issue is that such signals are subtle, with mm-sized displacements and long wavelengths vulnerable to systematic measurement errors. The accumulation of strain in the earth's crust is the first order indicator of future seismic hazard. The mission should allow the repeated measurement of surface change in seismically active areas along all continental margins as well as accommodating world-wide accessibility to account for targeting on new and previously unidentified areas of study. Temporal coverage should support an interval of 8 days for any particular area, or 24 days for all areas. We also require a surface displacement resolution of 2-5 mm statistical height error to track and model wide area deformation during and between major earthquakes. Specific high priority zones should be imaged every orbit if possible, while other areas can be imaged no fewer than 4 times per year The imaging must be accomplished from ascending and descending tracks, and looking to the right and left on orbit, in order to construct vector deformation fields.

Volcanic Hazards

The major observations in volcanology to be obtained by LightSAR are, 1) the spatial and temporal extent of deformation preceding and accompanying eruptions, key observables constraining models of magma migration, and 2) the spatial extent of new material produced during an eruption, derived from image decorrelation, an important diagnostic of the eruption process. As in earthquake studies, the mission should allow the measurement of surface change in volcanically active areas on an interval of 8 days for any particular area, or 24 days for all areas, with a surface displacement resolution of 1-3 cm statistical height error to track and model ground deformation prior to, during, and after volcanic eruptions or intrusive events. Surface change caused either by the emplacement of new lava flows or by the collapse of volcanic craters, should also be studied via the decorrelation of radar phase information at a spatial resolution of ~25 m/pixel. Specific high priority volcanoes (e.g., those in eruption or experiencing a "volcanic crisis" prior to eruption) must be imaged as often as possible (every orbit), while other areas should be imaged no fewer than 4 times per year (See coverage/frequency map). The imaging must be accomplished from ascending and descending tracks, and looking to the right and left on orbit, in order to construct vector deformation fields and to provide the greatest temporal resolution of time-varying events.

Other Hazards

LightSAR data will also be used to study a number of other natural hazards. Since floods build with time, frequent revisitation and weather-independent images will be used to plan for flood mitigation. Post-flood images will be used for quantitative damage assessment, and may be useful for rapid assessment during the immediate post-flood period when the area may still be cloud covered from continuing storms. For the same reason, SAR images may also be useful for rapid damage assessment after major hurricanes, when cloud cover and damaged infrastructure (telephones, roads, bridges) make conventional surveys difficult. Correlation measurements of landslide-prone areas will be used to detect early signs of incipient ground failure, and help assess the size and destructive potential of such events. Documenting the evolution of the correlation signatures will provide insight for physical models of the disasters, and for formulating mitigation strategies. LightSAR will also measure surface change caused by human activity, such as subsidence due to fluid withdrawal from aquifers or hydrocarbon reservoirs. Requirements for meeting these objectives are included in those presented in the previous two sections.

ICE-SHEET MASS BALANCE AND SEA LEVEL

Sustained development of coastal areas worldwide has made the global economy extremely vulnerable to changes in sea level. Ice sheets and glaciers contain a frozen reservoir totaling nearly 80% of the world's fresh water and are the primary source of future sea level rise. While the general retreat of mountain glaciers globally is believed responsible for approximately one-quarter to one-third of the current 2 mm/yr. increase in sea level, the majority of the remainder remains unidentified but likely is the result of yet undiscovered imbalances in the large polar ice sheets. Accordingly, the role of ice sheets and glaciers in the global water cycle, especially their impact on future sea level is a critical goal in the Long-term Climate area of the MTPE Science Research Plan.

There are three specific measurements that LightSAR will be able to make that will contribute significantly to this goal. The first two, glacier and ice-sheet velocities and topography are direct products of the interferometric capability of LightSAR. The third, monitoring of critical margins of ice sheets and glaciers utilize single polarization amplitude SAR data. With the exception of the now-concluded ERS-1/2 tandem mission, there are no current or planned SAR interferometric missions to provide the first two types of measurements and with the exception of the upcoming Radarsat Antarctic Mapping Project (RAMP) lasting only 18 days there is no SAR satellite designed to view the vast majority of Antarctica where over 90% of the earth's ice reservoir exists.

Glacier and Ice-Sheet Velocities

Ice velocity is the fundamental parameter representing the dynamics of ice. It can be compared with "balance" velocities (determined from a real integration of the snow accumulation) to assess the state of equilibrium of any ice mass, or portion of an ice mass. Even in the absence of accumulation data, the magnitude and direction of ice flow is critical input to dynamic models of ice flow and, when compared with surface topography, can identify regions that are far from equilibrium.

The mission should allow interferometric measurements from ascending and descending passes and from north and south viewing directions to provide the full velocity vector over the greatest portion of the ice sheets possible. The mission should allow for surface deformation measurements as rapidly as possible consistent with constraints imposed by other science objectives such as coverage and signal to noise ratio (SNR). The longest allowable repeat interval for ice objectives is 8 days.

L-band interferometry has been successfully demonstrated on glaciers with SIR-C, but not over the drier snow on ice sheets. In terms of the expected sensitivity to ice displacement, an 8-day repeat cycle at L- band compares with a 2-day repeat cycle at C-band. Thus, displacements will be twice what has already been measured with the highly productive 1-day ERS-1/2 tandem data set. Based on the experience with tandem data, longer repeat periods will limit the ice areas over which displacements can be measured due to phase unwrapping difficulties. The accuracy of the LightSAR interferometric motion product will be better than 1 m/yr, compatible with GPS measurements which will help control the final velocity fields. It is estimated that a global coverage of ice velocity would require about 150 hours of SAR data, preferably from early fall to late spring, and should be undertaken once every other year. Only 90 hours of coverage would be required for these subsequent mappings with an additional 10 hours in the even years to monitor variable glacier behavior.

Ice Surface Topography

The second interferometric product of ice sheets and glaciers is surface topography. Surface topography determines the magnitude and direction of the gravitational force driving the ice flow. As such, the detailed shape of the ice sheet determines the boundaries of individual drainage basins contained within the ice sheet. In addition, the undulated character of the ice-sheet surface provides proxy evidence for whether the ice flow is dominated by ice sliding over a well lubricated bed, or whether the ice is frozen to the subglacial bed. Finally, the complete elevation field can be an invaluable aid to the interpolation of laser altimetry (e.g., EOS GLAS) which inherently only measures elevations along very narrow corridors across the ice sheet.

With repeat-pass interferometry, surface topography and ice velocity are both contained in any single interferogram. However, because the displacement due to surface topography is fixed in time but motion displacements accrue, sequential interferograms can separate these two essential data sets by a technique known as double-differencing. Interferometric data for double-differencing and averaging would require about 8 complete mappings the first year with less data in remaining.

Ice Sheet and Glacier Boundaries

This is the most direct approach to detect change, but most challenging in deducing the cause of that change given the delayed response character of slow-moving ice. Nevertheless, SAR holds the advantage of viewing through clouds--frequently persistent at the edges of ice sheets and in mountainous terrain. By regularly imaging (once every 3-5 years) the Greenland and Antarctic Ice Sheets, LightSAR can contribute to building an unprecedented series of snapshots documenting the short term evolution of the ice sheet. This objective is particularly germane given the recent and unexpected disintegration of large portions of ice shelves in the Antarctic Peninsula. Planimetric accuracies required for the intercomparison are about 100 m. Twenty five meter resolution imaging with a SAR instrument would require about 30 hours of data distributed over a 30 day window once every 2 years.

In order to advance each one of these application to a new level of maturity, It is necessary for a new civilian SAR mission to overcome limitations of existing sensors and spacecraft. Comparison of the proposed mission to existing ones shows how this improvement is achieved. In addition, the need to achieve reliable interferomatric fringes over a variety of terrains, with different land covers, mandates the use of L-band for practical purposes. Finally, in order to guarantee that the majority of scene pairs taken during successive passes are in fact usable for interferometric processing requires tight orbit control, and extremely accurate orbit reconstruction.These goals can be achieved with an onboard GPS receiver.

The science goals listed above are practically identical to those listed for the simpler ECHO mission. LightSAR, as a multi-mode instrument, permits us to address a number of other science goals, for which polarimetry is an essential capability.

The Carbon Cycle

The global carbon cycle, especially as it relates to CO_2 and its important role as a greenhouse gas is fundamental to the study of Earth's climate. SAR contributions to this include, 1) quantifying the current rates of exchange of carbon dioxide between the atmosphere and the oceanic and terrestrial sources/sinks of carbon; 2) understanding how changes in climate and the concentration of carbon dioxide will influence patterns of vegetation distribution and regrowth after disturbance; and 3) estimating how changes in climate will influence processes controlling patterns of carbon storage in terrestrial ecosystems, particularly in organic soils in high northern latitudes. While much previous work has focused on remote sensing systems operating in the visible and near-infrared region of the EM spectrum (e.g., MODIS, Landsat), research has also demonstrated that imaging radar systems provide useful information as well.

Notwithstanding the burning of fossil fuels, worldwide deforestation and afforestation practices are believed to have the highest impact on the net flux of greenhouse gases. Growing forests remove atmospheric CO_2 and sequester carbon in new or growing trees. The sequestration rate of carbon (biomass production) in tropical forests, for instance, could be as much as 10 to 20 tons/hectare per year. Natural disturbances to forests (such as fires, insects and diseases) which result in large-scale mortality release large amounts of carbon to the atmosphere. Anthropogenic activities (such as deforestation and afforestation) also strongly influence the atmospheric carbon budget.

Since carbon is stored in the form of biomass in forests, which is interdependent with factors such as nutrient fluxes, water availability, age of forest, and temperature, monitoring the changes in biomass provides a critical piece of information in understanding the global carbon cycle. Monitoring the other factors just mentioned is also important, to the extent that they influence the biomass variations. Balancing the carbon budget is still an unresolved issue. The biogeochemical cycles that determine the atmospheric concentrations of greenhouse gases are not completely understood yet. Regional and global land-atmosphere exchange lack long-term observations of biomass in order to provide a definitive answer to the global change question. Among remote sensing instruments, radar has been shown to have the unique abilities to respond to biomass over a usable range and give reliable temporal information, because it sees through cloud cover. For an L-band radar, biomass values of up to 150-200 tons/hectare have been successfully retrieved.

Forest Regrowth and Biomass

Land cover change is one of the fundamental factors perturbing the global carbon cycle. In the most recent IPCC assessment, conversion of forests to managed systems (pastures and croplands) in the tropics was estimated to release 1.6 (+/-) Gt C/y to the atmosphere. Conversely, the regrowth of the mid-latitude forests harvested a half-century ago may be absorbing 0.5 to 1.0 Gt C/y. In addition to identifying primary land conversion, successful efforts are underway using SAR to estimate regrowth in secondary forests, a key factor in carbon balances.

The SIR-C mission has demonstrated that a polarimetric L-band radar would enable monitoring patterns of forest regrowth following disturbance in many different forest ecosystems. The development of LightSAR, therefore, would enable MTPE scientists to develop operational approaches for addressing issues (1) and (2) above. To clearly separate areas of disturbance from undisturbed areas and to produce the requisite accuracies in a real extent, resolution of 25 meters is required. The mission should allow the measurement of forest regeneration in the worldwide belts of tropical, temperate, and boreal forest at yearly intervals over at least a three-year period. Each region should be imaged at the same time of year: high summer for the boreal and tropical forests and the dry season(s) for the tropics. Imaging should be completed in a period of less than one month to ensure that the resulting regional maps of forest regeneration are consistent. Areas should be imaged at the same time of day, to minimize measurement uncertainties due to the diurnal cycle. The imaging can be accomplished from either ascending or descending tracks, and looking to the right and left on orbit, in order to minimize the time taken to construct a regional image map. Look angles should be between 25 and 35 degrees. Imaging the world's tropical and boreal forests as specified here would require a total of 72 million square kilometers or 54 hours of data every year, roughly half of which would be collected between May and July, and half between October and December. This results in a peak rate of 1.1 minutes worth of data per orbit during those periods.

To successfully monitor changes in forest regeneration, results from the SIR-C mission have shown that a radiometric calibration uncertainty of less than 1 dB, a channel-channel radiometric uncertainty of less than 0.5 dB, a channel-channel phase uncertainty of less than 10 degrees, a polarization purity (or isolation) of -25 dB, and a noise-equivalent sigma-naught (in all four polarimetric channels) of less than -30 dB are required.

THE HYDROLOGIC CYCLE

The redistribution of solar energy over the globe is central to global climate studies. Water plays a fundamental role in this redistribution through the energy associated with evapotranspiration, the transport of atmospheric water vapor, and precipitation. Residence time for atmospheric water is on the order of a week, and for soil moisture, from a couple of days to months, which emphasizes the active nature of the hydrologic cycle.

Perhaps the most important role that the land surface plays in global circulation, is the partitioning of incoming radiation into sensible and latent heat fluxes. The major factor involved in determining the relative proportions of the two heat fluxes is the availability of water, generally in the form of soil moisture. The role of soil moisture is equally important at smaller scales. Recent studies with mesoscale atmospheric models have similarly demonstrated a sensitivity to spatial gradients in soil moisture.

Soil Moisture

Soil moisture is an environmental descriptor that integrates much of the land surface hydrology and is the interface for interaction between the solid Earth surface and life. As central as this seems to the human existence and biogeochemical cycles, it is a descriptor that has not had wide spread application as a variable in land process models. There are two primary reasons for this. It is a difficult variable to measure, not at one point in time, but in a consistent and spatially comprehensive basis. Also, it exhibits very large spatial and temporal variability; thus point measurements have very little meaning. The practical result of this is that soil moisture has not been used as a variable in any of our current hydrologic, climatic, agricultural, or biogeochemical models.

Over the past decade or so, much research into the use of remote sensing to measure soil moisture has taken place. It is generally accepted that the only way to measure soil moisture to a depth exceeding a few centimeters requires a microwave instrument operating at L-band or lower frequencies. Passive microwave measurements from low flying aircraft have proven measurement accuracies on the order of 3% volumetric soil moisture at spacial scales of a few tens of meters. Unfortunately, similar instruments operating in space require large antennas, presenting a significant technological challenge. Even if this technological challenge could be overcome, the resolution of these instruments will be limited to tens of kilometers. Given the large spatial variability of soil moisture and land cover over spatial scales much smaller than tens of kilometers, it is unclear how the resulting measurement would be related to the soil moisture at any given point inside such a large pixel.

Active microwave instruments provide an alternative way of measuring soil moisture. To estimate soil moisture from active microwave measurements, one has to separate the effects of surface roughness and soil moisture, making this generally a more challenging problem that the passive microwave case. However, several algorithms have been developed, ranging from empirical models to ones based on complex electromagnetic scattering theories. All these algorithms seem to give similar results, with proven accuracies, compared to *in situ* measurements, of on the order of 4% volumetric soil moisture at spacial scales of a few tens of meters. More importantly, at least one of these algorithms have been applied to SIR-C data over the Washita site in Oklahoma, and the accuracy was verified with spaceborne data.

NASA/MTPE-sponsored research using the ERS SAR has demonstrated that spaceborne SAR systems can be used to monitor relative changes in soil moisture in fire-disturbed boreal forests. In these biomes, soil moisture is a key parameter in the estimation of rates of soil respiration. It has been estimated that climate warming will result in significant increases in soil respiration and release of carbon to the atmosphere in these biomes (thus, the ability to monitor variations in soil moisture is essential for estimating future fluxes of carbon. Polarimetric capabilities are required to separate the effects of changes in soil moisture from changes in biomass and surface roughness. This will significantly improve models of soil respiration in this region.

The development of an instrument such as LightSAR would provide an invaluable opportunity to move the measurement of soil moisture from the experimental to the operational phase, and to continue to extend the current algorithms to include areas with vegetation exceeding Normalized Difference Vegetation Index (NDVI) of 0.4. To accomplish this requires LightSAR, 1) operates at L-band or lower frequency – many experiments have shown that the estimated soil moisture for L-band frequencies correlate best with *in situ* measurements of soil moisture in the top 5 cm of the soil; 2) measures backscatter simultaneously at least at HH and VV polarizations – two measurements are required to separate the effects of surface roughness and soil moisture, full polarimetric capability is preferred but not required; 3) has a spatial resolution of 100 m or better to adequately sample the spatial variability in soil moisture; 4) has repeat observations of the same area at least every 8 days to adequately sample the temporal variability of soil moisture; and 5) repeats observations of the same area at as close as possible to the same time of day to minimize the effect of the diurnal variation in soil moisture on the measurement - predawn observations are preferred, but not required.

The redistribution of water is governed partly by atmospheric circulation. In recent years, models have been developed to trace circulation through space and time. Topographic roughness is a key parameter for such models, but one for which mapping data are mostly lacking. The ability to map large areas based on the radar backscatter coefficient was demonstrated by SIR-C for L-band. The application of this technology to refine circulation models will enable better understanding of water vapor transport, as well as general atmospheric motions.

Snow Properties-Snow Cover and Snow-Water Equivalence

Traditionally satellite data have been used extensively to map snow-covered area, i.e., to determine whether a pixel is snow-covered or snow-free. In clear weather snow is mapped best by optical sensors. A C-band dual-polarized SAR can map snow about 80% as well as the Landsat Thematic Mapper in all weather conditions, and a SAR can detect whether the snow is wet or dry. Data about snow-covered area are incorporated into operational snowmelt forecasting schemes, but the snow-covered area may not be a reliable indicator of the amount of water stored in the snowpack.

The most fundamental snow property, in terms of water supply forecasting, is the snow-water equivalence-the total amount of water the snow would yield at a point if it melted. Traditionally this variable is measured at several hundred snow courses throughout the mountainous regions of the western U.S. However, these snow courses do not adequately sample the terrain's variability-they are all on flat ground-and simple interpolation between snow courses does not produce useful results. Hence, the traditional snow-course data provide only an index to the amount of water in a basin. They do not provide data that are accurate enough to calculate a water balance for the basin.

Hence there is a need to estimate the spatial distribution of snow-water equivalence, and its basin-wide integral. Experiments with SIR-C/X-SAR data show that direct measurement of snow-water equivalence is now within our technological capability. The technique requires dual-polarization L-band data to estimate snow density, along with C-band data to estimate depth. The product of depth and density is the snow-water equivalence. Density does not vary rapidly, so the L-band and C-band measurements do not have to be simultaneous. Thus, C-band data from Radarsat or ERS/ENVISAT can be used.

With accurate estimates of snow-covered area, detection of melting snow, and the measurement of the spatial distribution of snow-water equivalence, we will be able to better forecast melt on short and season-long time scales. Such forecasts will improve the management of reservoirs in areas of snowmelt runoff, and thus improve the allocation of water for agriculture and other uses.

Tropospheric Water Vapor Measurements

Another application of SAR observations has attracted much interest recently: SAR interferograms frequently contain artifacts associated with lateral variations in tropospheric water vapor. This means that they may in principle be used to map the distribution of integrated tropospheric water vapor within a scene. Coupled with ground-based GPS observations, this offers excellent potential for collecting a novel type of calibrated meteorological data.

VG #25 shows the phase difference (line of sight millimeters) between two ERS Tandem interferograms. Horizontal axes are approximate kilometers in range and azimith. North is ~11 degrees to the left of up. The first interferogram is from SAR images taken in December 3 and 4 of 1995 while the second is from SAR images taken on January 07 and 08 of 1996. Since the time intervals do not span any tectonic event, the difference should be zero. The overall trend may be due to orbit error but this is not a unique interpretation. On the other hand, the corregated pattern is due to atmospheric delay, as can be corroborated based on an AVHRR image from Dec 4 which shows this pattern.

THE ROLE OF THE OCEAN IN CLIMATE CHANGE

Synthetic aperture radar images of the oceans contain a very large amount of information on both coastal and deep-ocean physical processes. This information is varied and impacts a rather wide variety of scientific oceanic disciplines. However, in the context of a global oceanic mission for LightSAR, probably the most significant is the role of the oceans in climate change. The importance of this role has been established by numerous national and international publications and has led to major observational and theoretical programs. These research activities will continue well past the lifetime of LightSAR and thus their objectives can be enhanced by SAR information.

The world is oceans play an exceedingly important role in establishing global weather and its long term average, climate. The oceans have the only significant heat capacity on the surface of the Earth, because (a) water has the largest specific heat of any known substance (save one), and (b) the seas cover 71 percent of the surface of the planet. The land heats up and cools down on diurnal time scales, and the atmosphere is far too tenuous to store heat in any concentration. Thus if significant amounts of solar energy are to be stored or released on time scales exceeding a very few days, the oceans must be looked to for the mechanisms of retention and release; they are well-known to provide those mechanisms.

Air/Sea Interaction and Ocean Climate Dynamics

Synthetic aperture radar images have recently been shown to display signatures of very important processes entering into air/sea interaction, by way of changes in small-scale surface roughness. Although the roughness modulations are often small (of the order of a very few percent), they nevertheless are quite apparent in the imagery and indeed, often mirror significant and extensive dynamics. For example, it is the interaction between the planetary boundary layer of the atmosphere and the upper ocean that establishes the interchange of heat, momentum, and moisture in both the lower and upper atmospheric. And it is those fluxes that must be determined if we are to understand such processes as control the mean temperature of the Earth, its humidity and cloudiness, and the amount of carbon dioxide in the atmosphere. Changes in long-term heat storage and release are major factors in the establishment of climate variability. While problems such as increases in carbon dioxide concentrations in the atmosphere are clearly important, it must be remembered that water vapor is a more radiatively active gas than carbon dioxide and is much more variable in time and space.

Much, if not most of the air/sea interchange occurs episodically during storms and high-wind events. During these events, the surface of the sea is hidden from remote sensors such as visible and infrared scanners because of cloud cover. Furthermore, ship and buoy-based measurements are inhibited or even compromised during such heavy weather episodes. Thus it is not presently possible to make accurate observations during those times when the physics is most active. It is at these times that spaceborne SAR provides views of the sea surface that are difficult to obtain by any other means.

The most important LightSAR requirements for oceanography are, 1) a wide swath – 250 to 500 km, because the spatial scales of the important processes are well in excess of the so-called oceanic Rossby radius of deformation (typically 50 km at mid-latitudes); 2) dual polarization (HH and VV), because of the possible of delineating atmospheric fluxes via differences in signatures in the two polarizations; 3) repeated observations of the non-stationary processes at work are required on repeat time of the order of a week. Both open-ocean and coastal observations are desired, the latter because many important mechanisms go on near to the edge of the continental shelves. Also, in coastal regions, many features visible in SAR images are useful to fishing, boating, shipping and offshore oil interests.

The climate-oriented observational program would likely concentrate on a few areas of the ocean known to be important: the Gulf Stream, the Greenland/Labrador Seas, the Norwegian Sea, and the Pacific Equatorial Current systems (this is an example of a tropical region). Observations would be focused on places and times when other relevant ocean research programs were taking place, thus leveraging the resources and providing ìsea truthî to the SAR. The details of the observational strategy to be used by LightSAR will depend on these *in situ* programs.

SENSOR REQUIREMENTS

FREQUENCY

An L-band sensor is required for repeat pass interferometry applications and surface characterization. (Traceability: Crustal deformation; Volcanology; Glaciology; Forest regrowth; soil moisture; snow density.)

CHANGE DETECTION

The mission shall include a mode of operation which will allow a 110 km wide strip of L-band HH image data to be acquired continuously at a resolution of at least 25 meters and a phase accuracy allowing a surface displacement resolution of 2-5 mm statistical height error over any swath, with any ground location visible every 8-10 days, and all ground locations visible every 24 days, with a minimum incidence angle of 20 degrees. (Traceability: Crustal deformation; Volcanology; Glaciology.)

MULTI-INCIDENCE ANGLE OBSERVATIONS

The mission shall include modes of operation which will allow observations ranging from 25 deg to 45 deg from nadir. (Traceability: Required for rapid site-revisit capability for earthquake and volcano deformation studies. Crustal deformation; Volcanology.)

POLARIMETRIC OBSERVATIONS

The mission shall include a mode of operation which will allow the simultaneous acquisition of the four polarization combinations: HH, HV, VH and VV. This mode shall have a spatial resolution of at least 25 m and a continuous swath of at least 50 km. (Traceability: Forest regrowth and biomass; soil moisture; snow density.)

WIDE SWATH MODE

The mission shall include a mode of operation which will allow 250-500 km swath to be imaged continuously with a spatial resolution of at least 100 m. This mode must be a dual (HH/VV) polarization mode. (Traceability: Ocean Feature and Mesoscale Eddy Mapping.)

ORBITAL REQUIREMENTS

INCLINATION

A polar orbit is required. (Traceability: Ice-sheet Mass Balance and Sea Level Objectives.)

REPEAT/REVISIT PERIOD

The revisit (exact repeat) time shall be 8-10 days. (Traceability: Crustal deformation; Volcanology; Glaciology Objectives.)

ORBITAL CONTROL

Sufficient orbital control is required to guarantee interferometric baselines less than 250 m. (Traceability: Crustal deformation; Volcanology; Glaciology Objectives).

ORBITAL KNOWLEDGE

<10 cm orbit knowledge within one orbit is required. (Traceability: Crustal deformation; Volcanology; Glaciology Objectives.)

OPERATIONAL REQUIREMENTS

MISSION DURATION

The LightSAR mission shall be designed for a 60-month (5 year) duration, equal to that of the spacecraft. (Traceability: Crustal deformation; Volcanology; Glaciology Objectives.)

DATA VOLUME AND RATE

The LightSAR mission shall be capable of acquiring at least 6 minutes of interferometry data per orbit on average, and 16 minutes peak. In addition, the LightSAR mission shall also be capable of collecting at least 1.5 minutes per orbit of fully polarimetric and/or dual-polarized data to meet the science objectives for monitoring forest regrowth and soil moisture monitoring. (Traceability: Crustal deformation; Volcanolog; Glaciology Objectives; Forest Regrowth And Biomass; Soil Moisture.)

REAL TIME MISSION PLANNING

Updates to the nominal timeline will require approval by a Mission Planning Board. Requests for new acquisitions to catch transient events will need to be accommodated. (Traceability: Crustal deformation; Volcanology.)

MODE-SPECIFIC REQUIREMENTS

RADIOMETRIC ACCURACY AND PRECISION

Relative amplitude calibration of 1dB is required. (Traceability: Forest regrowth and biomass; soil moisture; snow density.)

PHASE ACCURACY AND PRECISION

Phase calibration 10 deg. (Traceability: Forest regrowth and biomass; soil moisture; snow density.)

CHANNEL TO CHANNEL AMPLITUDE CALIBRATION

Channel to channel amplitude calibration of .5 dB is required. (Traceability: Forest regrowth and biomass; soil moisture; snow density.)

POLARIZATION ISOLATION

A polarization isolation of -25 dB is required. (Traceability: Forest regrowth and biomass; soil moisture; snow density.)

NOISE-EQUIVALENT σ_0

A noise-equivalent of σ_0 -30 dB is required across the swath. (Traceability: Crustal deformation; Volcanology.)

RECOMMENDED MISSION ENHANCEMENTS

DIRECT BROADCAST CAPABILITY AT X-BAND

An important consideration for the scientific community pertains to the ground operations and the process of data collection, distribution, and storage. An open skies" data collection policy, and a "free and open exchange" policy for data distribution would best serve science needs. The following discussion is taken *verbatim* from the ECHO ESSP proposal.

Ground Operations. ECHO presents a novel approach to ground operations rooted in a unique data distribution and access policy: *ECHO will provide free and open distribution of satellite data*, constrained only by project costs and the responsibility of the project to ensure adequate data coverage, availability, and quality. This is consistent with the EOS data policy and with the mode of operations planned for *EOSDIS*. We propose to contribute all ECHO data to EOSDIS in a timely manner, according to this policy. To that end:

- Data will be transmitted "live" as acquired at all times, and reception by any user is permitted without prior agreement with NASA.
- Data at certain downlink sites (see below) will be freely available on-line through the Internet for the scientific community.
- The project will establish a single archive depository for project-critical data.
- Raw data and software to process, calibrate, and validate the data are distributed, not high level data products.

The ECHO project will establish several downlink sites, and support operations at other sites. Any sites receiving support from ECHO will incur the responsibility to:

- save critical raw downlinked data, and ensure that the archive center receives a copy electronically or on tape;
- make any downlinked data freely available to the scientific community on line for a limited time after acquisition;

- participate in calibration and validation exercises as determined by the project; and
- ensure that data formats and quality conform to project standards.

Acquisition requests will be directed to the ECHO science team who will instruct the operations team as to priorities and conflict resolution. Acquisitions requiring on-board satellite recording of data for later downlink will be handled by a separate procedure from standard operations due to the additional planning required for spacecraft and ground resources.

Distributed downlink concept. ECHO will move away from centralized downlink and processing facilities and rely on a distributed downlink capability. ECHO will fund 5-6 new sites, with locations placed at centers of interferometric research where a vested interest in high quality observations exists. Ideally, these locations would be in critical areas of scientific interest, but they do not need to be uniformly distributed around the globe because the onboard storage capability of ECHO will buffer data taken in hard-to-access areas. Other interested users are welcome to add their own sites at their own cost, subject to the project guidelines for data quality and archiving. Approved sites will be linked by high-speed dedicated data lines. Acquired data will be written directly to disk and will be available on-line to any user for a limited time period after reception via *ftp*.

Several commercial companies are offering a new generation of X-band ground receiving stations at a cost approaching $500K, including a receiving system and interferometric processor. One possible configuration consists of a 5 m tracking antenna; custom or Atlanta Scientific demodulation and decoding boards; a small workstation for data handling; and a moderate workstation for interferometric processing

Operations cost will be low because very little processing is required at the receiving stations. Supported ground stations will be responsible for maintaining an anonymous *ftp* site for public access of acquired data, copying all project supported data to a low-cost storage medium such as DAT, and sending them to the central archive. These stations will ensure acquisition of all data to meet science objectives

Although agreements are not presently in place, we expect that ECHO will utilize existing X-band high rate stations operated by NASA, ESA, or others. Resources must be budgeted for support of these data takes.

Project-Supplied Resources: The ECHO project will construct a prototype receiving system and processing system that meets the functional requirements. While the project sets these functional requirements for station and processing systems, each site is responsible for implementation of these requirements, and can use the prototype hardware configuration that the project will develop, or a custom implementation of their own choosing.

The project will develop and make available a basic interferometric processing software package that will meet the functional product quality requirements. These programs will:

- form images, interferograms, correlation maps, and displacement maps;
- geocode products;
- estimate baselines – GPS state vector analysis and image derived baselines;
- calibrate products – corner reflector analysis code, tools for estimating temporal phase stability; and
- verify products – statistical package comparing ground truth GPS to interferometrically derived displacements.

Since the distributed system is a new concept, it involves nontraditional responsibilities for the site managers. Limited data for the ECHO user community must be acquired and data sent to the archive facility. All received data must be available publicly on-line for a specified period (probably 1-4 weeks) in raw form. Raw data quality must meet project standards and formats must conform to project guidelines.

ADDED FREQUENCY (C- OR X-BAND)

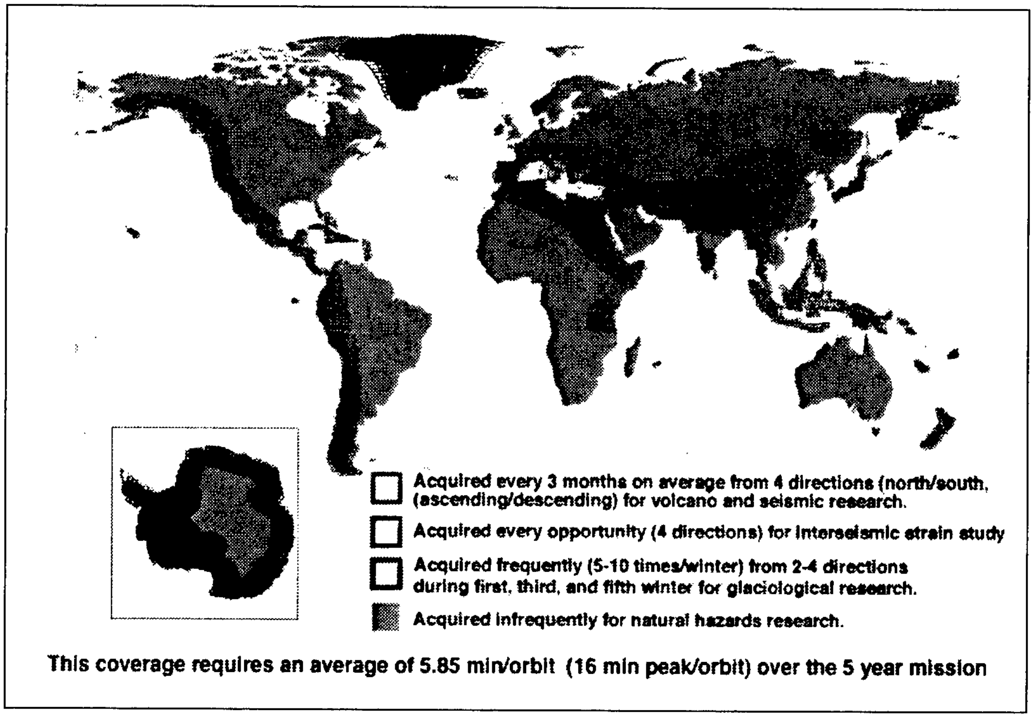


Figure 1: Samle Coverage Requirements.

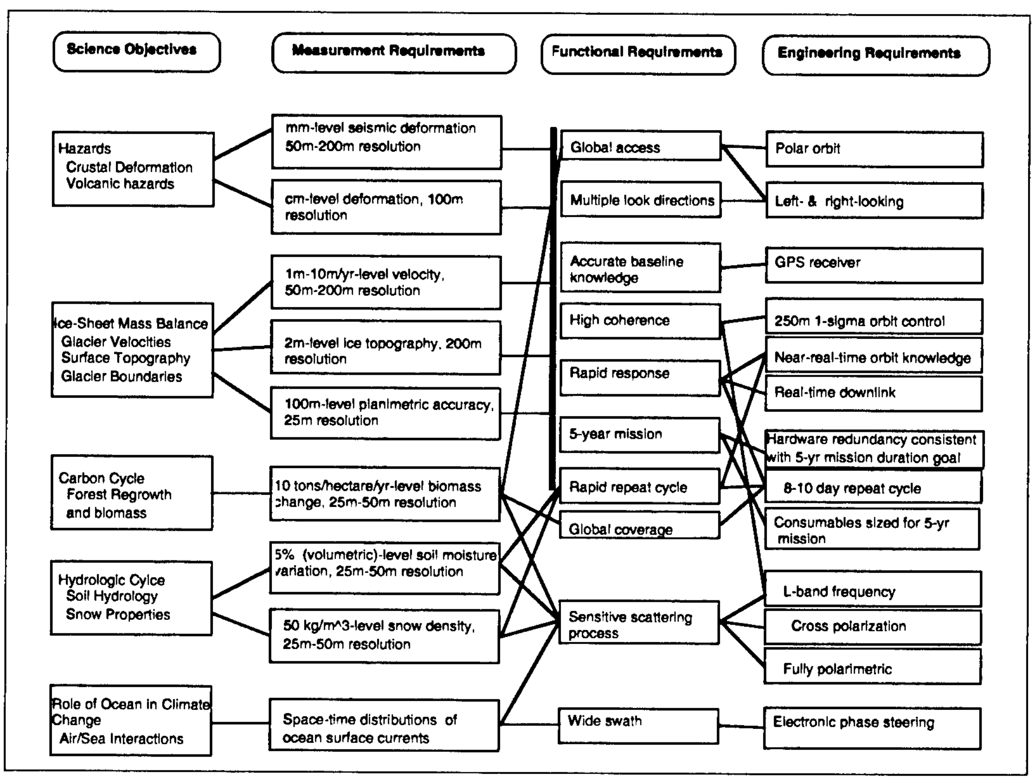


Figure 2: Flow from Science objectives to Requirements

Table 2: Examples of SAR Applications

GEOPHYSICAL PARAMETERS	ALGORITHMS AND MISSION PARAMETERS	MATURITY (I.E., READINESS FOR "OPERATIONAL" USE)
Surface Deformation	Repeat-pass interferometry within 1 month; L-band; orbit control	Validated (line-of-sight) Demonstrated (vector)
• **Pre-Seismic**	Multiple repeats (noise identification and reduction)	Research
• **Co-Seismic**	Pre- and post-coverage	Validated
• **Inter-Seismic**	Extended regional areal coverage (100s km) at low resolution (25m); long time series (yr.), regular repeats (mo.).	Demonstrated (Creep Zones) Research (Other Areas)
• **Pre-Eruptive**	Multiple repeats (noise identification and reduction)'	Research
• **Co-Eruptive**	Targeted coverage	Validated
• **Inter-Eruptive**	Long time series. Regular repeats	Demonstrated
• **Landslides**	Local coverage, high resolution	Demonstrated
• **Subsidence**	Regional and local coverage	Demonstrated
Other Geometrical Surface Changes (e.g., Lava Flow)	Long time series; regular repeats; L-band	Demonstrated
Glacier and Ice Sheet Velocity		
• **Ice Sheets**	L-band repeat-pass interferometry within 8 days, or C-band within 2 days, at latitude > 65∞	Demonstrated (L-band) Validated (C-band)
• **Glaciers**	Repeat-pass interferometry (1-2 days?) or pattern matching	Demonstrated
Glacier Volume and Topography	L-band repeat-pass interferometry within 8 days, or C-band within 2 days	Demonstrated
Forest Biomass		
• **Boreal**	L-band HV	Demonstrated
• **Temperate**	L-Band HV or P-band HV	Demonstrated
• **Tropical**	P-band HV	Demonstrated
Vegetation Classification		
• **Forest**	L-band dual-pol.	Research
• **Crops**	L-band quad-pol.	Research
Aerodynamic Roughness	L-band HV	Demonstrated
Vegetation Moisture	L-dual pol., or C-dual-pol. (+ species type ancillary)	Research
Soil Moisture		
• **Bare**	L-band quad-pol.	Demonstrated
• **Grass and Shrubs**	L-band quad-pol.	Research
• **Forest**	P-band quad-pol.	Research (Early Research?)
Snow Volume and Extent		
• **Snow-Covered ARea**	C-band HH + DEM, or C-band quad-pol.	Demonstrated
• **Wetness**	C-band quad-pol.	Research
• **Water Equivalence**	Density from L - quad-pol. + depth from C- or X-band	Research
Inundation and Extend (Floods)		
• **Forest**	L-band HH	Demonstrated
• **Non-Woody Wetlands**	C-band HH or VV	Demonstrated
Post Flood Inventory	C- and L-band HH and HV	Demonstrated
Oceans		
• **Ice Motion**	C-band HH and 3-day repeat	Operational
• **Ice Type**	L-band quad-pol.	Domesticated
• **Mesoscale Circulation**	L-band quad-pol.	Research

Appendix A

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APPENDIX C.

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APPENDIX D.

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NOAA SATELLITE PROGRAMS

Robert S. Winokur

SUMMARY

Space-based capabilities exist today for observing and understanding the ocean environment. Observations are taken operationally by the National Oceanic and Atmospheric Administration's suite of Earth observing/weather satellites. NOAA also ingests satellite data from many foreign spacebased earth observations systems, such as Canada's Radarsat, Japan's AdEOS and the European satellites ERS-1/2, Meteosat. In the near future, commercial systems will be launched with greatly improved spatial resolutions-on the order of a few meters as opposed to kilometers, which will further advance the field of oceanography.

TOPICS

- Status of NOAA Satellites
  - GOES
  - Polar
  - NPOESS
- International Satellite Programs
  - Present and Future Data Sources
  - CEOS
- Commercial Remote Sensing Opportunities

GOES AND POLAR PROGRAM OPERATIONAL POLICY

- Maintain 4 – spacecraft operational
  - 2 Polar
  - 2 Geostationary
- Fall back to single satellite coverage if outages of either system occur.
- Maintain available spacecraft in queue on ground*.
- Launch on failure of critical sensor (imager or sounder).
- Accelerate next launch call-up
- Launch call-up period
  - Polar – 150 days
  - GOES – 12 months (commercial)

**Exception: 1990-1994 due to development delay of GOES I-M and launch failure of GOES-G*

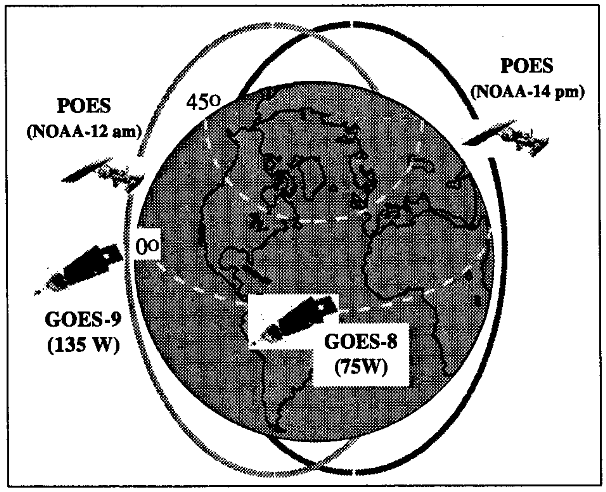


***Figure 1:** NOAA/NESDIS' Role in Space:*
- *Manages the nation's civil operational Earth-observing satellite systems.*
- *Provides environmental data and information critical to the national economy, national security and the protection of life and property.*

CURRENT GEOSTATIONARY SATELLITE INSTRUMENTS (NOAA GOES-8, GOES-9)

- Remote Sensing
  - Imager: 5 Channels
  - Sounder: 19 Channels
  - SEM: Space Environment Monitor:
    - Magnetometer
    - EPS and HEPAD – Monitor Solar Protons and Alpha Particles
    - XRS – Real-Time Measurements of Solar X-Ray Emissions in Two Channels (0.5 - 3 Angstroms, 1 - 8 Angstroms).
- Communications
  - Direct Broadcast: WEFAX, GOES-S Band (GVAR)
  - DCS: Data Collection System
  - SAR: Search and Rescue (SARSAT)

Current Polar Orbiting Satellite Instruments (NOAA-12, NOAA-14)

- Remote Sensing
  - AVHRR (Advanced Very High Resolution Radiometer): Imager
  - HIRS (High Resolution Infrared Sounder)
  - SSU (Stratospheric Sounding Unit): Sounder
  - MSU (Microwave Sounding Unit)
  - SEM (Space Environment Monitor)
  - ERBE (Earth Radiation Budget Experiment)
  - SBUV (Solar Backscatter Ultraviolet): Ozone
- Communications
  - Direct Broadcast
  - DCS (Data Collection System (ARGOS))
  - SAR (Search and Rescue (SARSAT))

NOAA K-N' Satellite Instruments

- Remote Sensing
  - AVHRR (Advanced Very High Resolution Radiometer): Imager
  - HIRS (High Resolution Infrared Sounder)
  - *AMSU-A (Microwave Temperature Sounder)*
  - *AMSU-B (Microwave Humidity Sounder)*
  - SEM (Space Environment Monitor)
  - ERBE (Earth Radiation Budget Experiment)
  - SBUV (Solar Backscatter Ultraviolet): Phone (PM Only)
- Communications
  - Direct Broadcast
  - DCS (Data Collection System (ARGOS))
  - SAR (Search and Rescue (SARSAT))

Table 3: GOES andPOES Imager Characteristics

Channel	Wavelength (μm) GOES	Wavelength (μm) Polar	Resolution (KM) GOES	Resolution (KM) Polar
1	0.52 - 0.72	0.58 - 0.68	1	1.1
2	3.78 - 4.03	0.725 - 1.0	4	1.1
3	6.47 7.02	3.55 - 3.93	8	1.1
4	10.2 - 11.2	10.3 - 11.3	4	1.1
5	11.5 - 12.5	11.4 - 12.4	4	1.1

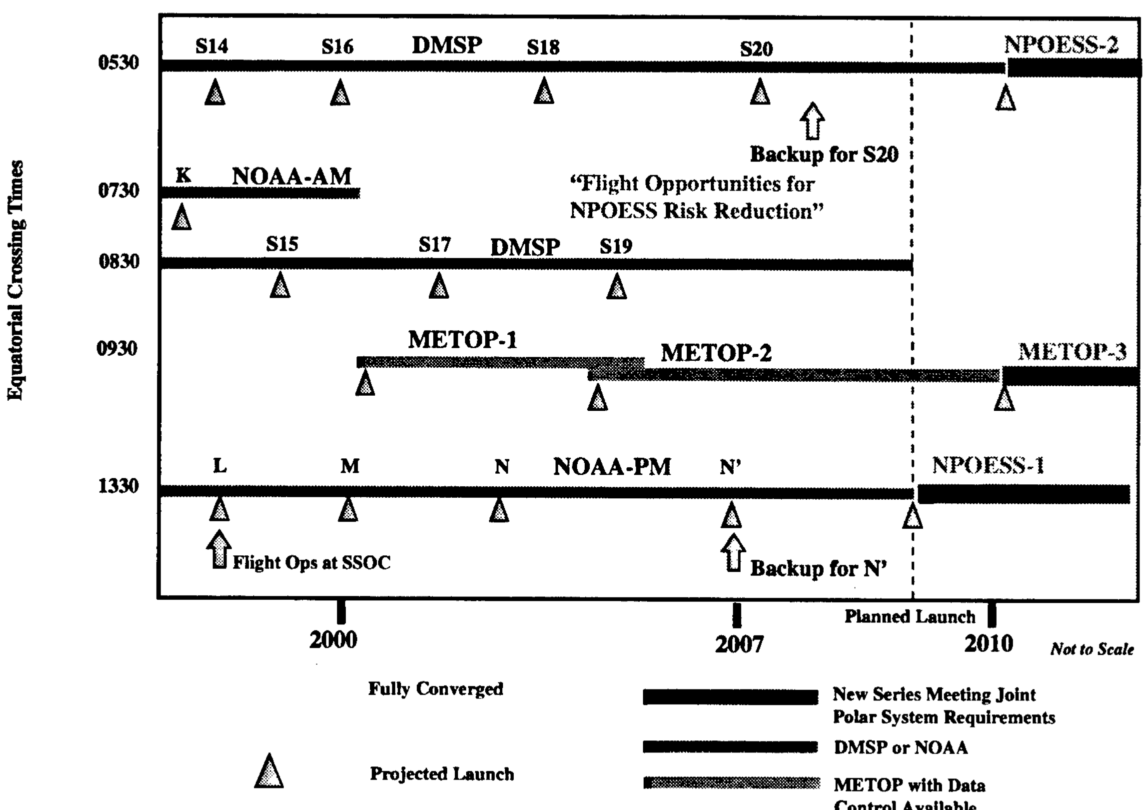


Figure 2. NPOESS Optimized Convergence

PERFORMANCE PARAMETERS

- Atmos Vertical Moisture Profile*
- Atmos Vertical Temp Profile *
- Imagery*
- Sea Surface Temperature*
- Sea Surface Winds*
- Soil Moisture*
- Aerosol Optical Thickness
- Aerosol Particle Size
- Albedo (Surface)
- Auroral Boundary
- Auroral Imagery
- Cloud Base Height
- Cloud Cover/Layers
- Cloud Effective Particle Size
- Cloud Ice Water Path
- Cloud Liquid Water
- Cloud Optical Depth/Transmittance
- Cloud Top Height
- Cloud Top Pressure
- Cloud Top Temperature
- Currents (Ocean)
- Dwn Longwave Rad (Surface)
- Electric Field
- Electron Den Profiles/Ionospheric Spec
- Fresh Water Ice Edge Motion
- Geomagnetic Field
- Ice Surface Temperature
- *In situ* Ion Drift Velocity
- *In situ* Plasma Density
- *In situ* Plasma Fluctuations
- *In situ* Plasma Temperature
- Insolation
- Ionospheric Scintillation
- Land Surface Temperature
- Littoral Sediment Transport
- Net Heat Flux
- Net Short Wave Rad (TOA)
- Neutral Den Profiles/Neutral Atmos Spec
- Normalized Difference Veg Index
- Ocean Color/Chlorophyll
- Ocean Wave Characteristics
- Ozone Total Column/Profile
- Precipitation Type/Rate
- Precipitable Water
- Pressure (Surface/Profile)
- Rad Belt/Low Energy Solar Particles
- Sea Ice Age and Edge Motion
- Sea Surface Hgt/Topography
- Snow Cover/Depth
- Solar EUV Flux
- Solar Irradiance
- Solar/Galactic Cosmic Ray Part
- Supra – Thermal – Auroral Particles
- Surface Wind Stress
- Suspended Matter
- Total Auroral Energy Deposition
- Total Longwave Rad (TOA)
- Total Water Content
- Turbidity
- Upper Atmospheric Airglow
- Vegetation Index/Surface Type

Key parameters

Table 4: NPOESS Notional Payloads to Satisfy IORD-I

USG PAYLOADS	0530	1330	EUM*
VISAR Imager/radiometer with Ocean color** (VIIRS)	X	X	X
Low-light vis imager (VIIRS)	X	X	X
Cross-Track MW Temp Sounder* (CrIMSS/AMSU-A)		X	X
Cross-Track IR Sounder* (CRLMSS/ ITS)		X	
Conical MW Imager/Sounder* (CMIS)	X	X	X
Ozone Profiles (OMPS)		X	
Data Collection System (DCS)	X	X	X
Search and Rescue (SARSAT)	X		X
Space Environmental Suite (SES)	X	X	X
Earth Radiation Budget Sensor (ERBS)		X	
Solar Irradiance Sensor (TSIS)	X		
Radar Altimeter (ALT)	X		

**Assumes European IR sounder (IASI) included.*
***Assumed critical payload.*

CMIS Mission EDRs

- Primary EDR Areas
  - Vertical Moisture/Temperature Profile
  - Imagery
  - Sea Surface Wind
  - Soil Moisture
  - Precipitable Water
  - Precipitation Type/Rate
  - Pressure (surface profile)
  - Total Water Content
  - Cloud Ice Water Path
  - Cloud Liquid Water
  - Cloud Base Height
  - Surface Wind Stress
  - Fresh Water Ice Edge/Motion
  - Ice Surface Temperature
  - Sea Ice Edge/Motion
  - Snow Cover /Depth
- Secondary EDR Areas
  - Sea Surface Temperature
  - Cloud Top Height/Pressure/Temperature
  - Land Surface Temperature
  - Vegetation/Surface Type
- Possible Additional EDR Support
  - Cloud Effective Particle Size
  - Cloud Optical Depth/Transmissivity

GPSOS EDR Areas

- Primary EDR Areas
  - Ionosphere Characterization
    - Electron Density
    - Total Electron Content (TEC)
- Some Contribution to
  - Auroral Boundaries
  - Plasma Density
  - Ionospheric Scintillation
- Secondary EDR Areas
  - None
- Possible Additional EDR Support
  - Temperature Profile
  - Moisture Profile

DMSP Istruments

Optical Linescan System (OLS) – Primary Sensor

- Provides visible and infrared imagery in low resolution (2.7 km) and high resolution (0.55 km)
- Swath width of 1080 (limb to limb)

- Special Sensor Microwave/Imager (SSM/I)
- Special Sensor Microwave/Atmospheric Temperature Profiler (SSM/T)
- Special Sensor Microwave/Atmospheric Water Vapor Profiler (SSM/T2)
- Special Sensor Precipitation Electron and Ion Spectrometer (SSJ/4)
- Special Sensor Ion Scintillation Monitor (SSIES)
- Special Sensor Magnetometer (SSM)

Table 5: Radar Satellite Systems

	Bands	Resolution	Swath	Repeat
Radarsat	5.36 GHz HH Extd1	19.0 M	75 KM	
Active	5.36 GHz HH Extd2	28.0 M	170 KM	
	5.36 GHz HH Fine	9.0 M	45 KM	6 Days
C-Band	5.36 GHz HH STD	25.0 M	100 KM	
	5.36 GHz HH Scan1	50.0 M	305 KM	
	5.36 GHz HH Scan2	100.0 M	510 KM	
	5.36 GHz HH Wide1	28.0 M	165 KM	
	5.36 GHz HH Wide2	25.0 M	150 KM	
ERS-2				
Active				
C-Band	5.36 GHz LV wave mode 5.36 GHz VV image	25 M 25 M	100KM	35 Days

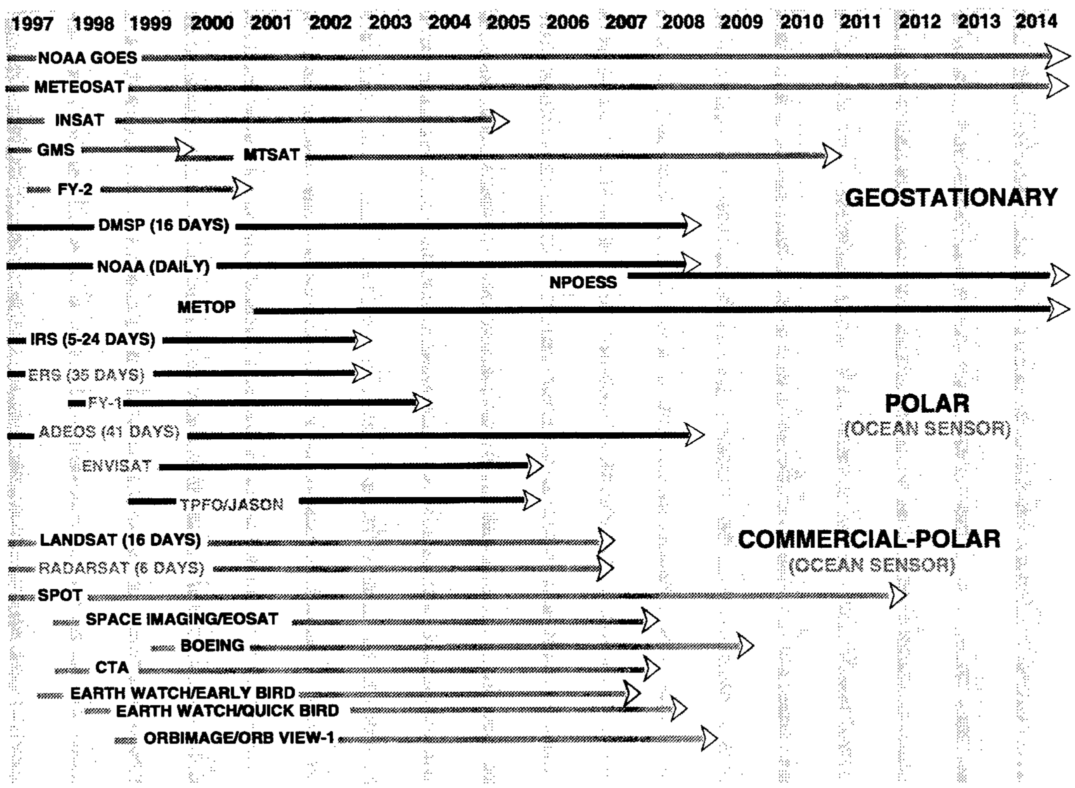


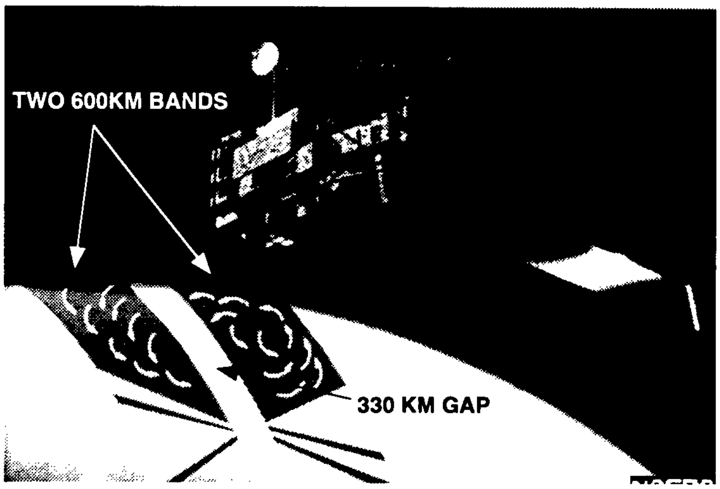
Figure 3. Sampling of current and future geostationary and polar-orbiting satellites.

Table 6: Advanced Earth Observing Satellite ADEOS (41a Day Repeat)

	BANDS µM	RESOLUTION	SWATH
Ocean Color and Temperature Scanner			
	0.402 - 0.422		
Visible	0.402 - 0.422 0.433 - 0.453 0.480 - 0.500 0.510 - 0.530 0.555 - 0.575 0.655 - 0.675 0.745 - 0.785 0.845 - 0.885	700 M	1400 KM
Mid Infrared	3.550- 3.880		
Thermal Infrared	08.25 - 08.80 10.30 - 11.40 11.40 - 12.50		
Advanced Visible and Near-IR Radiometer			
Visible	0.42 - 0.50 0.52 - 0.60 0.61 - 0.69	16M	80 KM
Infrared	0.76 - 0.89		
Panchromatic	0.52 - 0.69	9 M	

Table 7: Advanced Earth Observing Satellite ADEOS (Japan)

Scatterometer	Band	Wind Velocity	Wind Direction	Resolution	Swath
Active	14 GHz	2 m/s (rms)	20°	25 KM	1200 KM
Microwave		3-20 m/s	3-30 m/s	50 KM	
		10%		(0 degree wind cells)	
		20-30 m/s			



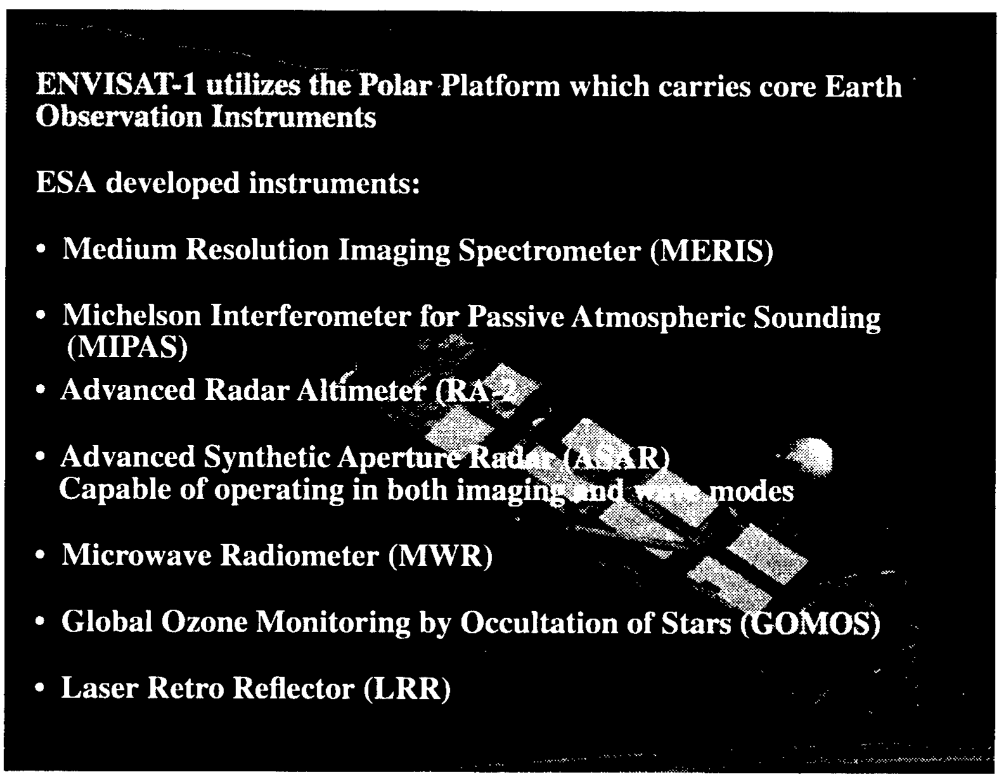


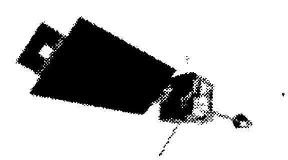
Figure 4. *ENVISAT*

CEOS MEMBERS AND SATELLITE PROGRAMS

- Australia
- Brazil – CBERS, MECB
- Canada– RADARSAT
- China – FY-2, FY-1
- Europe – METEOSAT, ERS METOP, ENVISAT
- France – TOPEX, POSEIDON, SPOT
- Germany
- India – INSAT, IRS
- Italy
- Japan – GMS, ADEOS, MOS, JERS
- Russia – GOMS, METEOR, OKEAN, RESOURCE, ALMAZ
- Sweden
- Ukraine
- United Kingdom
- United States – GOES, POES, DMSP, LANDSAT

COMMITTEE ON EARTH OBSERVATION SATELLITES (CEOS)

- Organization which aims to achieve international coordination in:
  - Planning of satellite mission for Earth observation
  - Maximizing the utilization of datafrom these missions worldwide
- European Space Agency (ESA) became a founder member in 1984



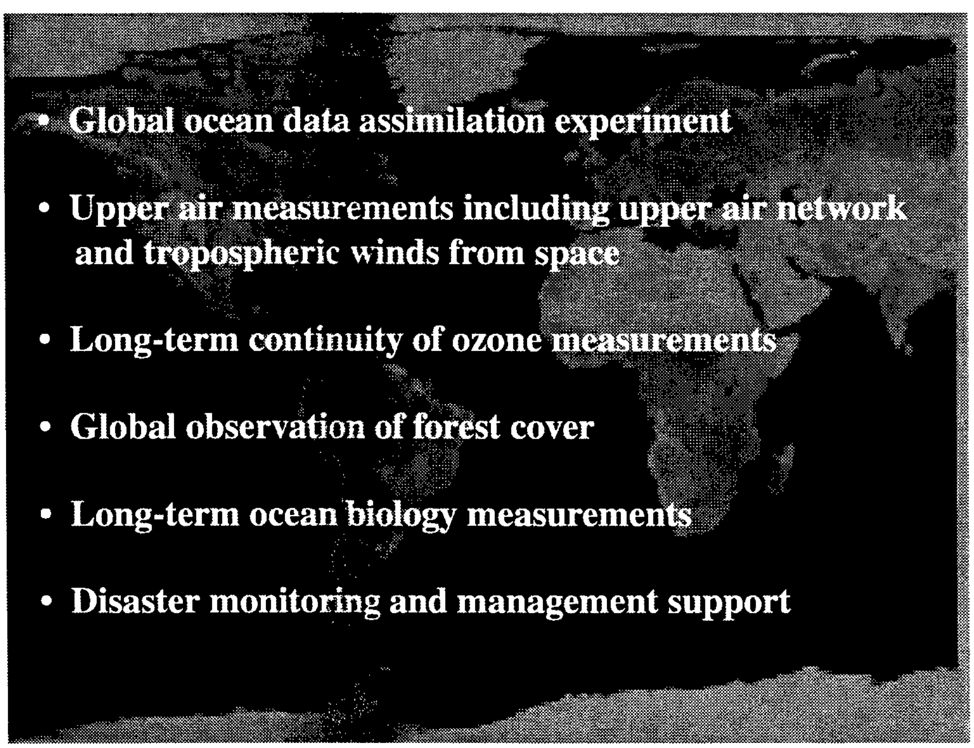


Figure 5. *Integrated Global Observing Strategy Pilot Projects.*

TOPEX/POSEIDON/ATOC: COORDINATED MEASUREMENTS OF THE OCEAN FROM ABOVE AND BENEATH

Dr. Walter Munk

The message is that joint monitoring of the ocean, electromagnetically from above, acoustically from beneath, gives far more information than the sum of the individual measurements. It is a case of:

$$1 + 1 = 4$$

The unclassified example given below is, I believe, representative of a broad class of civilian and Navy-oriented problems.

The particular example chosen is the testing and improvement of climate models (not a subject of direct Navy interest). Climate variability has a scale of 5000 to 10,000 km (Figure 1). Larger scales (such as the usual global means) smear features and are not good indicators. Smaller scales are subject to high intensity mesoscale variability which swamps the climatic signal. For example, a "hot spot" over Hawaii is associated with a decadal variability not related to global warming (Figure 2).

Altimetry measurements are ambiguous as indicator of ocean heat storage (Figure 3). Acoustic tomography have an up/down ambiguity associated with the turning points of rays (Figure 4 and 5). The two have been combined to "look" at the same paths in the northeast Pacific (Figure 6). Overlapping measurements from above and beneath (Figure 7) give far more information than either method by itself.

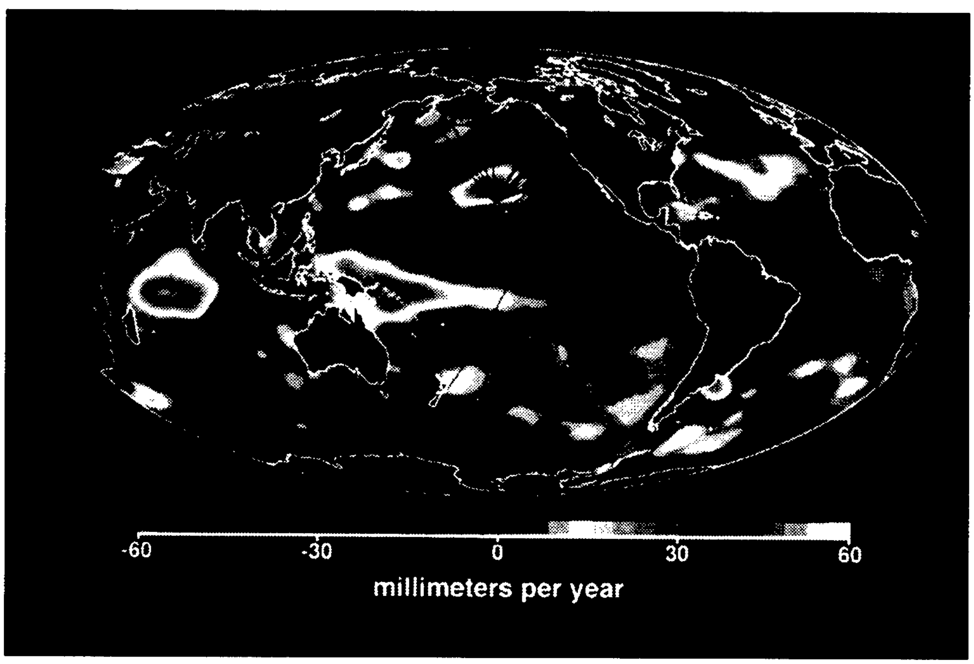


Figure 1: *The average year-to-year change in sea level measured by TOPEX/POSEIDON (T/P) altimetry. The global mean does not differ significantly from zero, but there are hot spots (>1 ft./y) and sinking areas. The scale of climate change is something like 5000 km.*

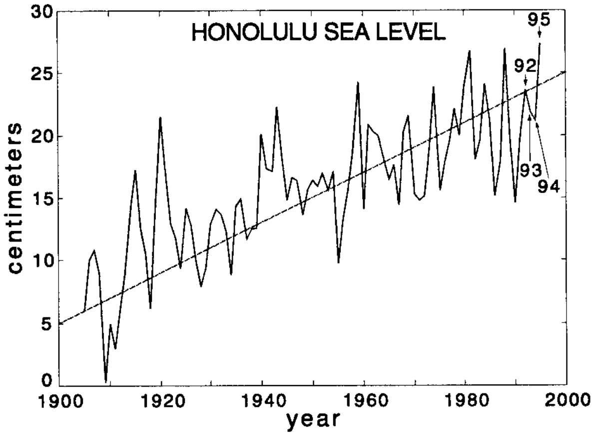


Figure 2: Honolulu Sea Level. Honolulu mean tide gauge level for the 20th century. The mean rise by 2mm/y is typical and associated with thermal expansion of a warming ocean. The rapid rise seen by T/P is representative of the 10 cm decadal oscillations.

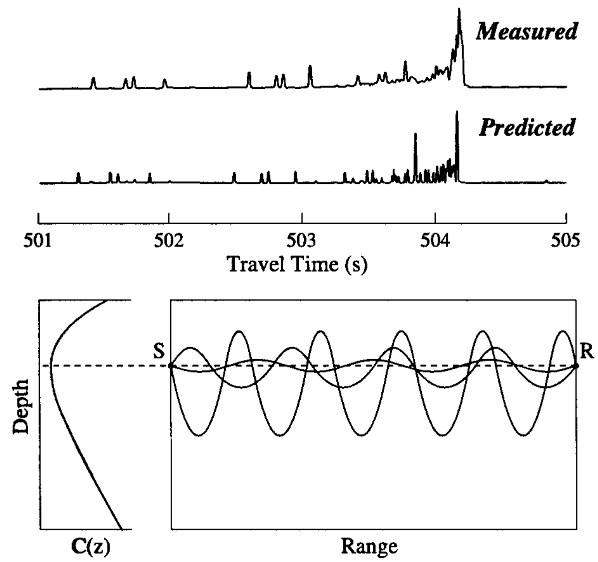


Figure 4: Principles of Acoustic Theamometry. The bottom figure shows a set of rays associated with a typical sound channel (lower left panel). The upper figure shows ray arrival patterns (see text).

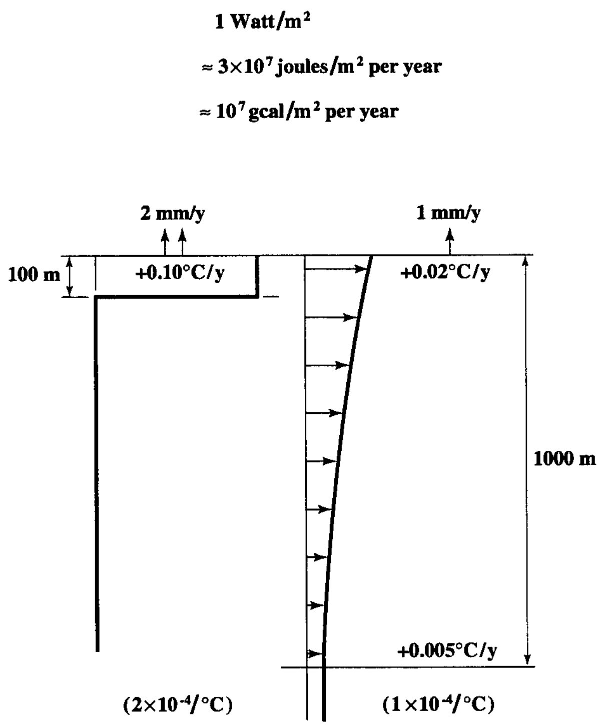


Figure 3: The altimetry measurements are ambiguous because of the strong dependence of the coefficient of thermal expansion on temperature. The same heating (1W/square meter) will cause twice the change in sea level if confined to the upper 100m, rather than 1000m, as shown.

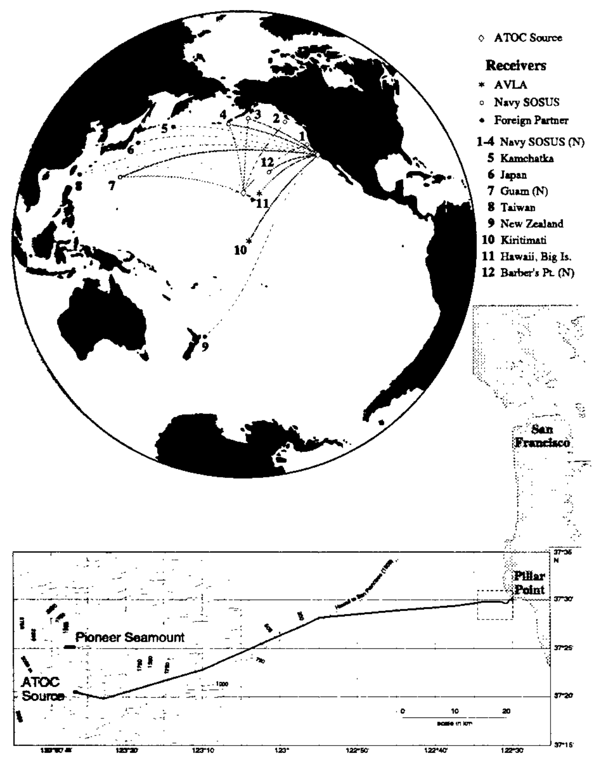


***Figure 5.** The ambiguity is removed by acoustic tomography. Red curves show acoustic travel paths from a source a Pioneer Seamount, red curves from Kauai. Receiving stations 9 and 10 are vertical arrays installed ATOC project (Acoustic Thermometry of Ocean Climate). The remaining stations are horizontal SOSUS arrays.*

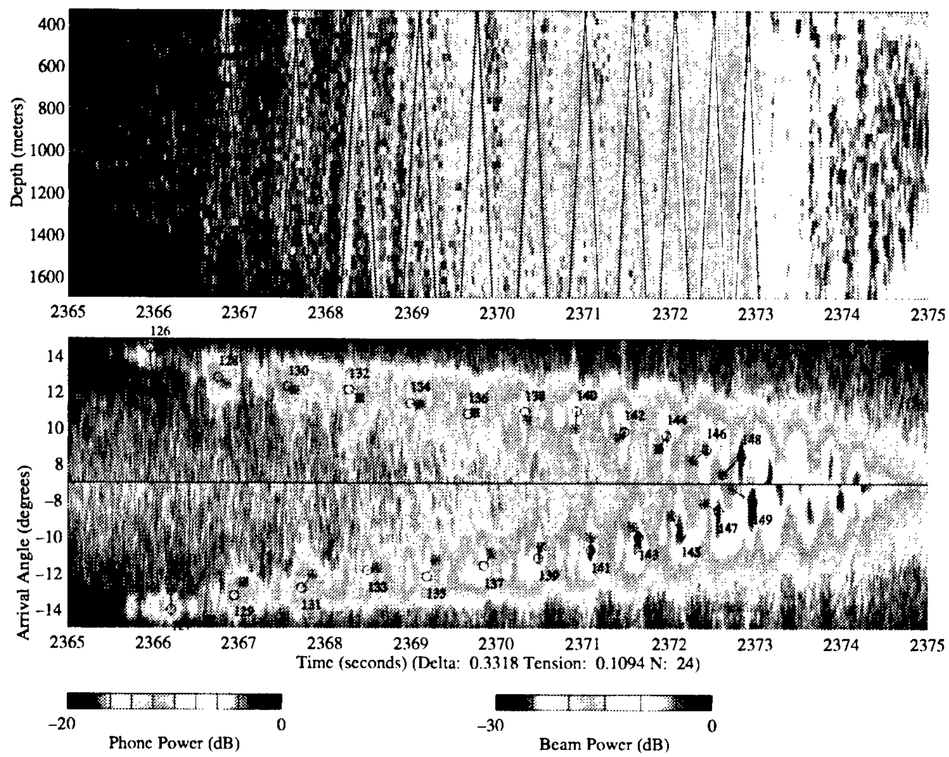


Figure 6. *The arrival pattern at 3000 km measured with a vertical array in arrival-time, depth space (top) and ray-inclination, depth space (bottom). Ray fronts are clearly discernible, permitting coherent beam forming at large ranges.*

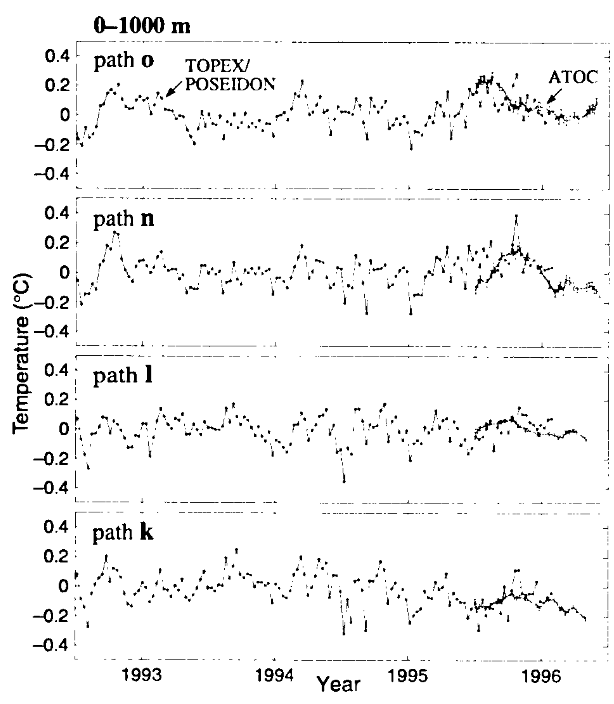


Figure 7: *Upper Ocean Temperature Along Four Paths Identified in Figure 4. Measurements from altimetry and acoustic tomography show some pleasing agreements, but there are differences which give important information.*

GLOBAL OCEAN DATA ASSIMILATION EXPERIMENT
THE GCOS/GOOS/WCRP OCEAN OBSERVATIONS PANEL FOR CLIMATE

Dr. Edward A. Frieman

OBJECTIVES

The fundamental objective is:

A practical demonstration of real-time global ocean data assimilation in order to provide a regular, complete depiction of the ocean circulation at time scales of a few days, space scales of several tens of kilometers, and consistent with a suite of remote and direct measurements and appropriate dynamical and physical constraints.

Associated objectives include:

- Provision of suitable oceanic boundary conditions for regional applications such as coastal ocean prediction systems;
- Provide a description of the ocean circulation and physics upon which more specialized systems, such as biological models, can be developed and tested;
- Provide a foundation for hypothesis testing, process studies and further experimentation, much as is commonplace in numerical weather prediction today;
- Provide initial conditions for climate predictions and analyses for validation of climate simulations; provide a unifying target for various research enterprises (observational, theoretical and modeling) over the coming years; and
- Provide a method for systematic handling, quality control and scientifically consistent interpretation (analysis) of additional data sets such as those from process studies and arising from incidental exploration.

ASSUMPTIONS

It is reasonable to assume that the experiment will: include global models of at least eddy-permitting resolution; build near-real-time operation by the start of the year 2003 and continue with a near-complete global observing system for around 3 years;

Encompass a variety of space-borne systems including:

- Altimetry
- Scatterometers
- Operational meteorological satellites
- Sea surface temperature
- Ocean colour
- Advanced telemetry and communications

Include a global direct (in situ) ocean observation network, comprising:

- Subsurface moorings
- Merchant vessels
- Autonomous floats
- Acoustic thermometry for sampling of the entire ocean depth and to assist calibration of the remote data.

The remote and direct observing contributions will be complementary. It is assumed that the experiment will include at least two model and data assimilation systems capable of resolving eddies and ingesting the variety of data types provided by remote sensing and direct sampling of the ocean. There will be a strong dependence on surface flux products from numerical weather prediction systems. There should be many overlapping interests with existing and planned operational ENSO forecast systems. There will also be several basin and/or coastal models with similar requirements to this project. Such models can take advantage of the global model for outer boundary conditions.

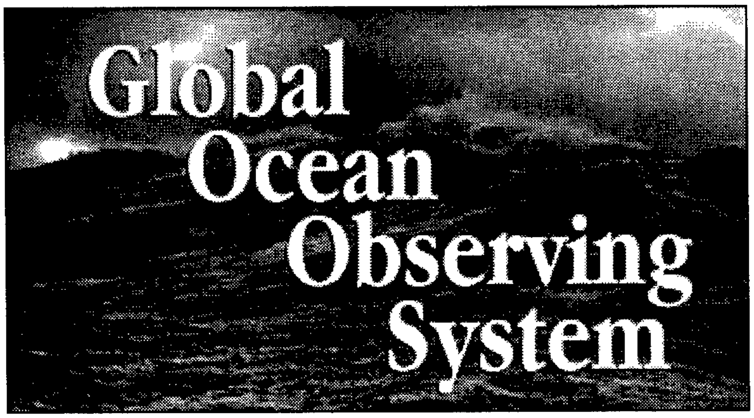
THE CHALLENGES

- To improve present determinations of surface forcing at least to the point where surface forcing errors do not dominate the solution.
- Develop a schedule that is compatible with, and takes maximum advantage of, the best-estimate schedule of satellite agencies.
- To evaluate and determine, then implement and maintain, appropriate suite of direct measurement networks.
- To provide a high resolution global ocean model capable of simulating the true global circulation and assimilating many types of data.
- To further advance our scientific understanding of ocean variability and measurements sensors so that maximum value can be extracted from the available observation set.
- To enhance and develop communications and telemetry so that GODAE can be conducted efficiently and effectively in near-real-time.

CIVIL SYSTEMS

PLANS FOR OCEAN OBSERVING SYSTEMS "GOOS"...

Dr. Otis B. Brown



SUMMARY

- GOOS planning is on track.
- Initial implementations will probably be in a bi-lateral context.
- Trial implementations, e.g., TAO Array, Drifting buoys, etc., in process.
- Additional national resource allocations required for full-up implementation.

OVERVIEW

- GOOS background
- Observing system design considerations
- Planning/Implementation Strategy
- Other considerations
- Conclusions

GOOS INFRASTRUCTURE

- GOOS Support Office [housed at IOC]
- I-GOOS [Intergovernmental Committee for GOOS]
- J-GOOS [Joint Scientific and Technical Committee for GOOS]

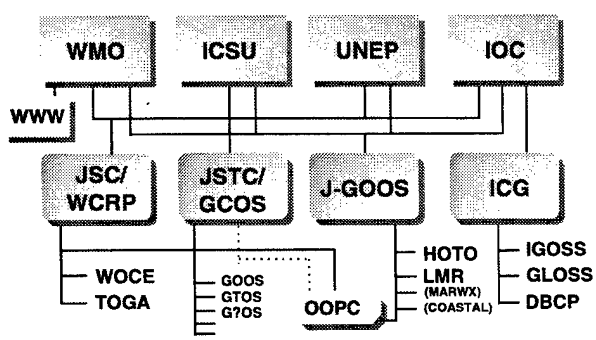


Figure 1: *J-GOOS Genealogy.*

GOOS Background

- Ocean lacks an operational observing system.
- Current observational network is quite sparse.
- Observational programs, such as occur, are usually driven by scientific programs.
- Unique characteristics of oceanic environment limit utilization of land based approaches.
- Problem is international due to geographical scope.

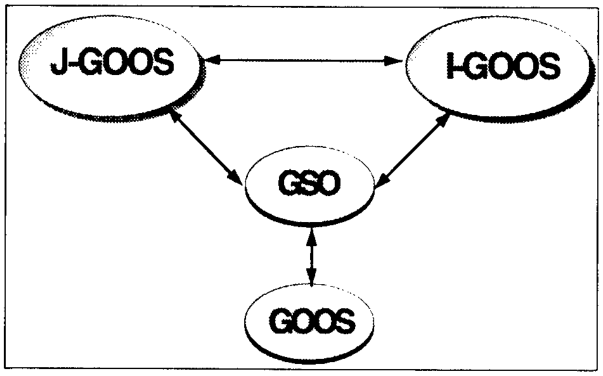


Figure 2: *GOOS Infrastructure Design.*

Why GOOS?

The aim of GOOS is to establish a global framework and method for systematic ocean observations to serve the regular and continuing needs of the ocean user community . . .

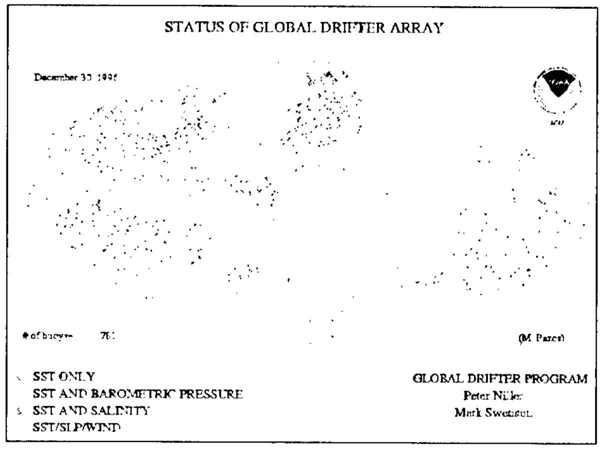


Figure 3: *Global Drifter Population.*

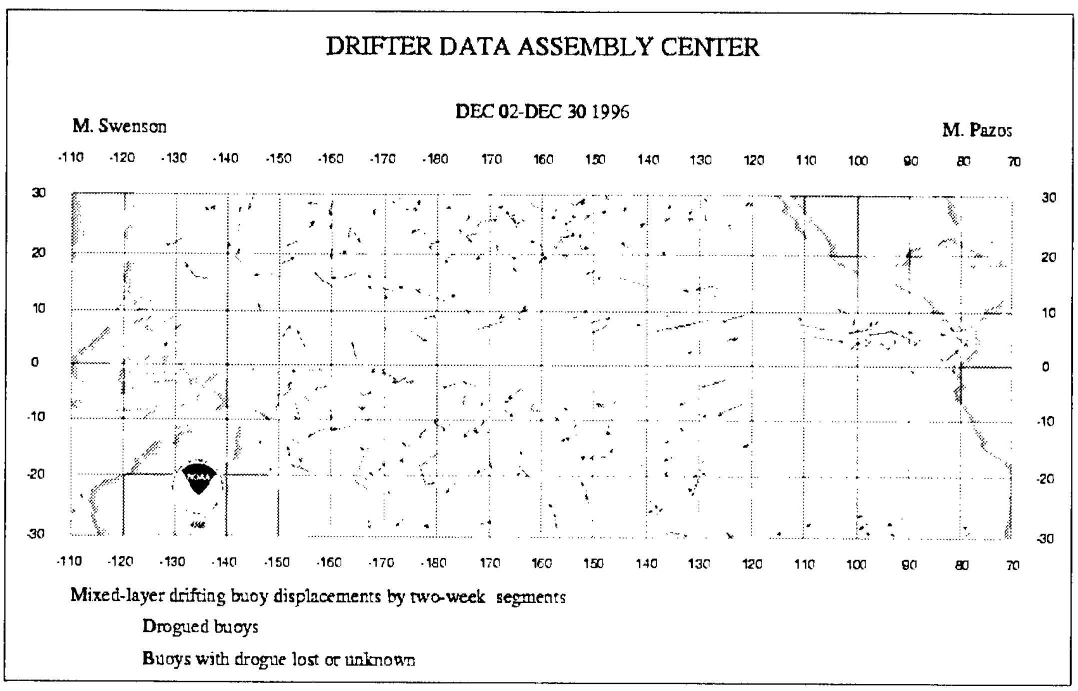


Figure 4: *Global Drifters – December 1996.*

GOOS RATIONALE

- Assessing the state of marine environment, its health and resources.
- Monitoring and prediction within the coastal zone.
- Marine forecasts.
- Monitoring and forecasting climate variability.
- Detecting climate change.
- Supporting an improved management and decision making process for living marine resources.
- Coastal zone management.
- Improved management and response to human-induced changes in the ocean environment.

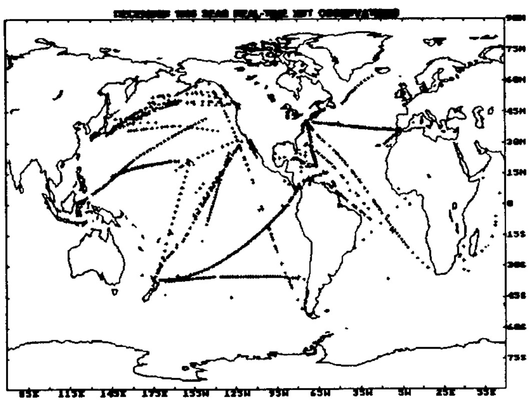


***Figure 5:** December 1996 – XBT Observations.*

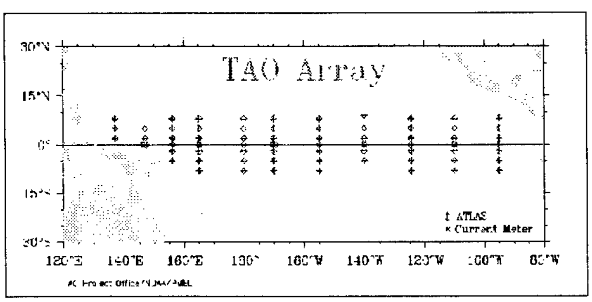


***Figure 6:** TAO Array.*

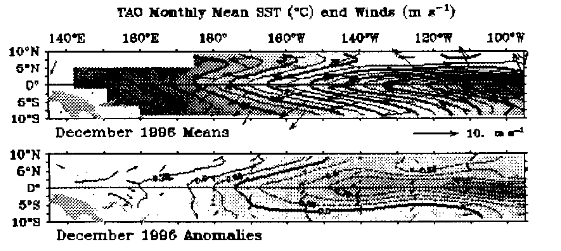


***Figure 7:** SST Infrared – December 1996.*

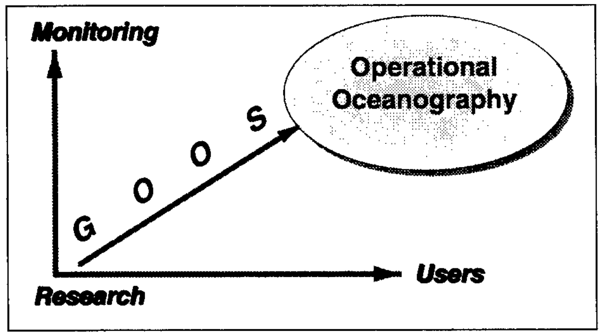


***Figure 8:** GOOS Evolution.*

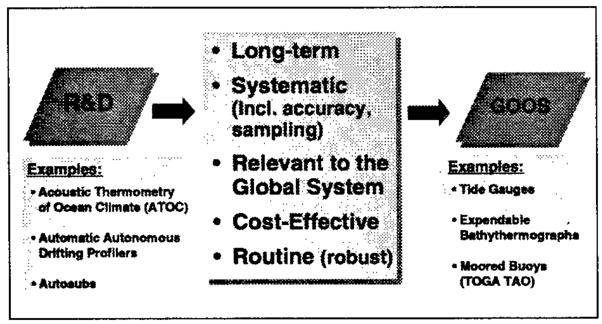


***Figure 9:** GOOS – Operational Considerations*

GOOS PLANNING IS MODULAR

- Climate monitoring and prediction
- Monitoring of the coastal environment and its changes
- Monitoring and assessment of living marine organisms
- Assessment and prediction of the health of the oceans
- Marine meteorological and ocean services

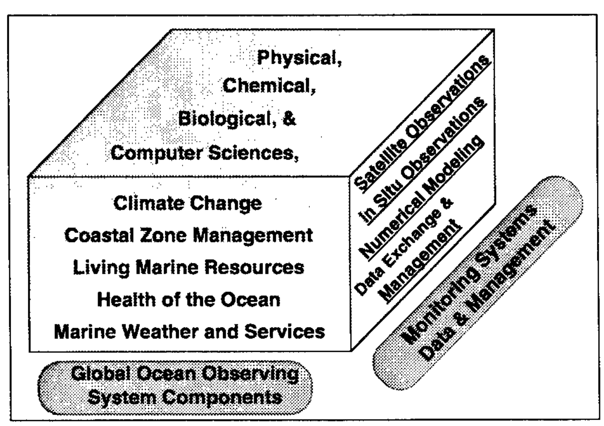


***Figure 10:** GOOS – Integration Themes.*

GOOS STRATEGY

- Scientific planning, including conceptualization, design and technical specification.
- Phased implementation, through Incremental enhancement of existing systems, transition of experimental networks, or pilot projects.
- Continual assessment of all phases of the observing system.

OBSERVING SYSTEM COMPONENTS

- *In situ* networks
- Space based
- Data Assimilation
- Product Generation
- GOOS is end-to-end ...

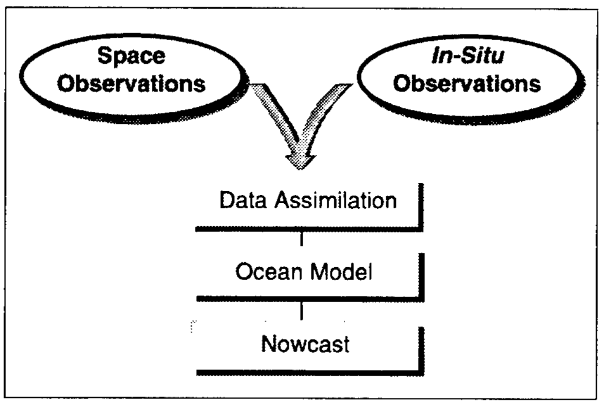


Figure 11: *An "Observing" System.*

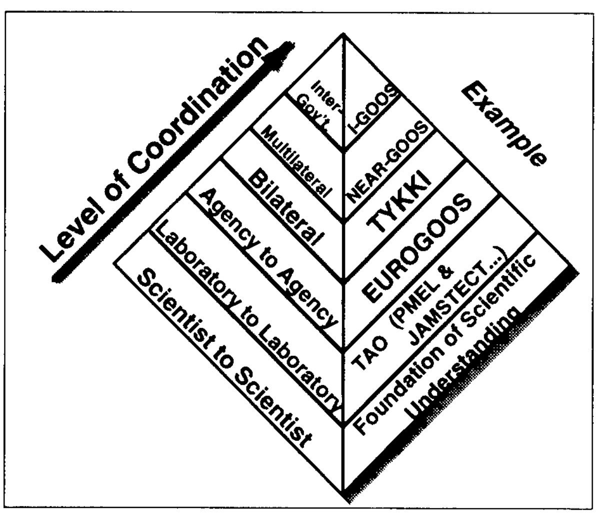


Figure 12: *GOOS Pyramid of Participation.*

OTHER CONSIDERATIONS

- National organizations provide observing system resources.
- Current interactions suggest bilateral arrangements between regional associations as a first step, e.g., EUROGOOS↔USGOOS↔NEAR-GOOS.
- Multi-lateral arrangements may be required for coastal and health components.

PLANNING

- Strategic Plan to be published in early 1997.
- "Toward the Realization of GOOS" planning document to be available in early 1998.
- Some test (quasi-operational) implementations are in place, additional ones planned in 1998/1999.

LITTORAL ZONE CHARACTERIZATION AND MONITORING

Dr. Peter Mikhalevsky

LITTORAL PREDICTIVE CAPABILITIES

Littoral environments are characterized by oceanographic phenomena of high spatial and temporal variability, severely limiting the predictive capabilities. Even though the fundamental equations of the geophysical fluid dynamics may be reasonably well understood, the predictability of the oceanography is severely limited by the multi-scale nature of the forcing and the boundary conditions. The formation and development of a coastal front may be driven by a combination of global tidal forces, estuarian processes such as fresh-water river run-off, and the local topography. There is obviously a trade-off between the size of the computational domain, *i.e.* the coverage, and the scale of the phenomena modeled, the resolution. For coastal processes the small time and spatial scales are important, and consequently the computational domain is severely limited. Because of the multi-scale forcing the boundary conditions are largely unknown, and accurate nowcasting and forecasting only becomes possible if the models are constrained by *in-situ* measurements through data assimilation.

Acoustic modeling is crucial for high resolution processing of importance to acoustics systems such as imaging sonars, passive and active matched field array processing and acoustic communication. These new techniques are dramatically improving performance by using the knowledge of the oceanographic (sound speed) maps in three dimensions as an integral part of the array and signal processing. In many situations the accuracy of the oceanography is the limiting factor for performance and in the highly dynamic coastal environments this will be an important issue. For example, modern communication technology uses channel equalization to adaptively adjust to the changing environment. Although very high data rates can be achieved using this approach in the open ocean, the short timescales of the changes in the coastal environments can limit the performance of such systems. Adaptive matched field processing [1] provides 3-D source localization and improved anisotropic noise rejection but is dependent on accurate representation of the acoustic environment provided by *in-situ* measurements or good oceanographic models. Even benign changes in the oceanography often have a dramatic effect on the acoustic environment. While the oceanography may change in a relatively small and linearly predictable manner, the associated acoustic environment may exhibit highly non-linear changes, such as shadow zone fading and caustic hot spots. Accurate modeling capabilities are readily available provided the oceanography is known, and consequently oceanographic predictability is the key to maintaining high performance of acoustic systems in shallow and littoral waters.

Recent progress in ocean sampling technology has opened the possibility of vastly increasing the amount of environmental data that can be assimilated into the oceanographic and acoustic models on a real-time basis, with the potential of significantly imp roving the predictive skill of the oceanographic models and acoustic systems performance. However, the amount, type and distribution of data that must be assimilated to achieve this is presently largely unknown.

ACOUSTICALLY FOCUSED OCEANOGRAPHIC SAMPLING NETWORK

The explosive progress achieved in recent years in developing small autonomous vehicles and underwater communication has provided the basis for a new paradigm for ocean measurements, the Autonomous Oceanographic Sampling Network (AOSN) [2]. The AOSN concept uses one or more inexpensive autonomous underwater vehicles (AUV) equipped with oceanographic sensors to make high resolution measurements in the ocean environment. A key component of AOSN is the acoustic communication which is provided through a combined acoustic- and radio-modem network, Figure 1.

The advantages of the AOSN concept is the adaptive, multiple scale sampling of the environment. Some AUV's may be applied to provide coverage by sampling the environment using a large scale survey pattern, while other vehicles adaptively are applied to make high-resolution measurements in regions of strong variability, such as fronts detected by survey vehicles or acoustic tomography. By combining the AOSN with an acoustic tomography capability with the cabled vertical line arrays (to be installed in the SBC in Spring 1998 as part of the DARPA/ONR funded Full Field Program (FFP)) as the tomography receivers, a low resolution, but synoptic and real-time map of the environment can be achieved. This is then used as a basis for adaptively directing the AUV'S towards areas of high variability, Figure 1. Including acoustic sources on the AUV's will permit moving source tomography with higher resolution and adaptive repositioning to optimally measure the environment. By combining the acoustic and non-acoustic measurements, this Acoustically Focused Oceanographic Sampling (AFOS) concept makes optimal use of the available AUV resources. The feasibility of various components of AFOS was demonstrated in the 1996 Haro Strait PRIMER Experiment [3,4]. The limited bandwidth of the radio-link, however, limited a complete

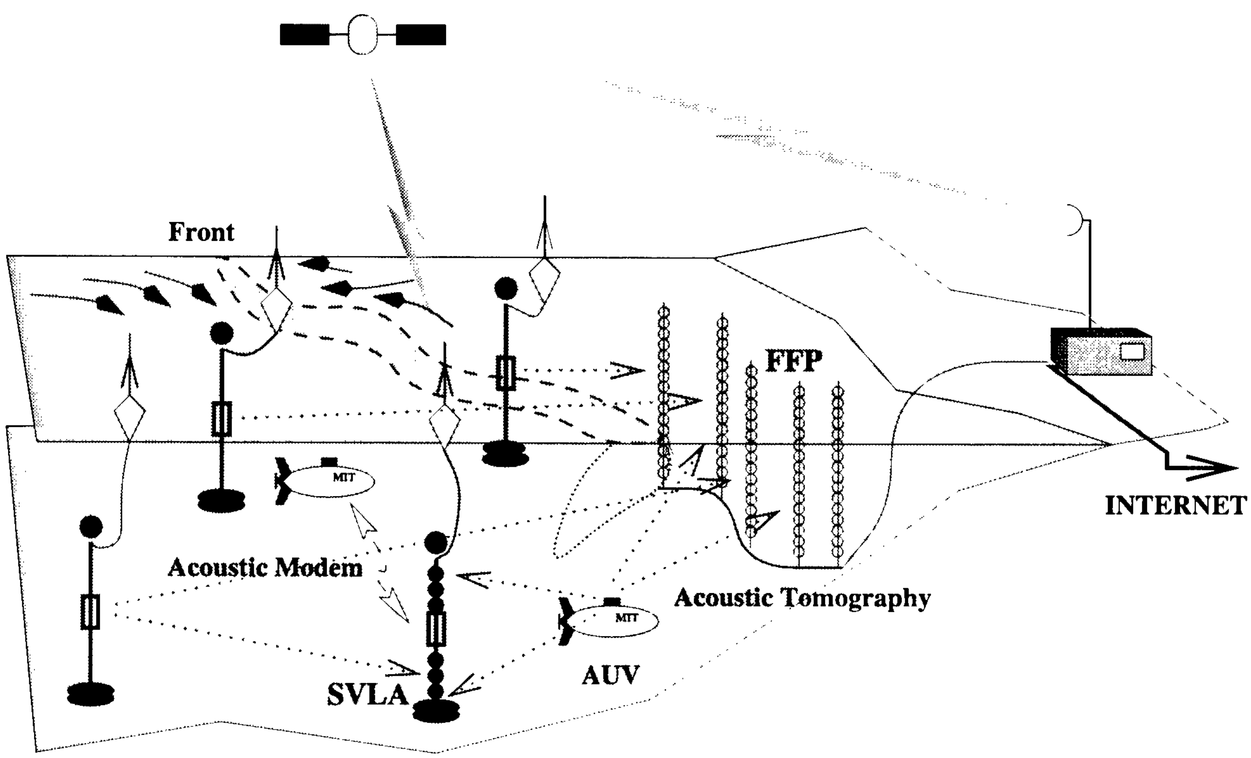


Figure 1: Conceptual picture of the Littoral Zone Characterization and Monitoring. Hardwired vertical line arrays are shown with the tomographic source moorings, an autonomous SVLA and Autonomous Oceanographic Sampling Network AUV's.

demonstration of the AFOS concept. The high bandwidth cabled FFP array provides a unique opportunity to demonstrate the full capability of AFOS.

SANTA BARBARA CHANNEL PHYSICAL OCEANOGRAPHY (AN EXAMPLE)

The Santa Barbara Channel (SBC) is an ideal place for testing these concepts for Littoral Zone Characterization and Monitoring as it has a complex circulation and oceanographic structure [5]. At the same time there is a significant societal benefit given the need to responsibly develop the offshore oil reserves of this coastal region. Since 1969 there has been a significant amount of study of the region, as a consequence of the oil spill of that year. Building upon a significant body of earlier work, the Minerals Management Service (MMS) and Scripps Institution of Oceanography in 1991 entered into a cooperative agreement to carry out a detailed study of the surface circulation of the channel and Santa Maria Basin region. The project has examined all the historical data, and conducted a field program with many oceanographic moorings, and use of NOAA AVHRR data for sea surface temperature maps. At least 4 of the oceanographic moorings will be operational through 1998, one of which is located very close to the deployment site of a fixed vertical line array (VLA) complex of five VLA's to be moored in early 1998.

The SBC is a semi-enclosed coastal basin located in a transition zone between the warm southern California Bight water and the cooler north/central California coastal water. A thermal front aligned approximately northwest to southeast across the channel is often observed [6 and 7]. Across-front temperature differences can be as much as 4 degrees C in summer. From the 1984 SBC study [8], the upper-layer flow is predominantly westward along the northern coast of the channel, and eastward along the southern side. This cyclonic flow pattern in the west appeared to be persistent year-round. In addition, there were strong current fluctuations at periods of 2 to 5 days and also at longer periods (2 to 3 weeks). These fluctuations were found to be uncorrelated with local winds, in contrast to the flows further north. More recent data and analyses by Scripps have revealed that small-scale eddies (~10km) and remote forcing play an important role. On the seasonal time scale, the flow is equatorward in spring and poleward between summer and winter, a robust observational feature that is most probably linked to the large-scale windstress curl over the Southern California Bight [9]. Moreover, the period during which the cyclonic circulation within the channel is strongest coincides with the period of strongest poleward flow through the eastern entrance [10]. Thus a detailed knowledge of the flow state (heat transport in particular) in the east would go a long way towards understanding the circulation dynamics in the channel. In this proposal, our objective is much more focused, however, to take advantage of the temperature and velocity fields derived from the acoustic tomography and AOSN measurements to develop a data-assimilation scheme that nowcasts and forecasts the detailed flow field in the eastern portion of the channel. The information on the poleward volume and heat transports will aid in calculating the momentum and heat balances that is presently in progress in the ONR/MMS-funded work discussed above that focuses also on the SBC physical oceanography 'processes' and 'dynamics.'

LITTORAL OCEANOGRAPHIC AND ACOUSTIC LABORATORY

The synergy of resources and research efforts composing the hypothetical Littoral Oceanographic and Acoustic Laboratory (LOAL) at Santa Barbara, California is illustrated in Figure 2. LOAL combines various measurement networks including fixed moorings and mobile platforms wit h state-of-the-art acoustic and ocean modeling to provide a versatile real-time environmental assessment capability. Measurement Network. The fixed current meter moorings already deployed by Scripps will provide long time series of the large scale oceanography in the Santa Barbara Channel. Similarly, the fixed vertical acoustic arrays and the autonomous SVLA, together with four tomographic source moorings would provide a 20 km aperture tomographic network over the eastern section of the channel, which could be operated over a full year, with real-time access and data retrieval via the INTERNET.

The AOSN component consists of two Odyssey AUV'S equipped with acoustic modems, tomography sources, Acoustic Doppler Current Profilers (ADCP) and CTD. The AUV'S will be navigated in a standard LBL navigation network, and the acoustic communication could be performed through modems installed on the fixed VLA's and the SVLA, with the former being directly connected via the shore link, and the latter being satellite linked (Figure 1). The AOSN network can be deployed with the full control infrastructure, developed by MIT Sea Grant as described in the attached statement.

Acoustic modeling and tomography. Acoustic modeling and tomography play multiple roles in LOAL. As illustrated in Figure 2, tomography is the equivalent to assimilation for acoustic environment assessment. Thus, tomography is used to constrain the acoustic models, and as such it produces a low-resolution, but synoptic assessment of the oceanographic environment. A unique aspect of using the FFP acoustic arrays as receivers for the tomography signals is the ability to perform spatial as well as temporal processing to separate modes and rays for the inversions in this shallow water environment.

In relation to Acoustically Focused Oceanographic Sampling (AFOS) the tomography processing is applied in real-time to provide an estimate of the oceanography and its uncertainty to be applied for adaptively focusing the direct measurement by the AUVs in regions of high spatial and temporal gradients. In addition, the tomographic results are applied to guide the AUVs carrying tomography sources to positions which will improve the resolution or coverage of the tomographic image.

One of the unique new features of LOAL is the combined use of tomographic inversions and direct oceanographic measurements for assimilation into the circulation models, with the expected outcome being a significantly improved real-time environmental assessment capability. In this regard, the tomographic signals produced by the fixed moorings will be applied to augment the SIO current measurements for assimilation into long-term hind-, now, and forecasting of the large scale SBC circulation. During the main experimental periods, the moving source capability of the AOSN in combination with the fixed VLA's and SVLA arrays can be applied to obtain higher resolution tomographic images of the Eastern entrance to

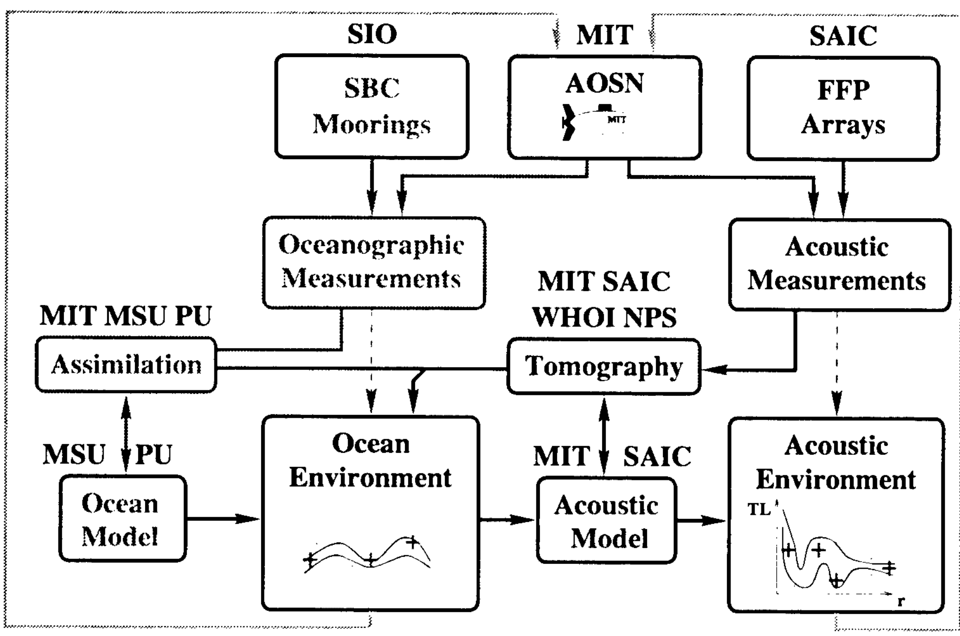


Figure 2: *Example program to assimilate oceanographic and acoustic data into acoustic and oceanographic models to obtain nowcasts and forecasts of the ocean environment.*

SBC, and assimilated into the high-resolution oceanographic models.

The feasibility of using acoustic tomography for providing low-resolution, but synoptic maps of highly dynamic littoral oceanography was demonstrated in the June 1996 Haro Strait PRIMER experiment [3,4]. Several different acoustic tomography experiments were carried out, using both the 1.5 kHz and 15 kHz sources on the vertical arrays and one of the deployed AUVs. Moving source tomography was performed using a series of light bulb sources deployed in the network [4]. In AFOS the resolution of the tomography component is secondary to processing speed and robustness. A layered algorithm using Gauss-Markov tomographic inversion for the direct and the surface reflected paths has been developed, which provide real-time tomographic mapping of the sound speed profile throughout the network volume with a resolution of less than 1 m/s. The inversion simultaneously determines the source localization, a feature which can be applied for AUV navigation in LOAL. The tomographically inverted sound speed profiles were verified by direct measurements by CTD and thermistor chains on the moorings. The tomographic processing scheme produces full 3-D spatial distributions of the oceanographic parameters. As an example, Figure 3 shows the sound speed perturbations in a horizontal plane at 50 m depth, inferred from four groups of light bulb sources. The source and array positions are indicated by crosses and circles, respectively. Only results with

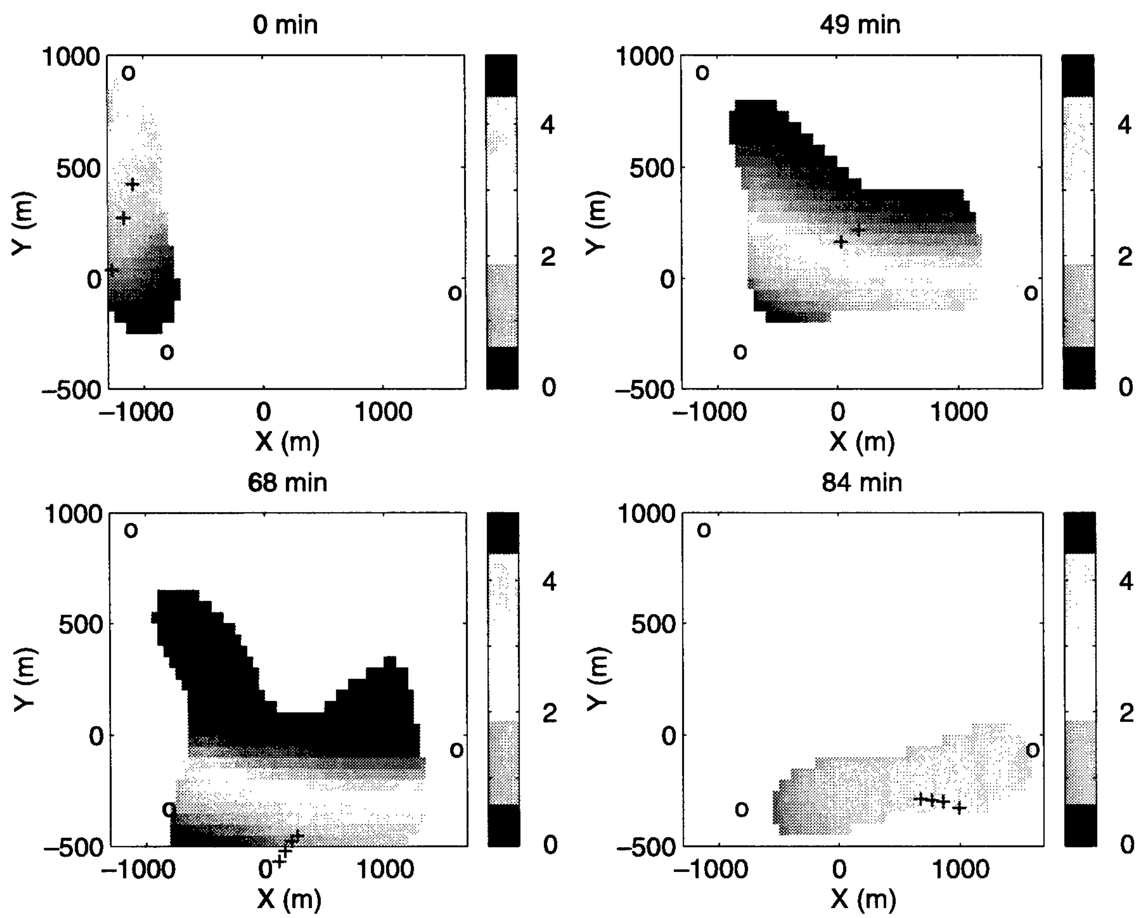


__Figure 3:__ Contours of sound speed profile perturbation at 50 m depth, determined by tomographic inversion of light bulb data in Haro Strait '96. The colours represent sound speed perturbation relative to a reference profile, in m/s, with red indicating higher, and blue lower speed. the Eastern entrance to SBC, and assimilated into the high-resolution oceanographic models

an error estimate of less than 1 m/s are contoured, reflecting the coverage provided by the arrays and sources.

Ocean Circulation Modeling. The modeling effort can combine the resources of Princeton University, Mississippi State University, the Earth and Planetary Sciences (EAPS) Department of MIT, and the Naval Post Graduate School (NPS). Both the Princeton OCNOM and MSU DieCAST models (see below) can be used. One of the major focuses of the modeling effort which would be the data assimilation task, particularly the temperature and current constraints provided by the acoustic tomography.

It is clear that a circulation model of the SBC must deal simultaneously with local, small-scale dynamics as well as remote, large-scale forcing. The Nested-grid Ocean Model (OCNOM) [11] can achieve this capability. At the core of OCNOM is the Princeton Ocean Model (POM) [12,13], it solves the three components of velocities, temperature and salinity (hence density), the free-surface elevation, and also turbulence energy and length scale [14]. The model provides high-resolution flow solution at a specific region embedded within a larger, coarser-grid model domain. Nesting begins with an initial fine-grid field interpolated from a coarse-grid solution (or a geostrophically balanced field). Time integration then proceeds with the coarse-grid solution imposed around the fine grid's boundaries, and feedback from the fine grid to coarse grid based on a flux-conservation scheme. This two-way nesting proves to be crucial to improving the model's accuracy especially in cases involving shelf wave propagation.

As part of an ongoing ONR/MMS-sponsored research to isolate the mechanisms that cause the seasonal poleward current, believed to have important consequences to the SBC circulation, the effect of a quasi-steady, localized wind curl forcing around Pt. Conception was investigated. A 3:1 nest was spawned inside a coarse-grid (15 km grid size) that extended from Baja California to northern California. The coarse-grid model was forced with COADS wind stress from 1979 through 1989; and the 5 km grid size in the nest filtered out the 'eddy-shedding' solution, so that effect of intensified wind curl could be isolated. The nest was 'turned on' on simulation date 4/1/81, when COADS wind was particularly strong (and equatorward). Figure 4shows the corresponding surface velocity and temperature. Note the development of a cyclonic

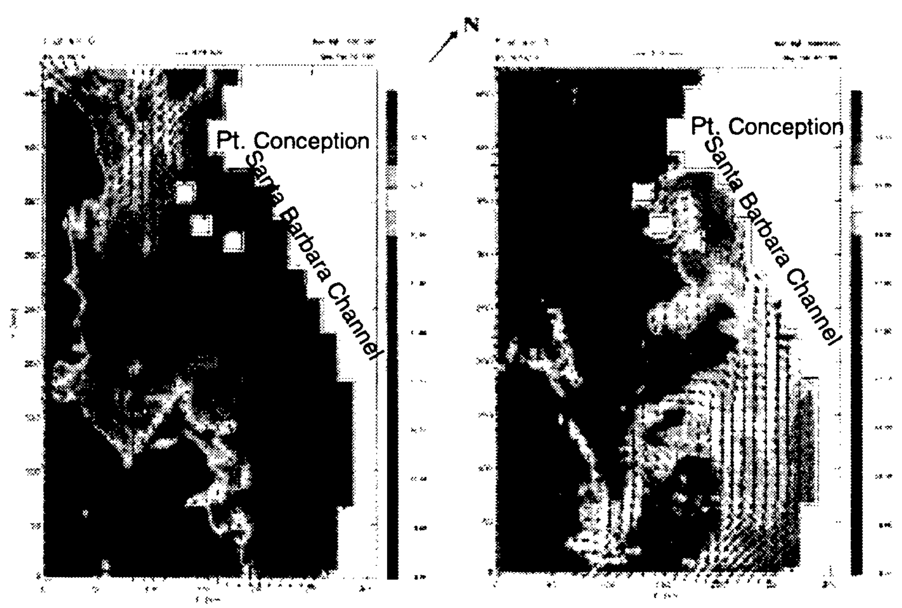


Figure 4: *The fine-grid model SST and velocity on April 16, 1981 (left) and May 16, 1981 (right), a period of intensified equatorward windstress of U.S. West Coast.*

eddy in the western SBC. The momentum analysis (not shown) confirmed that the eddy was induced by the intensified wind curl.

The MSU DieCAST model [15] has improved accuracy and greatly reduced numerical dispersion compared to the previous version, which has been validated by a myriad of observations and theory. The new version is better for both advection and inertia-gravity wave terms, and give faster convergence to the theoretical speed of coastally trapped Kelvin waves.

Data Assimilation. The goal is to develop a rapidly re-deployable nowcast/forecast system for coastal oceans. Using the Santa Barbara Channel (SBC) as a test-bed, an example system is proposed based on (movable) grid nesting and data-assimilation that utilizes acoustic tomographic measurements in the eastern part of the channel augmented by oceanographic measurements by moorings and the AUVs. The approach is unique in that remote forcing is accounted for in the overall nowcast/forecast schema, and is moreover dynamically coupled (two-way nesting) to the local, small-scale dynamics of the coastal region, issues that are often overlooked. An approximate Kalman filter approach [16] will be adapted to the SBC region for the purpose of real-time nowcast/ forecasts. Formally future data will be incorporated in the ensuing offline oceanographic analysis through a smoothing algorithm.

ACKNOWLEDGEMENTS

Henrik Schmidt (MIT), Leo Oey (Princeton) and David Dietrich (Mississippi State Univ.) provided substantial contributions to this report.

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Civil Systems

Autonomous Ocean Sampling Network

Dr. Thomas B. Curtin

The Key to Coupled Modeling – Sampling Systems and Littoral Naval Operations Paradigm Shift

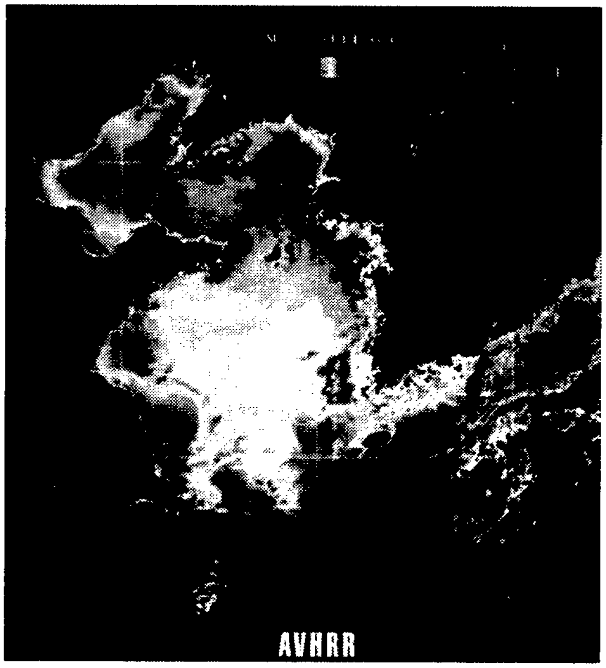


Figure 1: *Littoral scales of variability.*

Ocean Modeling and Prediction

- Mapping Littoral Variability
  - Time Constrained Surveys
- Validating High Resolution Models
  - Statistical, Dynamical
- Increasing Forecast Skill
  - Data Assimilation, Adaptive Sampling

↓

Coupled Modeling – Sampling Systems

Related Requirements

- Joint Littoral Warfare
  - Ship Self Defense
  - MCM: Defensive Mission Using Active Methods, All source Data Fusion, Defensive Mission Using Passive Methods, Undersea Coordination and Tactical Control, Undersea Environmental Assessment, Surveillance of the Undersea Battlespace, Undersea Covert/ Non-covert Indication and Warning, Special/ Unconventional Operations, Environmental Physics of Mine Warfare, Remote Control of Minefields, Mine Delivery
- Joint Surveillance
  - Tactical Reconnaissance
  - Mines
  - Surveillance Resource Management
- Forward Presence
  - Battlespace Dominance
  - Enable Force Self Defense
  - Environmental Stewardship

Navy Unmanned Undersea Vehicle (UUV) Plan

- 1994 Plan approved by N85 & ASN (RD&A); submitted to Congress by USD (A&T):
  - Navy's Expeditionary Warfare Division (N85) Established Navy's UUV program Priorities.
- 1st Priority: Develop near-term UUV with limited capability to conduct clandestine mine reconnaissance from an SSN.
- 2nd Priority: Develop long-term UUV with greatly improved capability to conduct clandestine mine reconnaissance.

- 3rd Priority: Develop UUV systems for surveillance, intelligence collection & tactical oceanography.
- 4th Priority: Explore advanced UUV designs for the future.
- 1995 Update to plan co-signed by N85B, N87 & PDASN-RD&A:
  - Reaffirmed the Navy's UUV priorities.
  - Provided progress report (R&D, procurement) concerning four priority areas.
  - Requirement to launch/recover LMRS from from surface ships eliminated via organic offboard mine reconnaissance CONOPS. doucument (co-signed by N85, N86 &N87)
- RMS program will cover surface fleet (non-clandestine).

Further Documented Requirements

- 1994 Navy UUV plan (reaffirmed in 1995 update)
  - "Tactical oceanography . . . *in situ* measurements . . . in politically sensitive or denied areas, while potentially the most critical, are often the hardest to obtain. As a result, utilization of a UUV system for shallow water oceanographic measurements will represent a breakthrough in tactical oceanography."
- April 1996 U.S. Navy MIW plan
  - "A sustained, peacetime MCM-oriented bottom mapping and environmental survey effort . . . is required."
  - "Mapping, charting & geodesy (MC&G) data . . . bathymetry, geodetic information, medium scale bottom mapping, feature morphology, etc . . . "
- June 1996 message on "FY 97 COMSIXTHFLT Command Technology Issues"
  - "Develop a UUV for underwater intelligence collection, reconnaissance, covert hydrographic operations, investigate enemy hydrographic and sonar arrays placed on the sea floor, and even provide OTH targeting . . . concepts includes launching a UUV from a submarine torpedo tube off a target coastline or port facility.

Ocean Prediction System

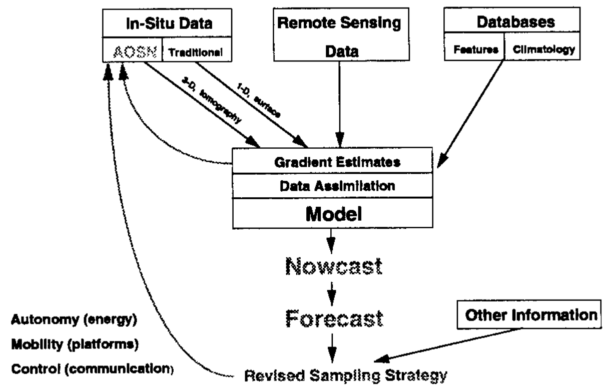
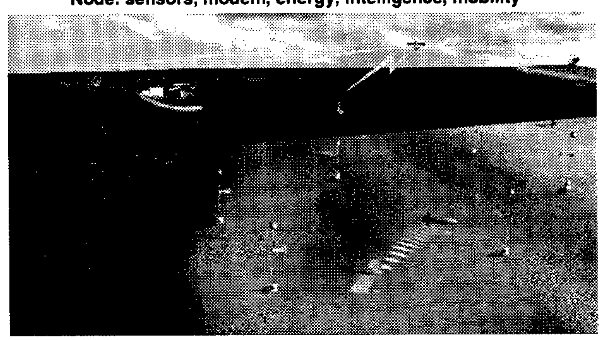


Figure 2: Coupled modeling – sampling systems.

(a) **Distributed Nodes**

Node: sensors, modem, energy, intelligence, mobility



(b) **Fixed Nodes + Mobile Nodes**

(Far Term : stationary nodes = AUV's)

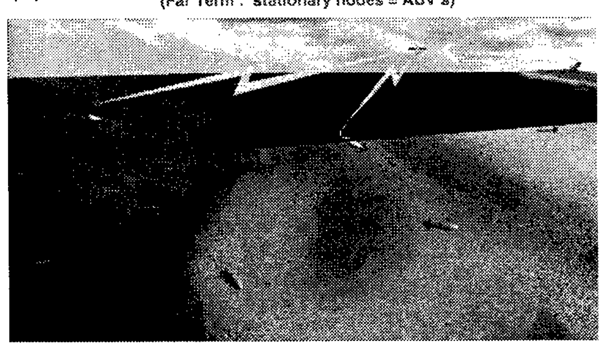


Figure 3a & b: Autonomous Ocean Sampling Network (AOSN).

AOSN Advantages

- 3-D aperture
  - (nav + com ➞ tomography)
- Adaptive resolution
  - (global + local knowledge)
- Real time control
- Energy management
- Robust to unit failure

AOSN Connectivity Standards

- Communication protocols
- Navigation system
- Energy transfer
- Algorithms, high level control

AOSN Implications and Configuration

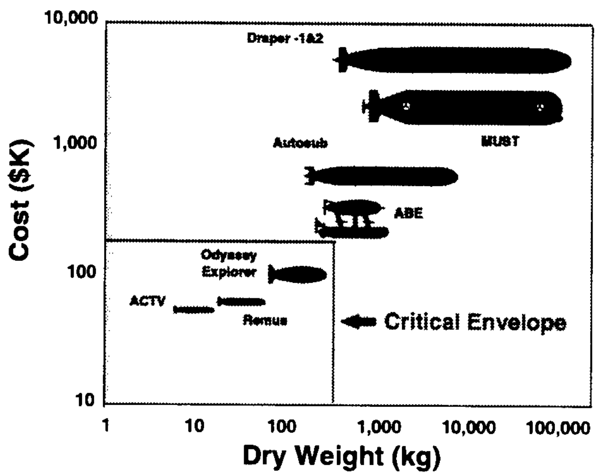


Figure 4: *AOSN Implications: small, low cost vehicles; reliable communication (Acoustic, RF); accurate navigation.*

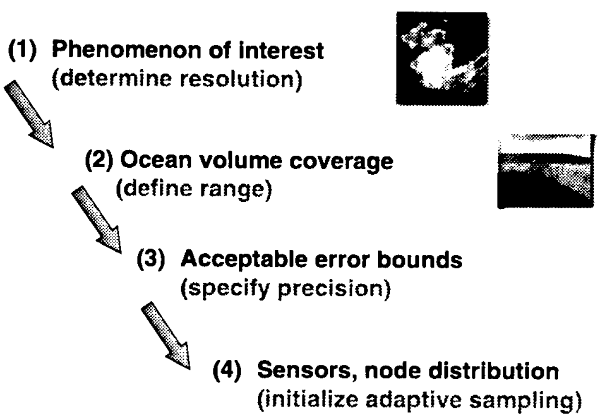


Figure 5: *Original AOSN Configuration.*

Technical Issues

Control, Communication, Navigation

- Integration of autonomous mission management and human supervisory control.
- Performance predictability of autonomous mission management.
- Integrated reliability within an adaptive control environment.
- Delayed control through long range acoustic communication links.
- Arbitration of behaviors with competing objectives.
- Compilers for high level mission conversions into state tables.
- Survey, gradient/terrain following, path optimization algorithms.
- Docking algorithms.
- Collision resolution multiple access (CRMA) acoustic data transfer among multiple vehicles in close proximity.
- Integrated undersea/satellite network communication architecture, protocols.
- Optimum search strategies related to mission goals, sensors, and communication constraints.
- Measures of effectiveness in group performance.
- Optimization in group behavior (individual capability versus inter-individual communication limits).
- Convergence of acoustic navigation precision by bootstrap methods.
- Optimal initial deployment of multiple vehicles for desired adaptive behavior and mission completion.

Sensor

- MEMS technology for low power, low cost, wide dynamic range mechanical transduction.
- Fiber optic/spectrophotometer technology for optical, chemical biological sensing.
- Inversion of acoustic communication data packets for sound speed field (tomography).

Propulsion

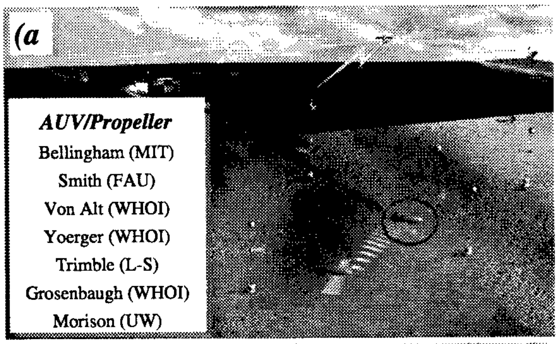
- Stability in high sea states.
- Performance optimization over wide speed ranges.
- Propeller/buoyancy driven hybrid vehicles.

Power

- High pressure battery charging.
- Efficient, reliable underwater non-contact power coupling.
- Renewable energy sources.

AOSN System Elements

- AUV (Propeller, Glider)
- AUV Docking
- Navigation
- Acoustic Communication
- RF Communication
- Energy
- Network Control
- Sensors



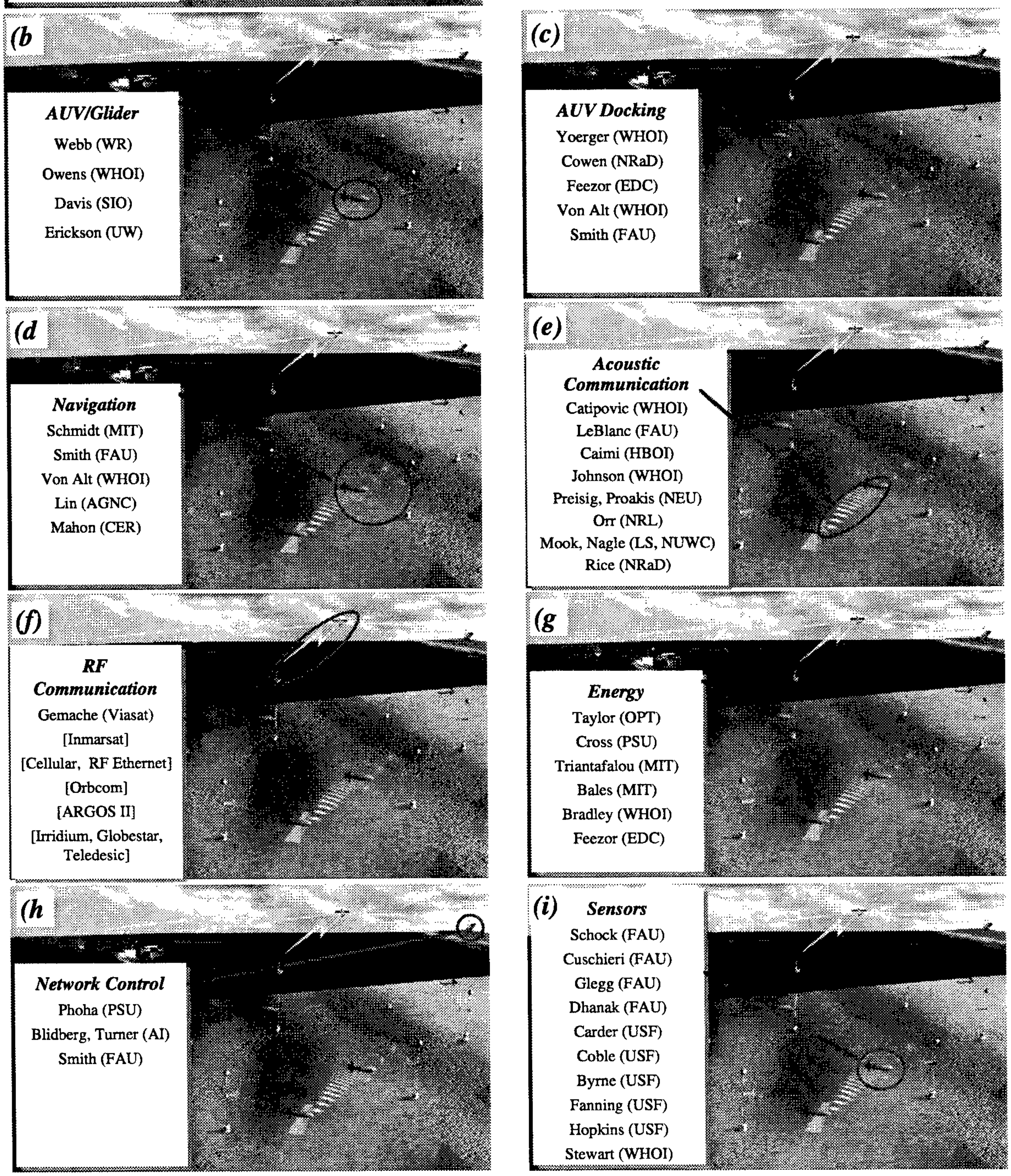


Figure 6a - 6i: *AOSN System Elements.*

Acoustic Communication Element

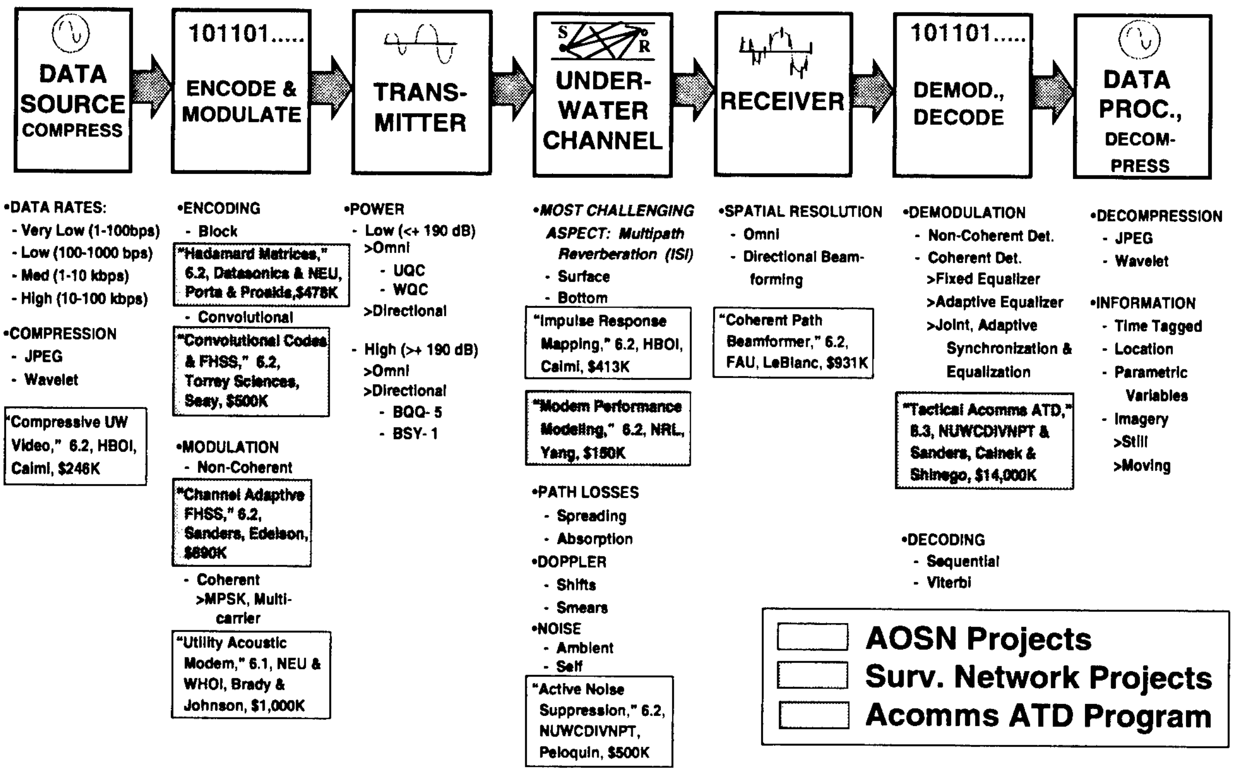


***Figure 7:** Acoustic Communication (6.1/6.2/6.3).*

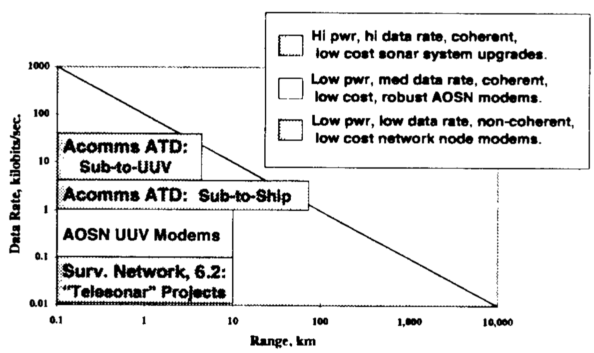


***Figure 8:** Acoustic Communication.*

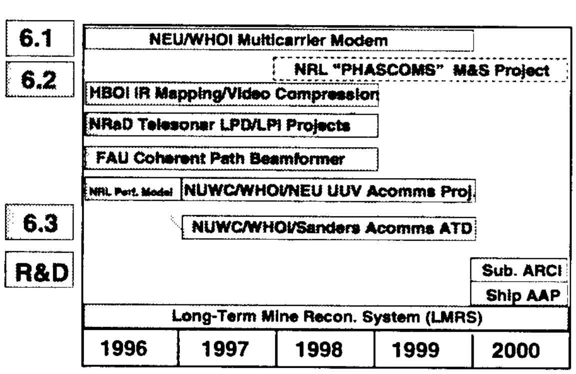


***Figure 9:** Acoustic Communication Roadmap.*

AOSN Demonstrations

- Frontal Dynamics Experiment (Haro Strait)
- Deep Convection Experiment (Labrador Sea)
- Seafloor Geo-Acoustics (Florida)
- Coastal Predictive Skill Experiments (TBD)
- Bathymetric Mapping (NAVO)
- V. Shallow Water Recon (Spec Ops)
- Mine Countermeasures (TBD)
- AUVSI Underwater Competition

Acoustically Focused Oceanographic Sampling – Frontal Dynamics in Haro Strait

Accomplishments

- Tomographic network with 4 VLAs deployed in highly dynamic coastal environment.
- Low, medium and high frequency tomography.
- Moving source tomography with AUVs.
- 66 single and dual AUV missions with ADCP, CTD and side-scan imagery.
- Low rate acoustic communication for adaptive AUV control.
- LBL acoustic navigation of AUVs.
- Effect of sound on marine mammals.

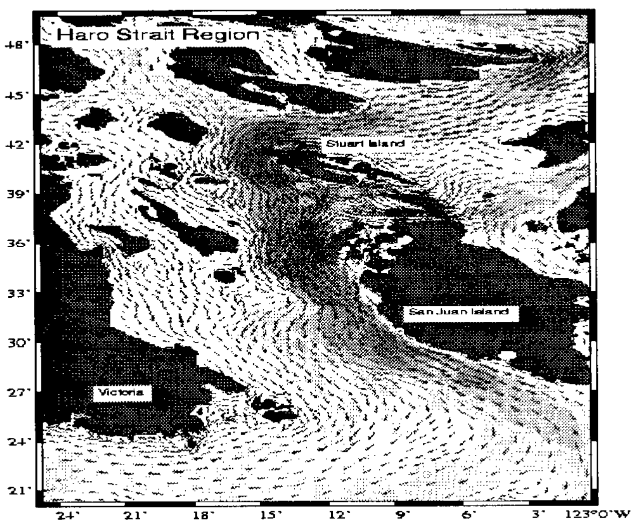


Figure 10: *Frontal Dynamics Experiment (Haro Strait). Predicted surface currents at 1800Z, 1/7/1996 (From Pawlowicz and Farmer, Institute of Ocean Sciences).*

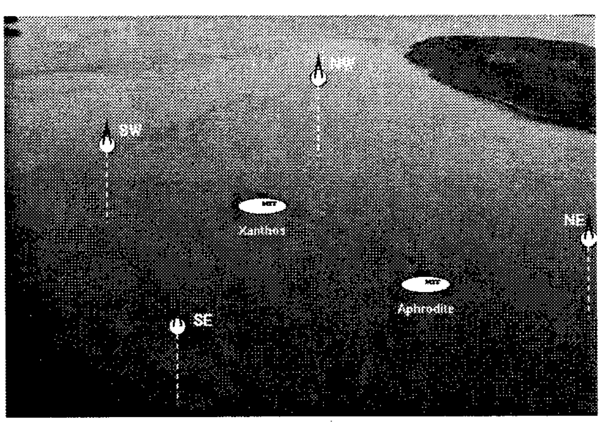


Figure 11: *Haro Strait Frontal Dynamics; acoustic network.*

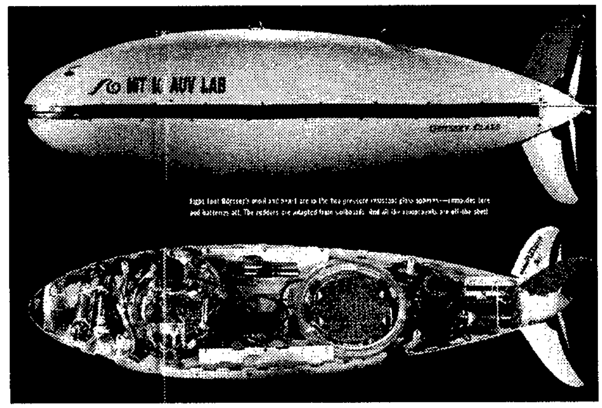


Figure 12: *Haro Strait Odyssey Configuration.*

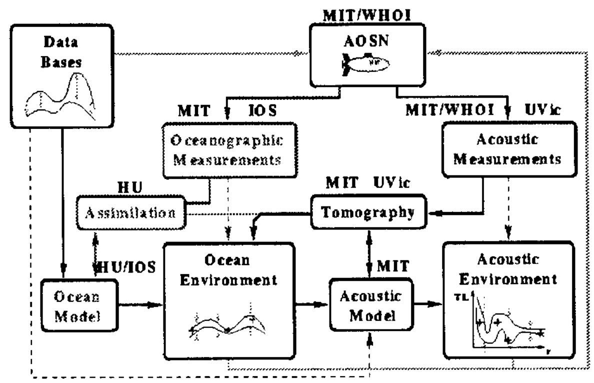


Figure 13 *Haro Strait Frontal Dynamics: estimation of the ocean and acoustic environments.*

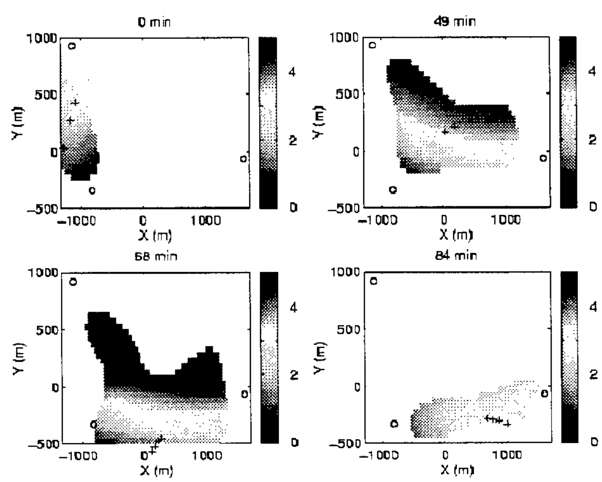


Figure 14: *Haro Strait Low-frequency Tomography: sound-speed perturbation, z = 40-50m.*

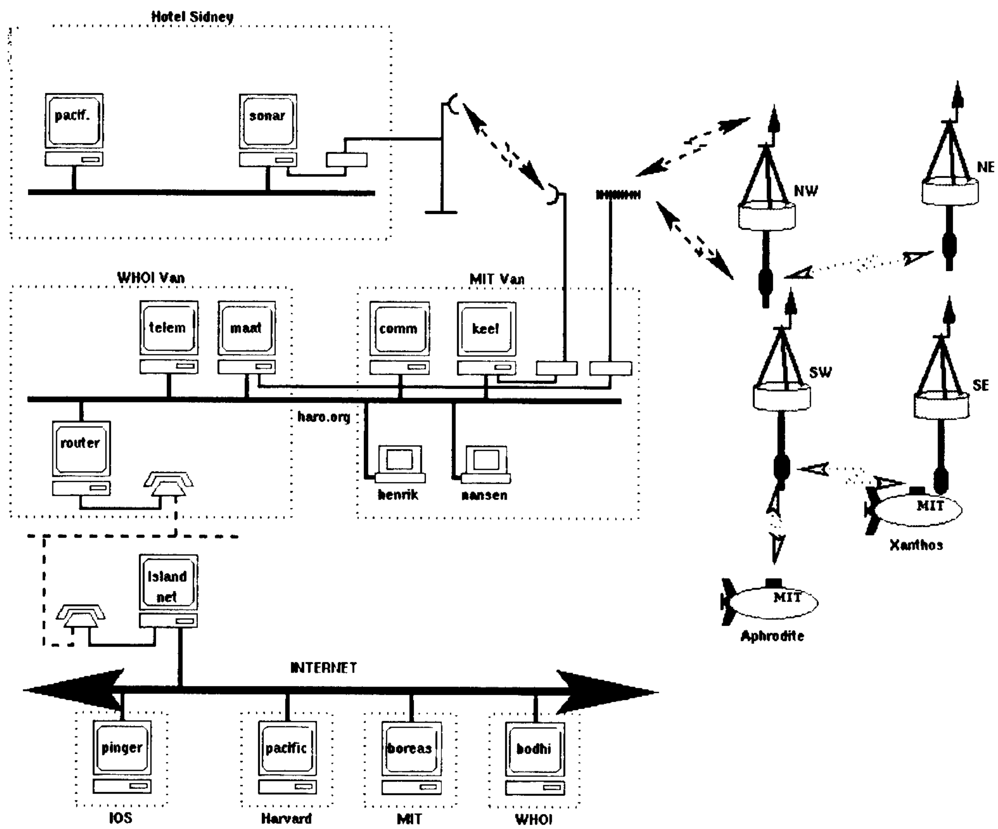


Figure 15: *Frontal Dynamics Experiment (Haro Strait): network configuration.*

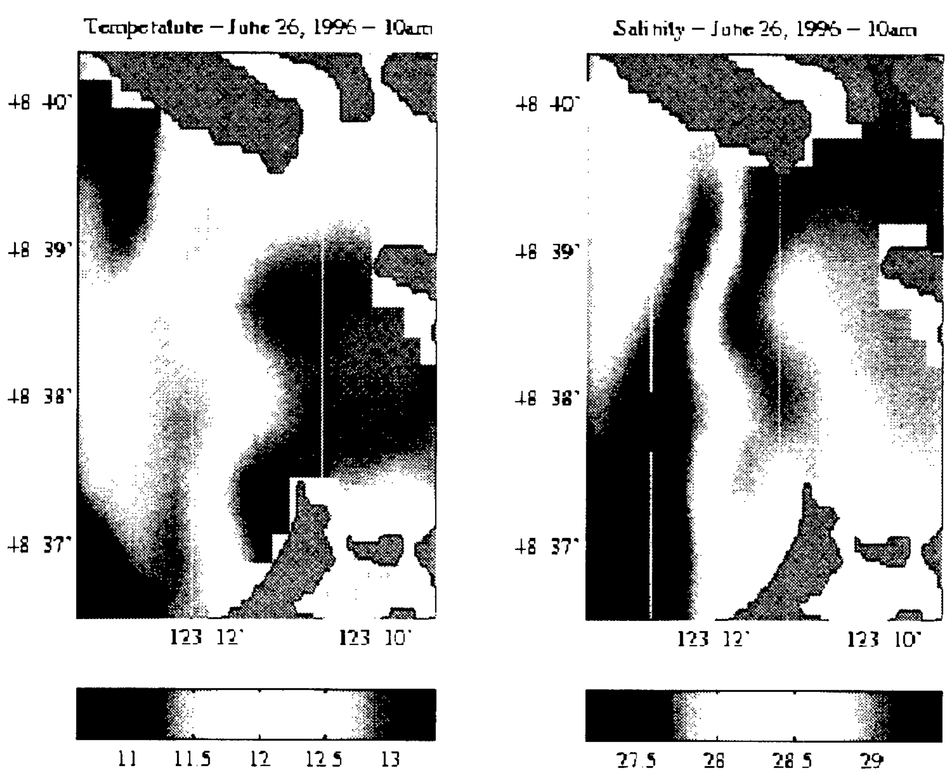


Figure 16: *Frontal Dynamics Experiment (Haro Strait):assimilation and modeling temperature and salinity forecasts.*

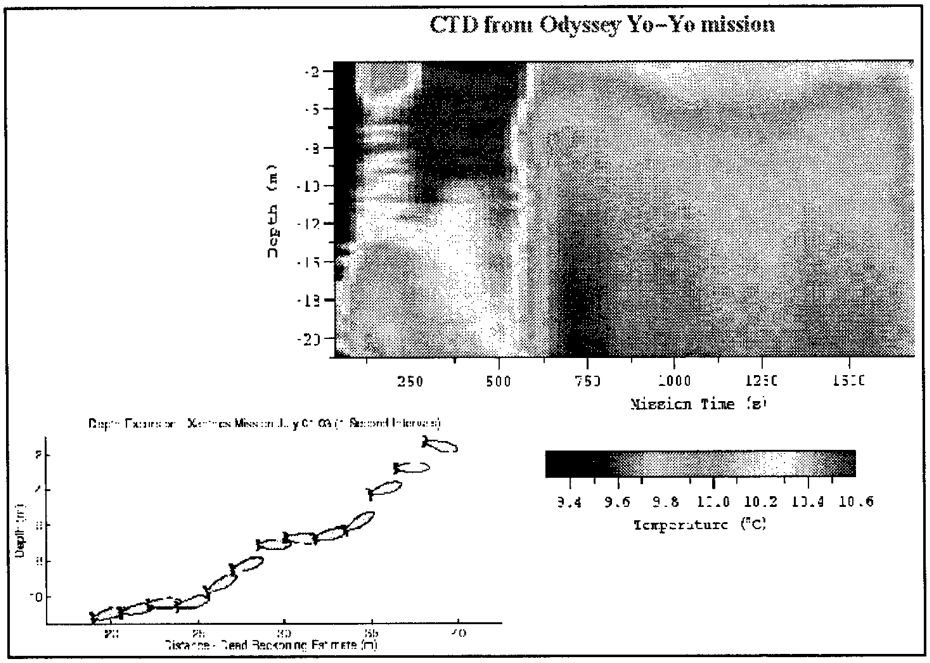


***Figure 17:** Frontal Mapping with Odyssey AUV based on model forecasts, Frontal Dynamics Experiment (Haro Strait).*

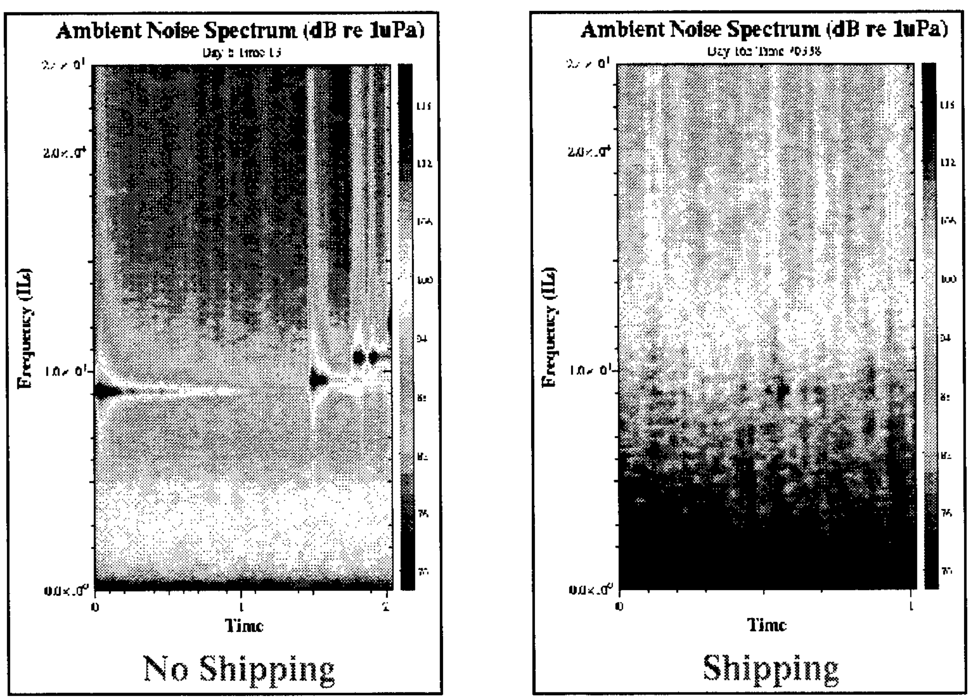


***Figure 18:** Long Baseline Acoustic Navigation, Frontal Dynamics Experiment (Haro Strait).*

CONCLUSIONS

- AOSN feasible for mapping highly dynamic coastal oceanography on multiple scales.
- Ambient noise due to shipping severe problem for acoustic systems.
- High-rate acoustic communication not yet robust in highly dynamic coastal environments.
- Closed-loop Acoustically Focused Sampling not yet achieved in real time, but accomplished with some delays.

Adaptive Sampling of Deep Ocean Convection

Bathymetric Map of the Labrador Sea

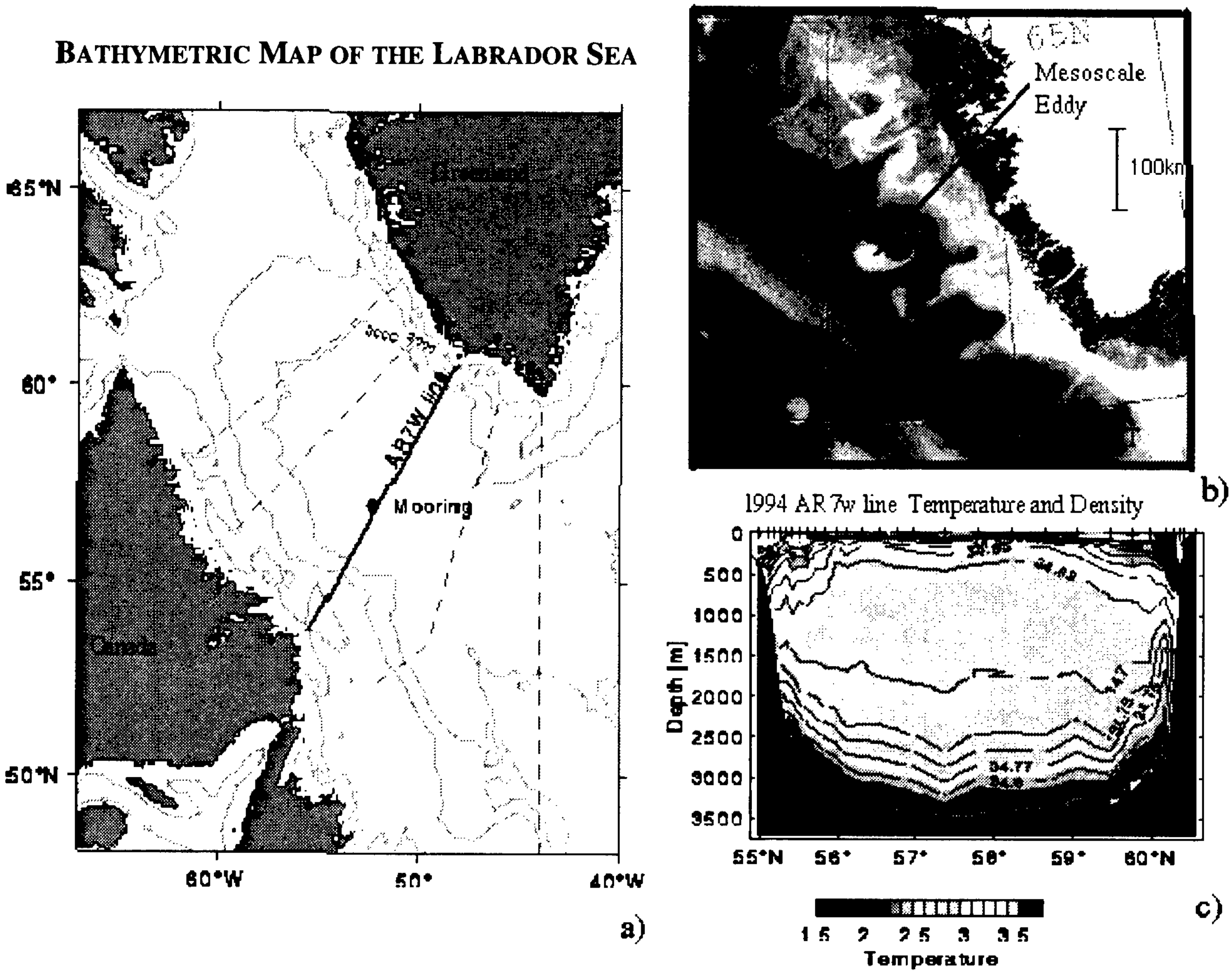


Figure 19: Deep Convection Experiment (Labrador Sea).

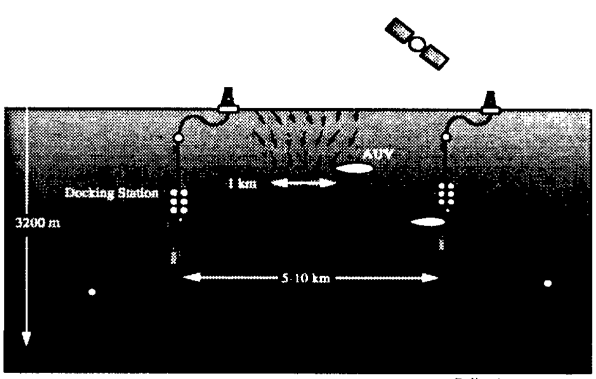


Figure 20: Deep Convection Exeriment (Labrador Sea).

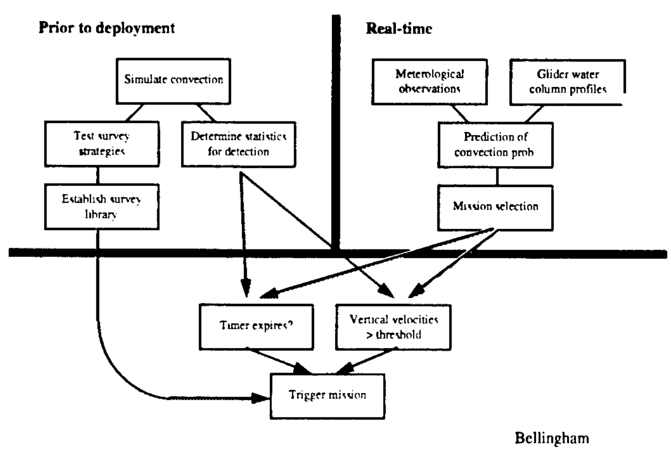


Figure 21: Mission Triggers; Deep Convection Experiment (Labrador Sea).

INTELLIGENT INTEGRATION OF INFORMATION: MINING THE INFORMATION INFRASTRUCTURE

Dr. Robert C. Spindel

ABSTRACT

The explosion of publicly available information in easily accessible digital form, and the inevitable evolution and global expansion of networked systems well into the 21st Century, provide opportunities for greatly enhanced intelligence, surveillance and reconnaissance. The key to effective exploitation of this resource will be the ability to extract relevant information out of a large body of mostly irrelevant data, and tailoring it to the needs of the Naval warfighter. This can be accomplished by adapting specifically for Naval applications data-mining techniques being developed in the commercial sector.

SUMMARY

An exploding global information infrastructure consisting of high-speed, digital, networked, information systems, easily accessible world-wide, provide sources of information that can be critical to military success and that offer opportunities for enhanced intelligence, surveillance and reconnaissance. The ability to mine this information (which is also available to an enemy) effectively and efficiently will be an essential part of achieving information superiority.

While commercial interests will pace the technologies associated with data mining, information extraction, content management, and display, they will not be tailored to the specific needs of the military user, or the even more particular requirements of the Naval user. The Navy must undertake the responsibility of developing application specific data mining algorithms and intelligent software agents that will provide Naval Forces with the custom products they need to fight and win.

INFORMATION INFRASTRUCTURE

The information revolution that we are witnessing today will continue well into the next century. It is characterized by rapidly proliferating and globally linked communication and data networks, information systems, and digital technologies that together will provide a broad range of information and communication services world-wide, readily accessible by U.S. Naval forces, as well as by our adversaries.

Naval forces will be increasingly dependent upon these information resources to accomplish a broad set of missions, ranging from ambassadorial visits and humanitarian relief at one end of the scale, to military action on the other, whether brief, swift action to deter aggression, or supporting longer-term regional conflicts. The tenets of JCS Vision 2010, dominant maneuver, precision engagement, full dimensional protection and focused logistics, each depend on the ability to exploit all available information sources to best advantage-- from historical and archived, to real-time and in-situ, and from secure and classified, to open and public. The victor in future conflict will be characterized by information dominance – information superiority – in tactical data and situational awareness, intelligence, surveillance and reconnaissance. The ability to fight and win will depend on dominating the technologies of information collection, dissemination, fusion, interpretation and management. In its recent report on Technology for the United States Navy and Marine Corps, 2000-2035 (Vol. 3, "Information and Warfare," National Academy Press, Washington, D.C., 1997), the Naval Studies Board of the National Academy of Sciences states, "A major challenge for the Department of Defense and the Department of the

Navy will be the development of strategies and organizational structures to allow for maximum utilization of global commercially developed information systems . . ."

Most of the technology associated with the 21st century information infrastructure is being developed by the commercial sector, and except for perhaps a few special requirements, such as multi-level security protection and access, certain special sensors and sensor interfaces, and low probability of intercept communications, the Navy can adopt these advances and exploit their capabilities.

However, while the commercial sector will develop information management techniques tailored to its special requirements, it will not develop those specific to Naval applications. The Navy must sign up to this task.

Extraction of Content

A rich source of information is the Internet and World Wide Web, and similar civilian and military information networks. Data available on the web even now can, if assembled and presented correctly, yield potentially very important military information. Given the inevitable evolution and global expansion of information-based systems well into the 21st century it is clear that the ability to mine these sources of information will be essential to achieve information superiority. Further, since this information is also available to an enemy, who will undoubtedly use it, our ability to extract and utilize the correct information must be more effective and efficient.

The issue is not accessibility to the information, but rather extraction of content. It is the gathering of relevant information with the rejection of the irrelevant, and the processing of that data so that it takes a form useful to the end-user. There is a burgeoning glut of information, and it is clear that the trend will continue. Data bases are huge, and growing. New sensors, many addressed in other parts of this report, will generate new data sets. For example, remote sensing systems will provide additional information on the dynamic state of the oceans which will require software to monitor data streams, and to update data descriptions, so that time critical missions, disaster prediction, logistics support routing, and other needs can be met. Data must be discovered, organized, cataloged, interpreted, processed, tailored, and finally communicated to the warfighter.

The requirement is to provide an information product custom made for a particular user.

Intelligent Software Agents

Intelligent software agents are a key to accomplishing this. They can be constructed to be aware of a users' needs, to ferret out information to satisfy those needs, and present it in a form that is efficient and pointed. They can accomplish this without user intervention, indeed, without the user even instructing them. While commercial search and inference engines satisfy certain data mining requirements, military needs are sufficiently unique to require especially designed and configured agents, tailored to specific users, tasks and missions.

Mission Planning – An Example

Mission planning, a crucial precursor to military action, and the intelligence that must be gathered and integrated to construct an effective plan, provides an example of how an intelligent agent might be employed. Even trained tactical officers find it difficult to consult all information sources, prioritize, affect, monitor retrievals (with recovery from failures), and assimilate the retrieved data into a useful form. Moreover, it is currently beyond even the capabilities of an highly trained and intelligent human to rapidly analyze, disambiguate, and resolve conflicts among geospatial data sets. Intelligent agents can be constructed to understand high-level mission goals, to execute only relevant information collection, to organize and fuse it, to self-monitor the status of the entire process, and then to deliver the product to the appropriate user. These activities can occur continuously, in real time, as background tasks, with the result of having available immediately the most timely information.

A simple example illustrates how intelligent agents might work in the context of mission planning: Joint Forces developing plans for an amphibious assault. While each participant needs much of the same information, each has special requirements, and benefits most from tailored views. Consider bathymetry and topography. For airborne operations, say pre-strike sorties, a planner may not need high resolution, but he may want data quickly. He may not need bathymetry, but will certainly want topography. He may be satisfied with archival data. The beach assault team planner needs high resolution data, and he probably wants to be able to update his information with in-situ, real-time collection. He will want detailed bathymetry in the LCAC assault corridors, and in the surf zone, and he will want detailed topography in the beach and craft landing zones. The follow-on logistics support activity planner may only need high quality data in areas where temporary port facilities are established, and low quality, or even no data, elsewhere. Each profits most by specifically tailored information. Of course, this simple example might not require an intelligent software agent, but when one considers the enormous variety of actions, plans, and parameters that are needed to complete a successful assault, it is not difficult to image the benefits of agents automatically sorting the data, assessing it for quality, retaining only the relevant portions, formatting it for different applications, and therefore providing users with the specific product that meets their need.

Other examples of the need for intelligent agents are provided by even the most casual search of the unclassified Internet, the Defense Internet, or any one of the many commercial or government database services (e.g. LEXUS, NEXUS, FBIS, SIPRNET). An inquiry on almost any subject will return sometimes hundreds of data sources, articles and other links, only few of which are pertinent, and none of which may be in the most efficiently presented format. A further difficulty that can be overcome with intelligent agents is the variation of names associated with the same thing. An elevated location can be called a hill, mountain, peak, berg, rock, mesa, volcano, butte, summit, and so on, and it can be abbreviated as mt., mtn., mnt., mount. An agent can understand the user's basic information requirement, say what is the highest point within a 50 km radius of the assault location, and can locate it no matter what it is called in various databases.

The Naval Pacific Meteorology and Oceanography Facility's new METOC center, SMARTCEN, described in an article in this volume, is an example of where an intelligent information integration capability, based on agents, would enhance the ultimate METOC product. SMARTCEN has been established to explore many aspects of information gathering, especially through the unclassified Internet and the restricted SIPRNET, to support Navy missions and mission planning, in particular for the Sixth Fleet.

The University of Washington's Applied Physics Laboratory and Department of Computer Science and Engineering have developed several approaches to intelligent agents for METOC data and mission planning. The search engine Flipper, using Metacrawler/Softbot technology allows geospatial data collection agents to communicate their needs directly without human intervention. Flipper accesses information stored in HTML pages that are normally accessible to humans, queries multiple pages automatically and in parallel, sorts the query responses by a rudimentary data quality measure, and returns the data to the requesting agent. This simple, centrist approach has demonstrated how several significant information management burdens can be shifted away from the human.

They have employed a mobile agent framework in their Tactical Environmental Information Agents (TEIA). This development was driven by the need to respond to an emerging requirement to gather, store, and use real-time, in-situ measurements from operational combatants in unsurveyed littoral waters. An application was developed to integrate data from real-time (AN/SQS-53C sonar system) and historical sources to estimate parameters that influence the propagation of sound. The application displays its data in multipanel visualizations that are synchronized with real-time data acquisition and processing. It embodies software that mediates and coordinates multiple 'views,' which include displays, but also refer to access to only relevant parts of the whole data set (such as in the bathymetry example above), and to specific processing to meet a particular user's requirements. The goal is to develop tactical environmental information agents that can be embedded into Naval systems such as SPAWAR NITES, ICAPS-II, SFMPL and SIMAS-II.

ISR MISSION: IMPLEMENTING ISR CONCEPT

CAPT Gerald K. Nifontoff

SUMMARY

The theme of our symposium is "ISR" (Intelligence, Surveillance and Reconnaissance). ISR is not necessarily clearly defined, but can be described as a concept that looks at all information sources, especially sensors, in an integrated way. The concept's main assumption is that the information from multiple sources, properly fused, enhances the warrior's knowledge beyond what is provided by the individual sources. It is a generalization of the rather simple functionality that exists today, for example the correlation of ELINT and radar information. ELINT generally provides good classification clues but poor position information, while radar generally provides accurate position information and few classification clues. When properly fused, ELINT and radar information is turned into enhanced knowledge, i.e., both position and classification. Generalizing, one would presume that the more different information sources (including, e.g., intelligence databases) one can apply to a problem, the better the level of knowledge that can be achieved.

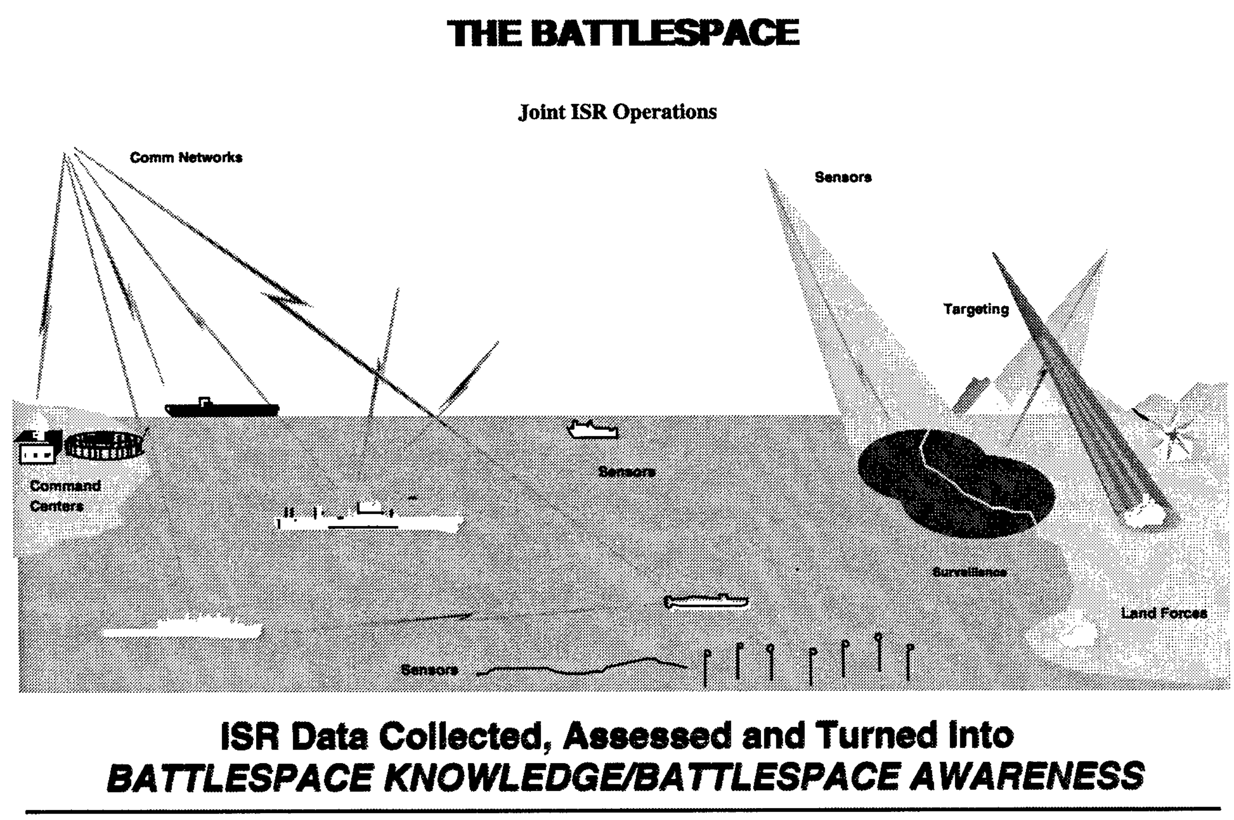


***Figure 1:** The Vision: Intelligence Surveillance and Reconnaissance (ISR) "On Demand".*

We're looking at the ISR concept relative to the broad problem of Ocean Surveillance, whose targets include both surface ships and submarines. Ocean Surveillance includes not only surveillance of ships and submarines, but also of the environment itself, since knowledge of the environment is known to enhance the performance of conventional target sensors, and is, by itself, important to the Navy's use of the ocean.

The military's emphasis has shifted from the open ocean to the Littoral, where both target surveillance and environmental sensing are much more complicated. In addition, the Command and Control philosophy has shifted completely from one that relied on the "push" of information to the warfighting commander, to one that assumes the commanders want access to everything, all the time, in a "pull" framework. Information overload is, of course, a problem . . . and we're seeing it.

At the most simplistic level, we see all sensors and sources of information forming a virtual "sensor grid" and being able to feed a virtual "information transfer bus," from which the warrior can pull information to feed fusion engines, visualization tools, decision aids, etc., when needed. The broad technical challenges associated with this vision include:

- Establishing the needed connectivity and bandwidth;
- Establishing rules for managing huge distributed databases;
- Developing data mining tools ("aglets"?) to find information;
- Developing knowledge discovery tools to turn information into knowledge;
- Fusion engines?;
- Inference engines?;
- Visualization tools?;
- Automating operator analysis and decision functions for sensors;
- Orders of magnitude more information from sensors / databases; and
- The number of sensor operators has to be reduced by an order of magnitude.

The fundamental question to be asked of our panelists is: "Given what we know about national sensors, undersea surveillance sensors, commercial sensors, and environmental sensors, how can they be used together to provide an Ocean Surveillance capability better than we have today?" The underlying problem is that we currently find it very difficult to fuse the outputs of our many sensors and the contents of our many databases into a coherent tactical picture.

Some Aspects of the Problem

- There are two aspects to the problem. The first is: How do we massage the information available from all our sensors, to turn it into awareness and knowledge for the warrior? The second is: For which sensors, and under what circumstances, does an investment in sensor and fusion technology make sense?
- The first question is rather far reaching, and we could meet for months to discuss it. The second question is a bit more tractable...and should be our current focus.
- The second question breaks down into two more components. Which pairs of sensors can provide more knowledge if their outputs were fused than if their outputs were used independently? And what is the potential operational value of each sensor pairing? Pairing is used here in a general sense . . . extendable to larger sets.
- There is no specific set of sensors that can adequately detect, track and localize all the targets that might be of interest in Ocean Surveillance, under all circumstances. There are numerous factors that need to be taken into account. Some obvious ones, which drive sensor effectiveness are:

Operational Factors

- Types of targets, and how one would detect them:
  - Submarines, periscope depth or deep – acoustic/non-acoustic; and
  - Surface ships, merchant or military – optic/ electromagnetic/acoustic.

- The objective of detecting targets (drives time scale and tolerance for uncertainty):
  - Strategic surveillance – Indication and Warning;
  - Tactical surveillance – Operational planning;
  - Tactical reconnaissance – Battlespace knowledge / Force disposition/Seek engagement; and
  - Point or area defense – Battlespace knowledge/Force disposition/Avoid engagement.

THE TIME AND DISTANCE SCALES OF INTEREST:

- Days: 10^4 sq km
- Hours: 10^3 sq km
- Minutes: 10^2 sq km

TECHNICAL FACTORS

- Sensor coverage: area per unit time.
- Sensor sensitivity vs. target vulnerability (e.g., deep/slow submarines are not vulnerable to optic sensors).
- Sensor resolution in time and space.
- Sensor ability to classify targets.
- Cross-sensor connectivity requirements.
- Fusion capability - similar and dissimilar sources (e.g. sonar, ELINT and Intelligence database).

Some examples of what the panel might want to discuss:

- How well do current overhead assets work tracking surface ships? What is the potential value-added of using acoustic sensors in conjunction with overhead assets?
- What is the potential of using overhead assets for submarine detection? Again, in conjunction with acoustic sensors?
- How well can we classify ships using IMINT?
- In general, what are the multi-sensor correlation possibilities, and what might be their value-added?
- Can we discern "normal" and "abnormal" surface ship behavior patterns? Can we come up with a "motion model" to alert us to "abnormal" (e.g., mine laying or drug running) behavior?
- What are some options for environmental sensors, remote and *in situ,* that can be applied to predicting E/M and acoustic propagation.
- What commercial sensors can be applied to the ocean surveillance problem, and how?
- From an operational point of view, how well is the Ocean Surveillance function working today? (e.g., how many ships can we track? What more is needed?)
- If we need to do more, on what should we focus our Science and Technology efforts? What kind of algorithms do we need?

A GI/IMAGERY/OCN/WX SYSTEM OF SYSTEMS FOR OCEAN SURVEILLANCE

CAPT James F. Etro

SUMMARY

Given what we know about national sensors, undersea surveillance sensors, commercial sensors, and environmental sensors, how can they be used together to provide an Ocean Surveillance capability better than we have today."

The objective of military and civil ocean surveillance is to obtain knowledge and insight to the natural environment and the objects in the environment.

Many sensors (from various unrelated, often stove-pipe, communities) generate many sources of information and data. The sources are of various fidelity and accuracy based on location of the sensor, navigation of the sensor, the parts of the energy spectrum used and sensed, the time scale of change of that being sensed, and the repeatability of the navigation and sensing process.

All sensors/sources, if taken as a whole, can characterize the space and lead to the objective. Fusion of all the sources in a common system of systems, maintaining the relationships of the data and information, leads to characterization that leads to human visualization that leads to understanding to be acted on.

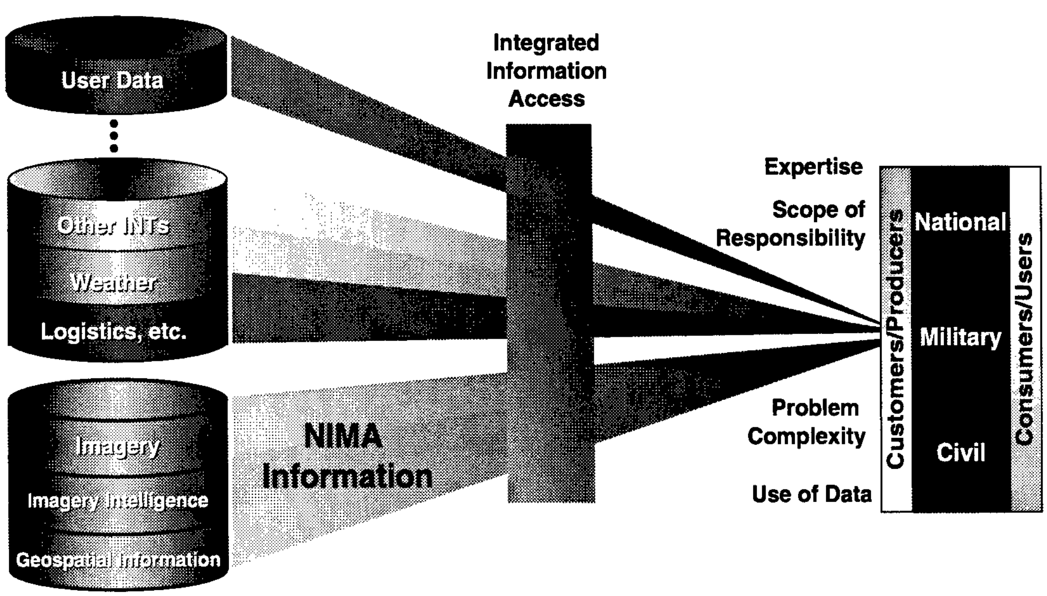


Figure 1: NIMA Strategic Direction Customer Need: Integrated Access to Information (DATA). NIMA provides information and data to address a range (strategic – tactical; military – civil) of customers and applications.

The technologies of extracting foundation information from source, data modeling, data storage and relationships, and communications are critical for improving ocean surveillance. If the technologies are treated as contributing to a system of systems none of the technologies become the critical path to improving our capabilities, but, all technologies impact by making the whole greater than the sum of the parts.

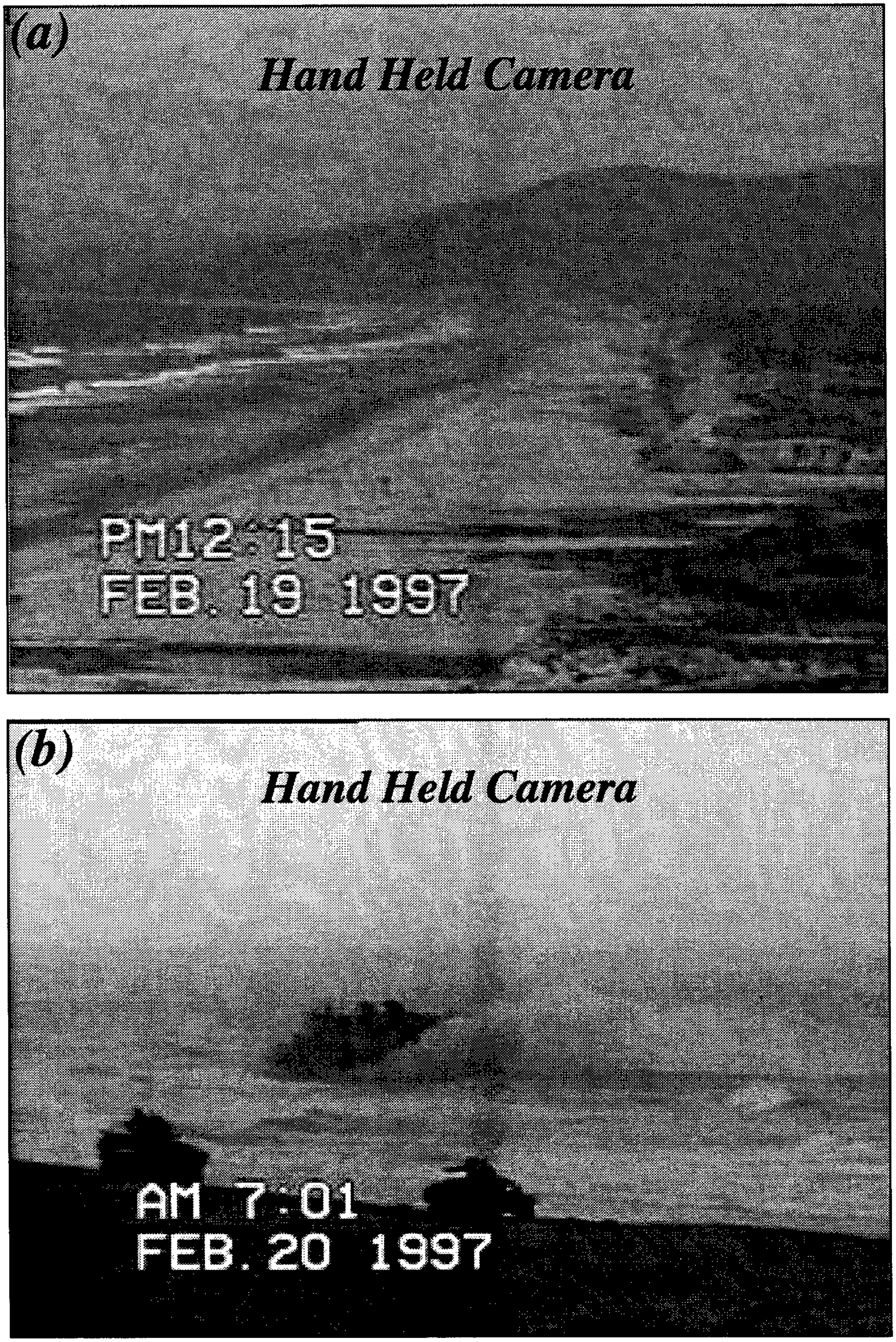
ORGANIZING CONCEPTS

- Understand and capture the fundamental (or foundation) data that the source (radar, sonar, radio, . . .) sees. That is, "what are all the data that can be derived directly from sensor analyses."
- Group foundation data into similar sets or understand and maintain the relationships or how the objects are related.
- Model and find commonality of the modeled representation of the foundation data.
- Capture the foundation data in x, y, z, and t coordinates with an objective understanding of the errors associated with x, y, z, and t based on the source and collection method employed.
- Be able to use data relationships to be able to fuse unrelated (stove pipe) data sets to model the real world. Retain the knowledge of errors in the fused data.
- Commercial technology is available to solve the problem.

ACTION

Stitch COTS packages together to demo capability.

Figure 2: IMAGERY – Can be exploited as source to full dB. Can be exploited to be used in visualization tool with data.



Figures 3a & 3b: *Tactical Imagery.*

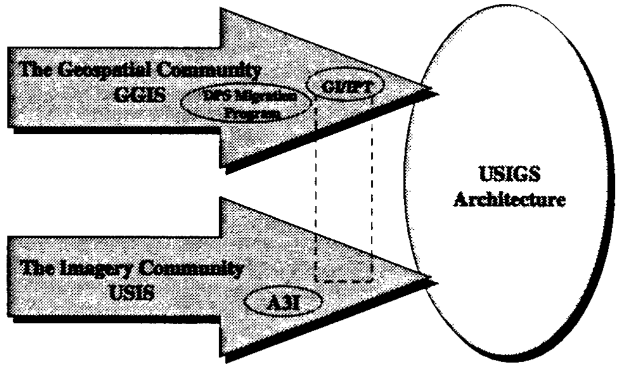


Figure 4: *USIGS Vision: The Road Ahead (USIGS = U.S. Imagery and Geospatial System). NIMA is working toward bringing imagery and geospatial data together.*

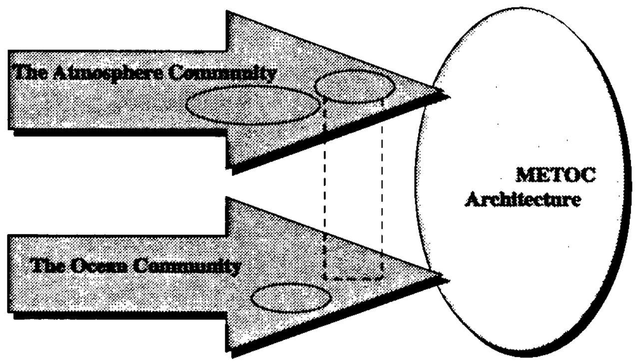


Figure 5: *Navy METOC Vision: The Road Ahead. The METOC community is bringing the MET and OCEAN together.*

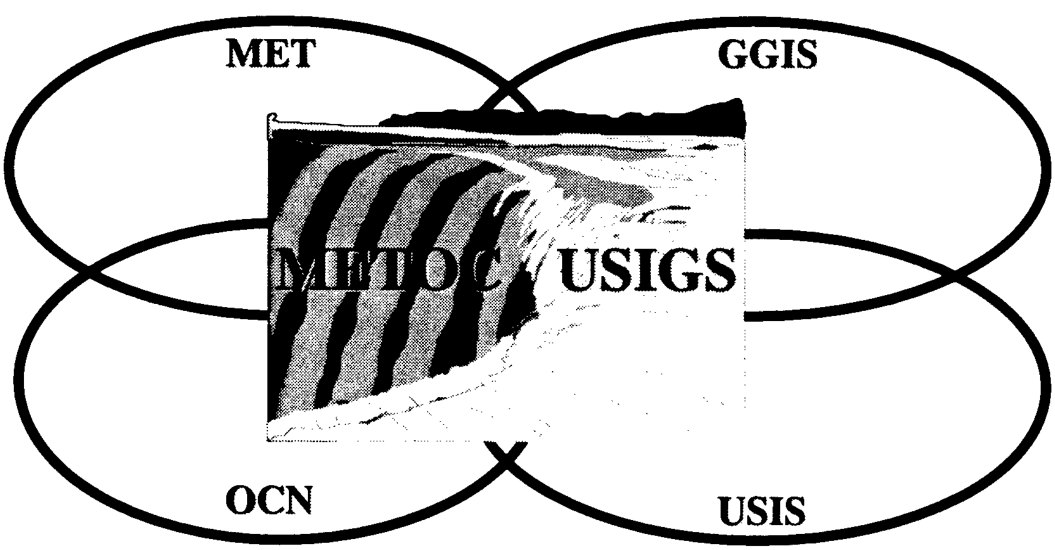


Figure 6: *System of Systems Architecture. Whole Earth Vision: The road ahead. The communities can work to this if the data (information) is electronic data and accessible.*

SHIP DETECTION TECHNIQUES

Dr. Daria J. Bielecki

OVERVIEW/SUMMARY

The Naval Research Laboratory has been supporting efforts focused on addressing the Navy's ocean surveillance mission. This has been done by executing demonstration projects for several agencies including the Office of Naval Research, Office of Naval Intelligence, the National Security Agency, and others. Through this sequence of demonstrations we have been able to demonstrate the ability to hold tracks on "most" deep water ocean going vessels. The demonstrations have shown that ship identification requires fusion with other Intelligence sources.

Part of this effort has been involved in the establishment of an R&D facility at the Chesapeake Bay Detachment of the Naval Research Laboratory. This facility is a fully automated chokepoint monitoring system which consists of a Raytheon Pathfinder Vessel Traffic Control (VTC) tracking radar, a set of ELINT receivers, and a short baseline Time Difference of Arrival (TDOA) system. The information from these systems are automatically correlated in a TAC-4 workstation 24 hours a day. The fused data is then automatically disseminated to NRL-Washington on a prearranged schedule for use as ground-truth data in a variety of analytical efforts.

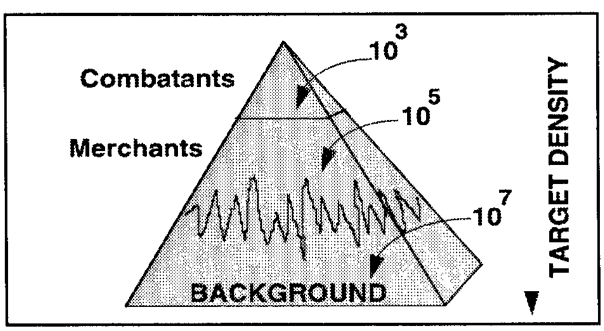


Figure 1: *Increased target density from combatants to merchants. National needs supported by series of ocean surveillance demonstrations.*

The most recent demonstration which was held in Oct-Nov 1996 focused on the fusion of information from two different sensors at an established maritime chokepoint. This exercise was able to show that data from National systems could be used to cue tactical sensors (acoustic and ESM) allowing the target to be acquired or reacquired by tactical units.

These efforts have illustrated that many different problems can have a common basis for a solution and that complex missions require smart ways of doing business which include multi-sensor cueing and operation and multi-agency cooperation.

NATIONAL NEEDS

DETECT, TRACK, ID TO SUPPORT

- Strategic Trade Intelligence
- Embargo
- Treaty Verification
- Counter narcotics
- ASuW, OTH-T
- Sanctions
- Arms Shipment Monitoring

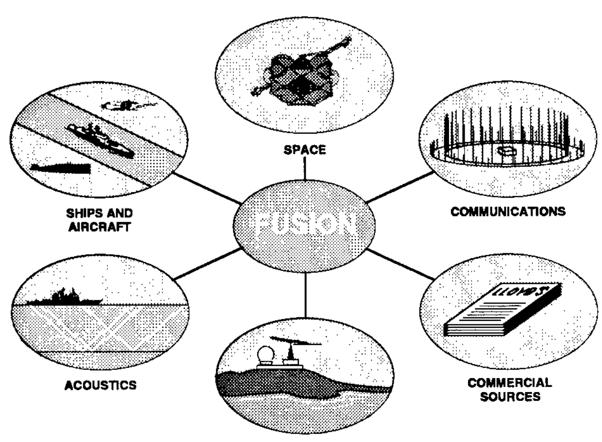


Figure 2: *Components of an Ocean Surveillance Architecture.*

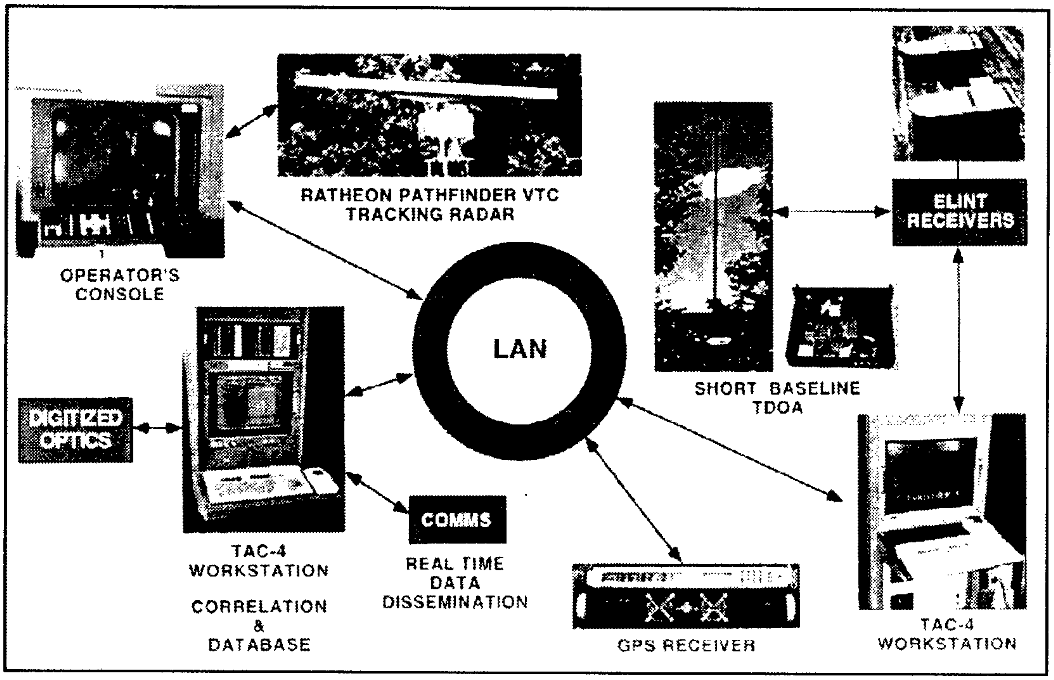


***Figure 3:** R&D Chokepoint Monitoring System located at Chesapeake Bay Detachment of the Naval Research Laboratory.*

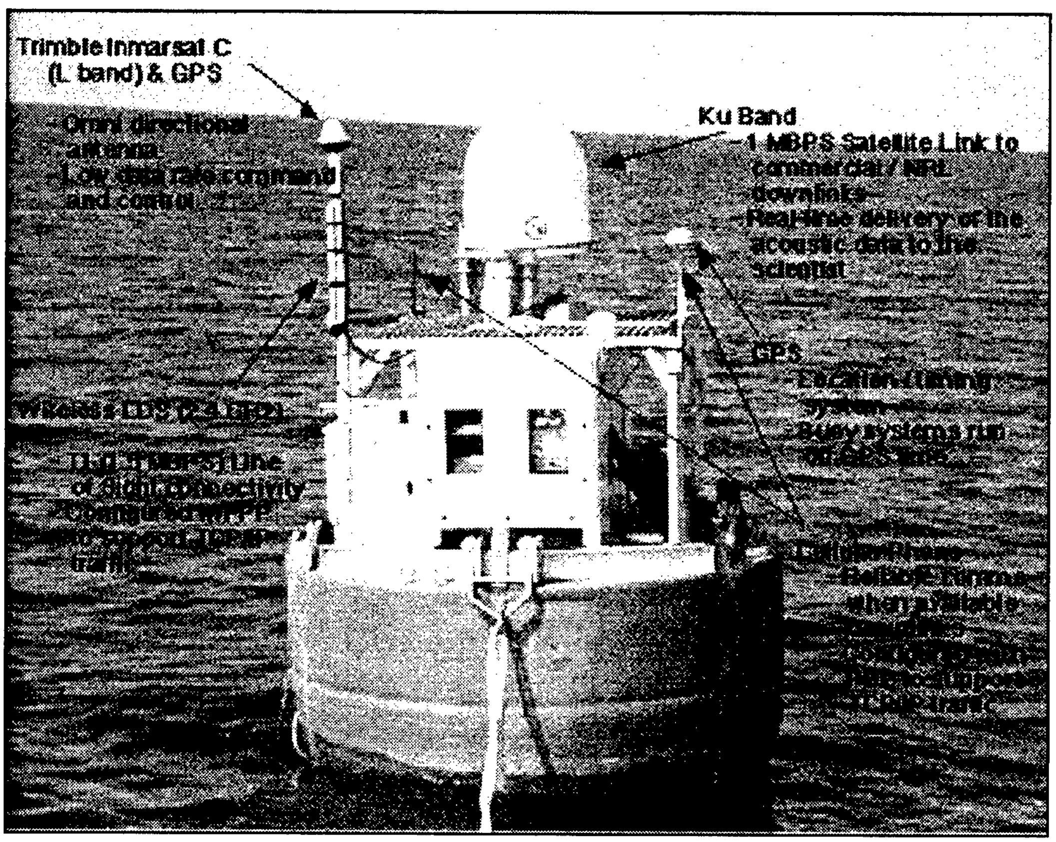


***Figure 4:** Example of multi-sensor buoy that could be used to cue other sensors and tactical assets.*

REMOTE SENSING OFF THE NEARSHORE

Dr. Rob Holman

NAVAL INTELLIGENCE INTEGRATION IN THE SURF ZONE AND NEARSHORE REGIONS

SUMMARY

- Many Important Nearshore variables are visible.
- Visible signals can be easily quantified.
- Primary challenge for moving sensors is dwell time.
- Confidence intervals required for all estimates.

THE PROBLEM

The Metoc and reconnaissance needs of Marine Expeditionary and Special Operation Forces are quite different from the traditional needs of the Navy. Many of their operational difficulties lie in depths shallower than 10 m where scales of change are short in both space and time. Wave heights and currents exhibit large spatial gradients that can impact operations, with bathymetry itself can undergo important changes in times as short as a day.

The nearshore is principally a civilian domain. In contrast to the deep ocean where naval forces have been responsible for the bulk of data collection and knowledge development, shallow-water coasts belong to the civilian communities who have developed a long-standing relationship with the ocean. Fisherman and surfers have an enormous corporate knowledge of the surf zone and very nearshore regions.

SOURCES OF INFORMATION

The nearshore plays a large role in the life of nearshore communities through both work and recreation. Coastal zone management for coastal towns is usually based on the extensive experience of individual professionals. Perhaps the most extensive knowledge base lies with older surfers

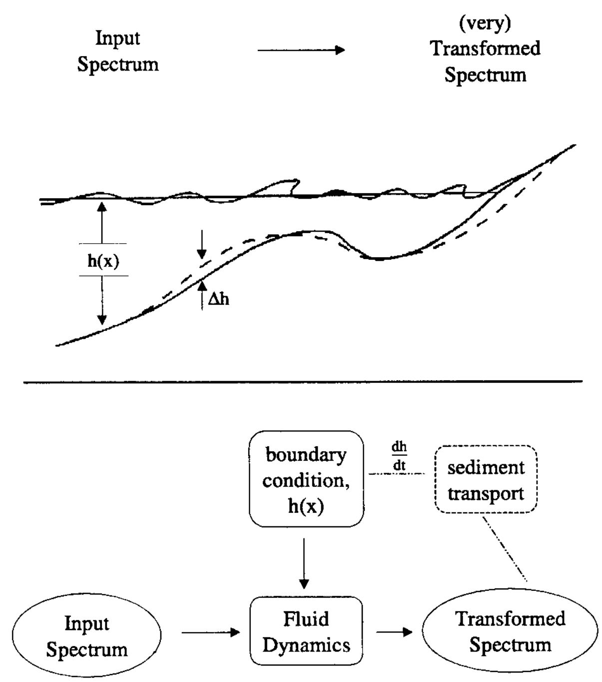


Figure 1. *The nearshore is a region wherein waves undergo a rapid evolution as they progress over shoaling bathymetry (upper panel). Spatial scales are short and gradients large. In addition, the bathymetry in turn responds to those fluid motions. The feedback between the fluid forcing and bathymetric response (bottom panel) gives rise to the potential for chaos and complex behavior in the nearshore. Sampling must accommodate this spatial and temporal complexity.*

who have had intimate contact with the nearshore over decades, and who have more practical understanding of nearshore wave and currents and the evolving bathymetry of a beach system than any other source. The value of this knowledge is shown by the fact that the chief analyst in the Warfighting Support Center, Kurt Meyers, bases his work on a lifetime of surfing and sailing experience (and is very good at what he does).

Sources of more quantitative data are becoming increasingly available on Internet and web site. For example, wave height data are regularly updated for many locations, while video imagery of a number of beach sites reveal a range of data. Naval Metoc groups are just beginning to exploit some of these sources.

For enemy-held sites, these data are not likely to be available and reconnaissance products must be based on modeling or remote sensing (or other clandestine approaches that are often dangerous or difficult). While models of many aspects of nearshore fluid dynamics are becoming quite useful, some aspects such as currents are not well handled, and all predictions depend on good knowledge of the underlying bathymetry. Bathymetry data, in turn, is highly changeable in ways that are presently not predictable, so must be sampled either *in situ* or remotely. Clandestine remote sensing requires image resolution that is more consistent with NTM or airborne sensors that with the bulk of available civilian satellites, although higher resolution space sensors are either being licensed at this time or are already becoming available in the civilian sector.

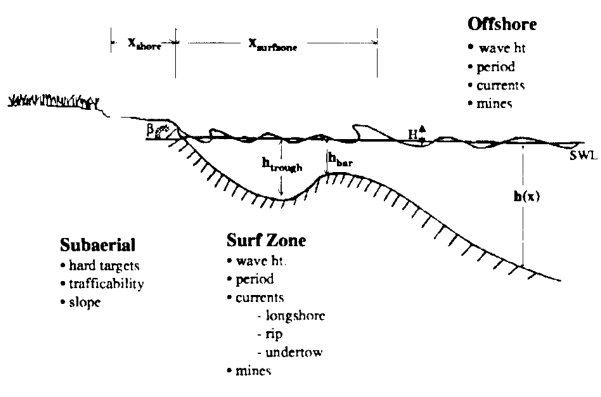


***Figure 2:** Naval Forces have interest in a range of variables in the nearshore. Physical scales include the width of the dry beach (distance to cover) and of the surf zone, as well as depths everywhere, but specifically over the sand bar crest and in the bar trough. Wave and current conditions are needed, as well as information on the foreshore slope and trafficability and the presence of mines.*

POTENTIAL FOR CONTRIBUTION FROM THE CIVIL SECTOR

A foreign country planning to invade North America could take advantage of the ready availability of enormous amounts of information on the surf zone and very nearshore. Less information is likely to be available for sites of strategic interest to the U.S. The information deficit can be addressed by either modeling (or understanding site analogs, e.g., a mud flat site or beach with a sand bar) or by remote sampling. The civil sector may make some contribution to the latter aspect if higher resolution sensors proliferate. Our knowledge holdings in nearshore dynamics and behavior, however, lie primarily on the civilian side. An enormous amount of practical experience and knowledge lies with coastal communities and individuals who live with the nearshore on a daily basis. More quantitative and modeling skills lie in academia, civilian federal agencies with coastal responsibility and the coastal engineering community.

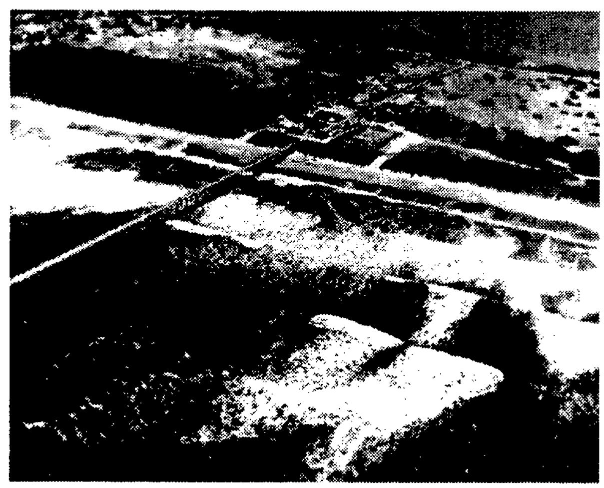


***Figure 3:** Many of the needed variables are directly visible by eye, or have usable signatures. For example, the width of the beach and surf zone are directly observable while the wave breaking pattern can indicate the presence of submerged sand bars. Advection of foam can be observed to estimate currents.*

AVAILABLE REMOTE SENSING TOOLS

ACTIVE
- RAR
- SAR
- ISAR
- Lidar

PASSIVE
- IR
- EO
  - Panchromatic
  - Hyperspectral

PLATFORM
- Spaceborne
- Airborne
- Fixed Platform

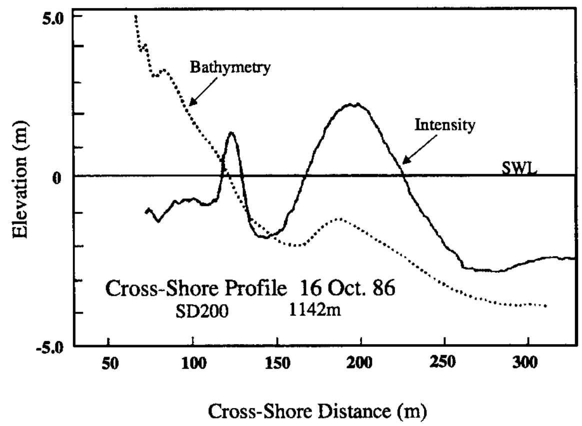


***Figure 5:** Previous ground truth tests have shown the relationship between submerged sand bars and the wave breaking signal visible from time exposures.*

> ***A number of sensors and platforms are available. The following figures, unless otherwise indicated, will focus on video imagery from fixed platforms.***

Oblique View

Rectified View

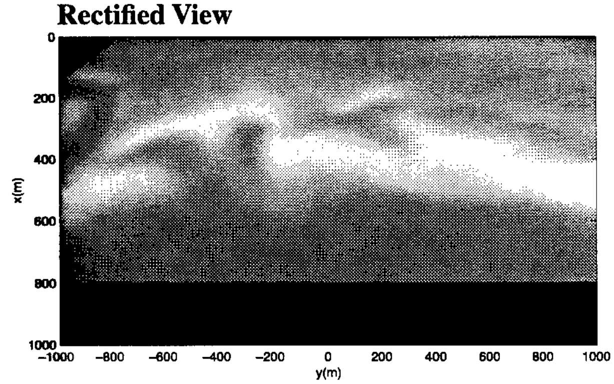


***Figure 6:** Yaquina Head, Oregon. These images can easily be collected and can span very large regions of beach. For example, the upper panel shows 5 km of the mid-Oregon coast near Newport. Using traditional photogrammetic approaches, maps can be made from these images, indicating the locations and scales of bars and rip channels, potentially very useful in planning for special operations.*

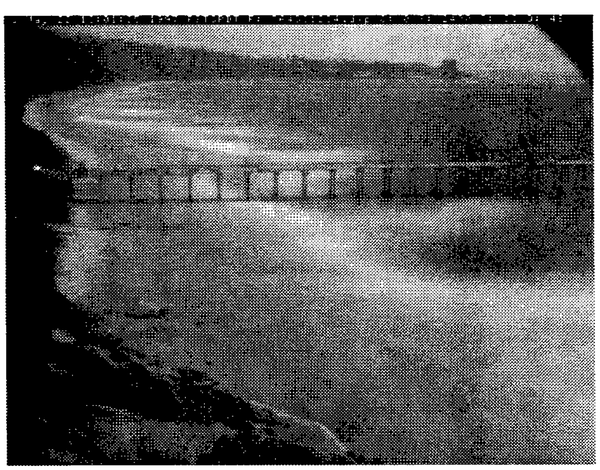
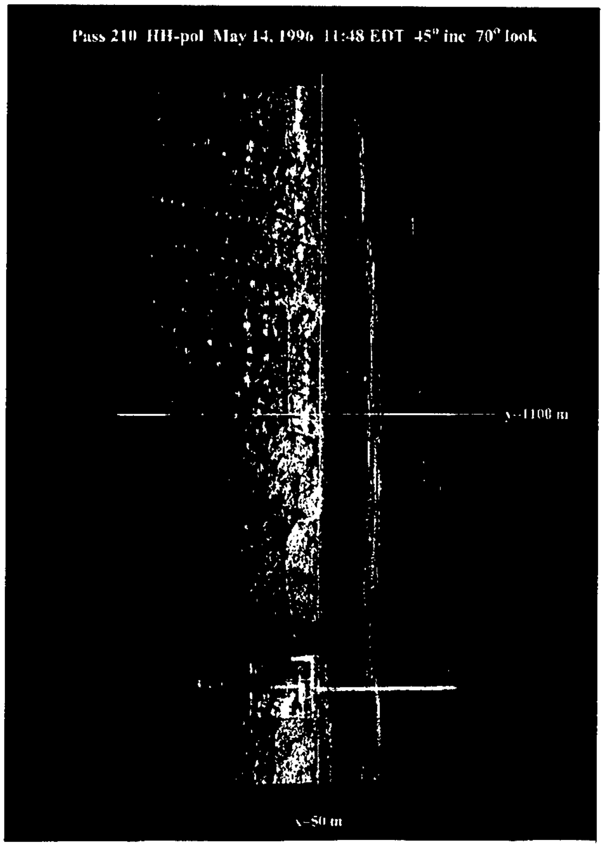
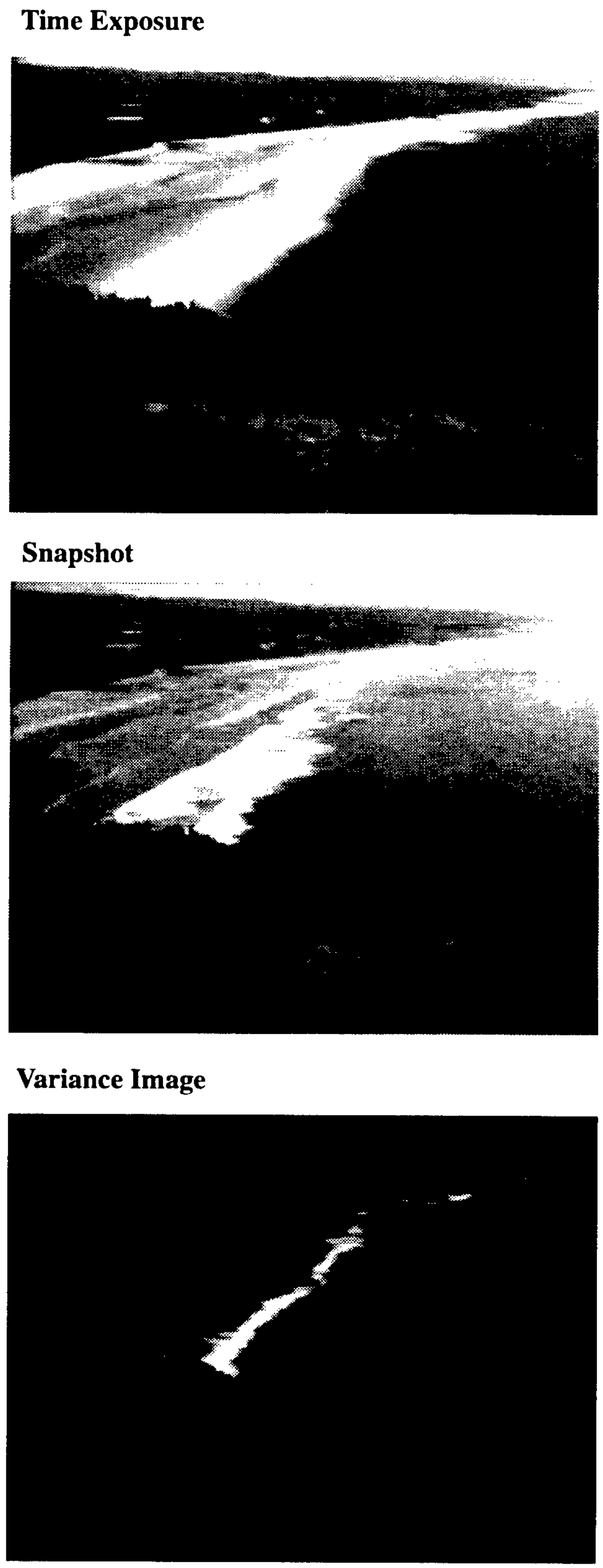


***Figure 4:** The presence of submerged sand bars can be inferred from the location of preferred wave breaking shown in a ten-minute time exposure image. This image is from the permanent Scripps Argus camera, May 22, 1997 (Oregon State University), available on the SIPRENT.*



Lyzenga
Erim

Figure 7: *Preliminary work with airborne SAR imagery (here at Duck, North Carolina) suggest the potential of SAR for revealing sand bars in a similar manner.*

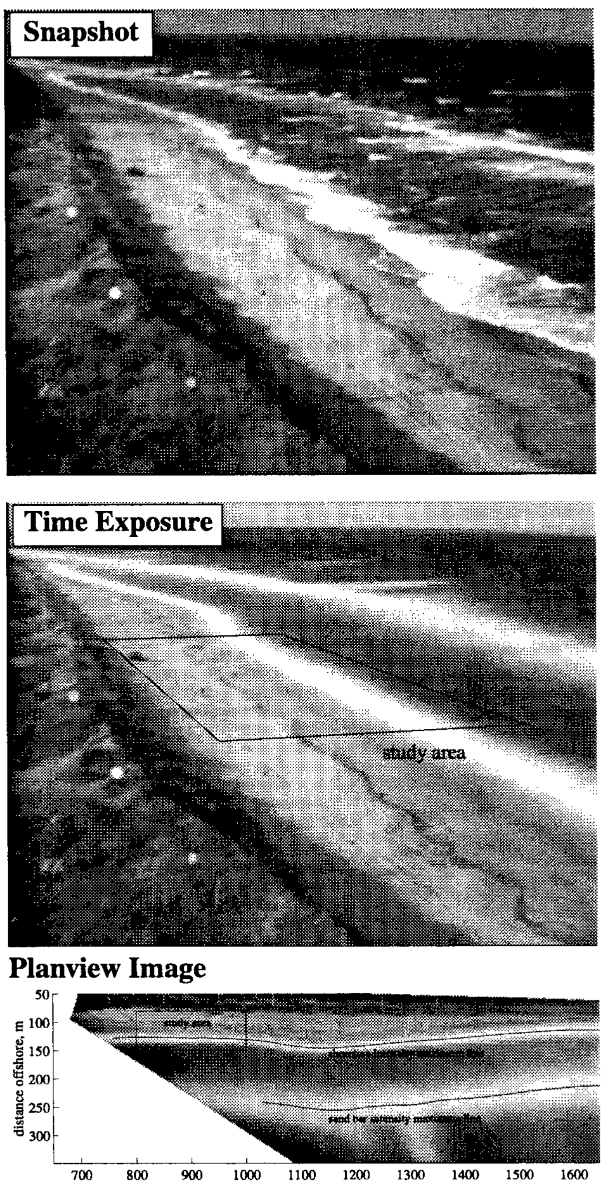


(Agate Beach, Oregon, 09/08/96)

Figure 8: *The upper and middle panel show a snapshot and ten-minute time-exposure image from the mid-Oregon coast. These type of images have been used for over a decade to study nearshore morphological evolution. More recently, different image types are being explored. The lower panel shows a variance image, for which the brightness of each pixel corresponds to the variance of intensity over the ten minute period. The beach, being bright but constant, disappears making the shoreline easier to extract.*

RESEARCH AND LOGIC ISSUES TO DO WITH TIME EXPOSURE ISSUES MAPPING OF NEARSHORE MORPHOLOGY

- Other Sensors?
  - No restrictions on sensor
  - Some artifacts with SAR
  - Signal processing issues for moving platforms
- Signal Processing Questions
  - Importance of record length (compared to wave group time scale)
  - Importance of N, Δt
- Errors in Xbar
- Loss of Signal (Small Waves, No Breaking)
- Effects of Currents?
  - Signatures of rip currents
- Identification of Hard Targets?
- Shelf Life of Map?



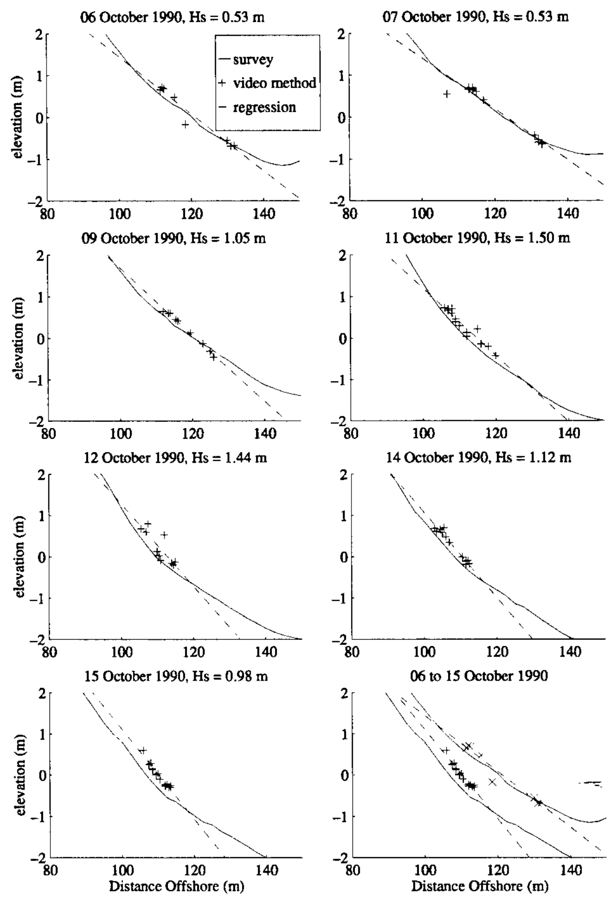


***Figure 10:** Estimation of the foreshore beach slope from maps of the moving location of the shore break with changing tide. Each plus sign is one location estimate. Each panel shows one day's worth of hourly estimates and the least-squares fit plane slope for that day. Curved lines are the measured profiles for the day. The dashed line in the bottom right panel shows the change of foreshore over the 10 days of sampling.*

***Figure 9:** The upper and middle panels show oblique snapshots and time exposures from Duck, North Carolina. Wave breaking at the shoreline (known as the shore break) yields a white band which can be used to demark the shoreline (in map view in the lower panel). Variations of the shoreline position with changing tide allows estimation of the foreshore beach slope.*

ISSUES OF CONCERN FOR THE FORESHORE SLOPE ESTIMATION TECHNIQUE

- Other Sensors?
  - Same as video time exposure
- Results Improve With Tide Range . . .
  - Also better at spring tide
- S/N Better On Low-Sloping Beaches . . .
  - But shoreline signature not as clear. improvement in other image type?
- Some Beach Geometry Sensitivities
- Couple With Model For Trafficability?

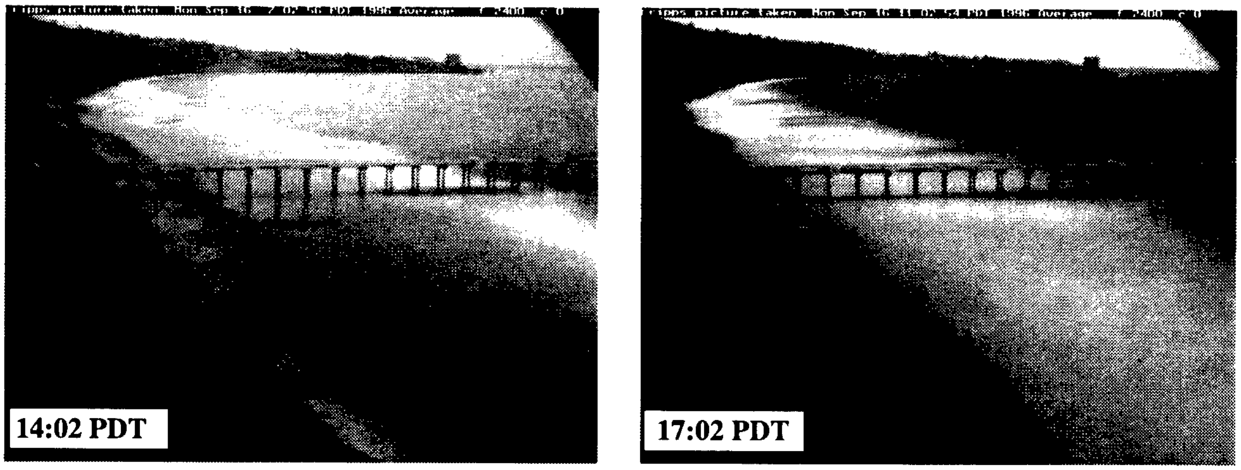
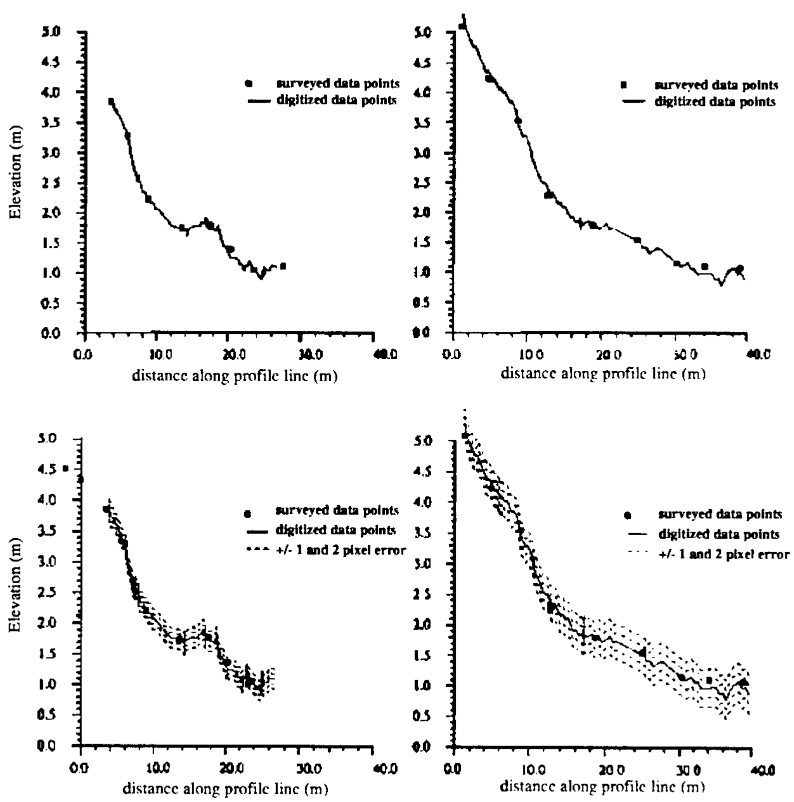


Figure 11: *Pier Shadows, La Jolla, California: Time exposure images from the Scripps Argus station also show clear shadows of the Scripps pier. Knowing the image times, these can be measured to reveal subaerial beach profile out to the mean sea level at the time of the image, and the tide level further seaward.*



Holman, Lippmann, O'Neill and Hathaway

Figure 12: *Test of the shadow technique done at Duck, North Carolina. Solid lines show the beach profile estimated from shadows, while the solid markers indicate surveyed values. The video technique usually provides values to within one pixel resolution.*

ISSUES CONCERNING SHADOW TECHNIQUES.

(Note that any source of shadow can be used (shadows of opportunity?)

- Primarily an EO technique
- Requires only a snapshot
- Any shadow will do:
  - Pier
  - Building
  - Telephone pole
  - Shadow of another plane?
- Can also use self-shading of the beach/dune?
  - Application of terrain masking

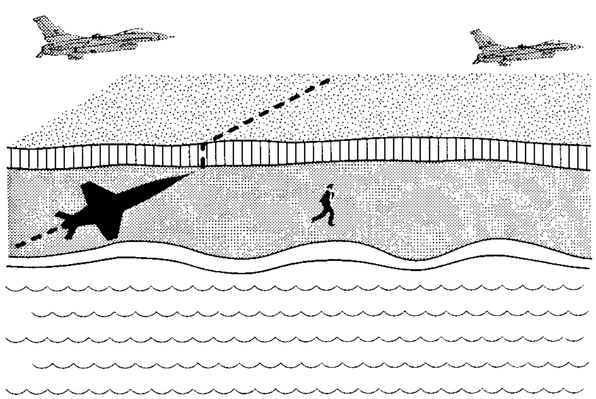


Figure 13: *Shadow technique.*

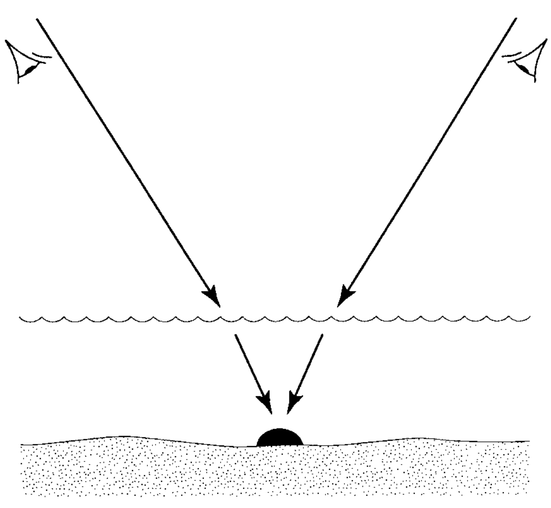


Figure 14: *Subaqueous stereo.*

SUBAQUEOUS STEREO

In principle, stereo approaches can be used to locate objects beneath the sea surface (hence providing bathymetry) provided there is sufficient water clarity and that the effects of a wave refraction surface can be removed. The latter issue could be a major problem.

ISSUES

- Water clarity
- Removal of waves
- Requires identifiable features

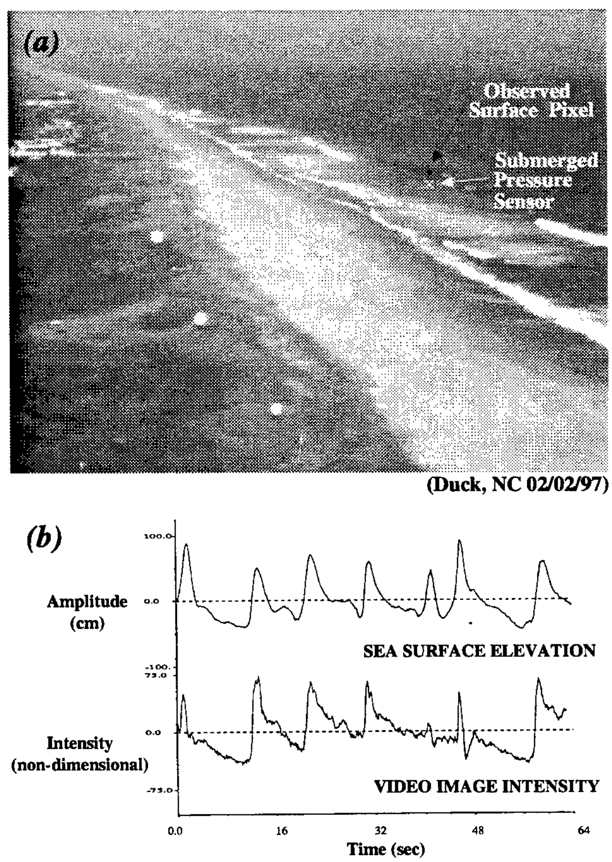


Figure 15a & b: *Pixel intensity time serires. Image data can also be used in non-traditional ways. For example, individual pixels can be monitored to provide time series of image intensity. The bottom panel shows that these time series can be excellent proxies for a submerged pressure wave signal. While not all cases provide as close a correspondence, video and* in situ *signals are almost always coherent with a locally-fixed phase.*

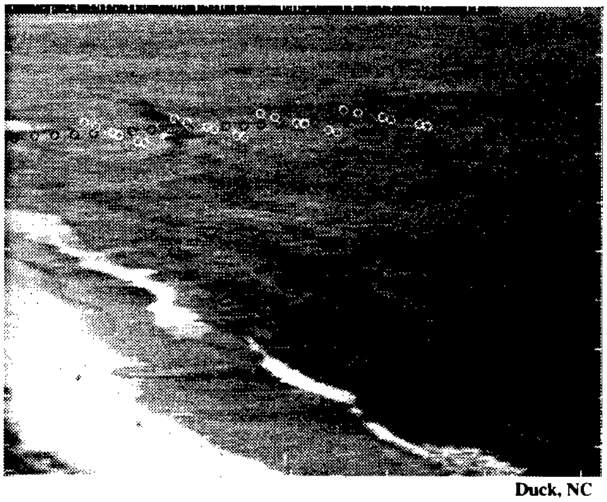


Figure 16: *Pixel array sampling. Collection of pixel time series from arrays of pixels allows array analysis for a range of oceanographic variables. These include wave period, wave angle (from longshore-oriented arrays of pixels), wave phase speed (primarily from cross-shore arrays) and water depth (derived from wave phase speed).*

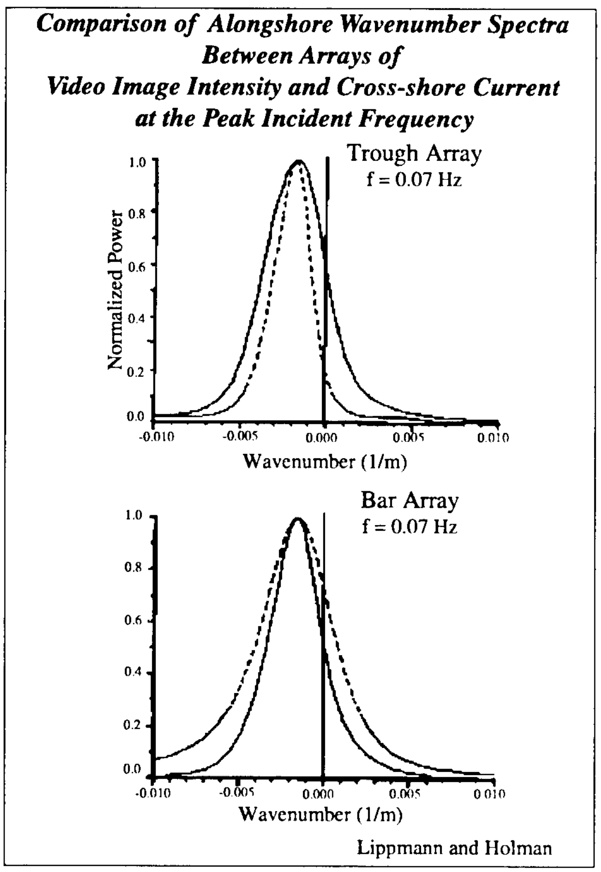


Figure 17. *Example comparison of wave angle (represented by longshore wavenumber) measured by an* in situ *pressure sensor and by a pixel array.*

Resulting Capabilities

- Wave Period
- Wave Angel of Incidence
- Wave Speed (Celerity)
- Water Depth (From Celerity)

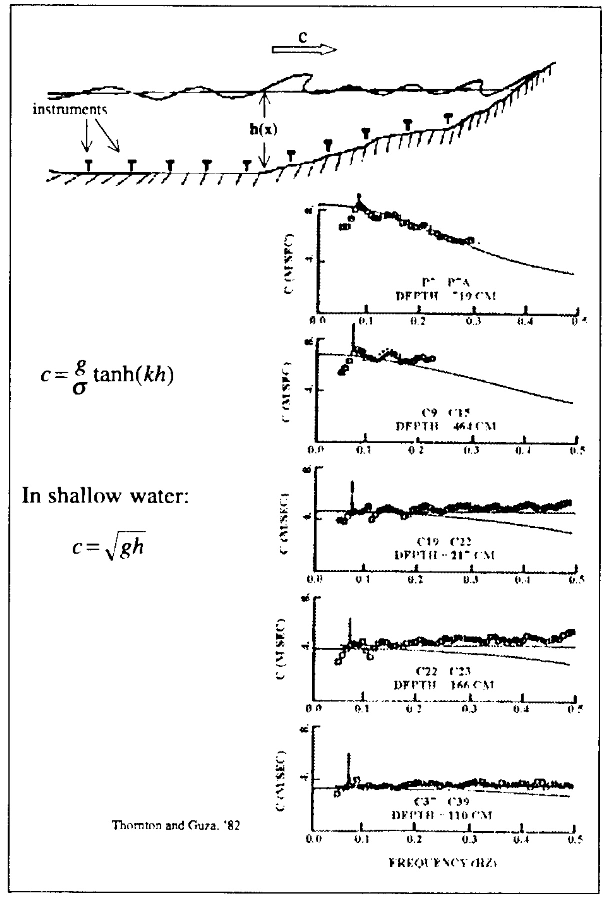


Figure 18: *Bathymetry estimation: The speed, c, with which waves progress across the nearshore is primarily a function of depth. Previous work on low-sloping beaches by Guza and Thornton has shown that this relationship works very well, especially near the incident frequency (arrow in each of the graphs). This suggests that the relationship can be inverted to allow depth estimation from remotely-measured celerity.*

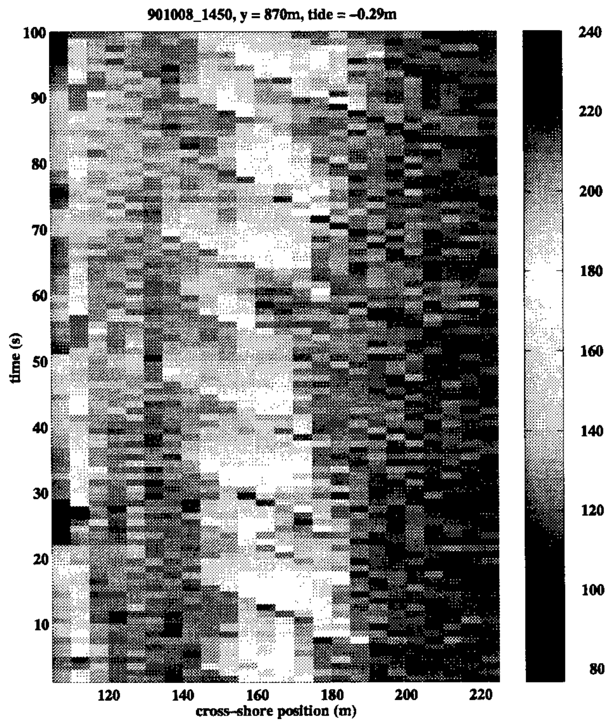


Figure 19: *Intensity time stack, Duck, North Carolina. The basic data from the celerity analysis can be derived from a cross-shore array of pixel time series, shown in this figure. Time proceeds vertically. Oblique lines correspond to wave progressing onshore with time. The slope of the lines corresponds to the celerity (change of position with change in time).*

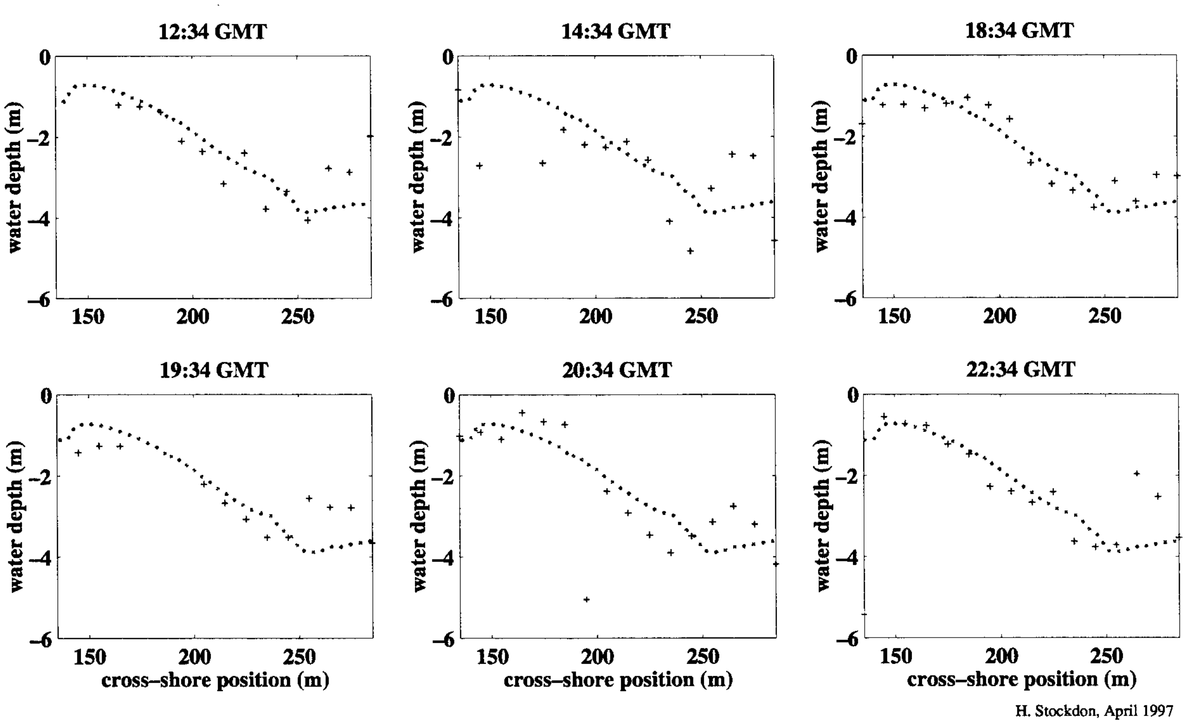


Figure 20: *Duck, North Carolina, April 7, 1997. Measured (dotted) and remotely-estimated (plus signs) depths from Duck, North Carolina, for a number of example data collections.*

BATHYMETRY ISSUES

Issues related to using remotely-measured phase speed to estimate depth. This is primarily a signal processing problem. Estimation of confidence intervals is required to separate valid from invalid results

- Test theory on Barred Beaches
- Modulation Transfer Issues
- Signal Processing? (Patch analysis)
  - Analysis Sensitivities
    - *Δt, T, Δx, Lx, Δy, Ly*
    - *High resolution techniques*
- Confidence Intervals
- "Condition-Dependent" Sampling
- "Use" Of The Tide

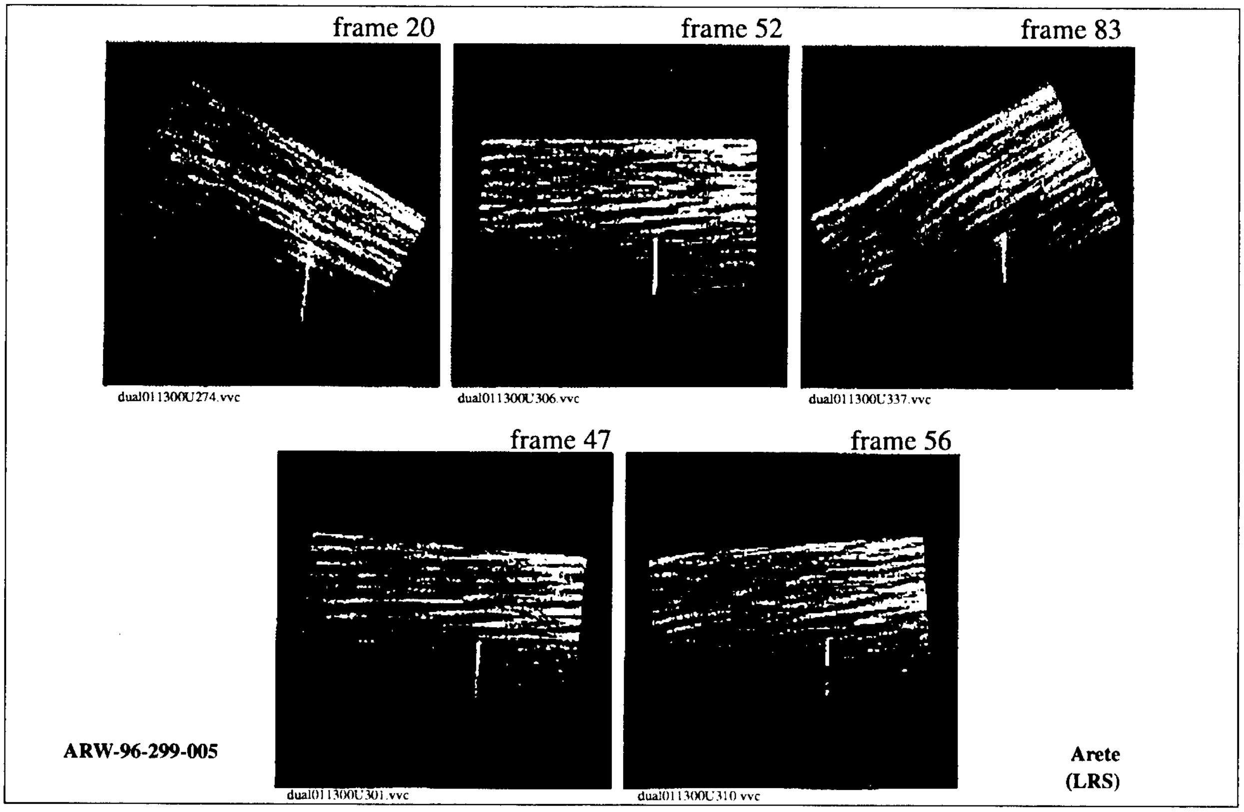
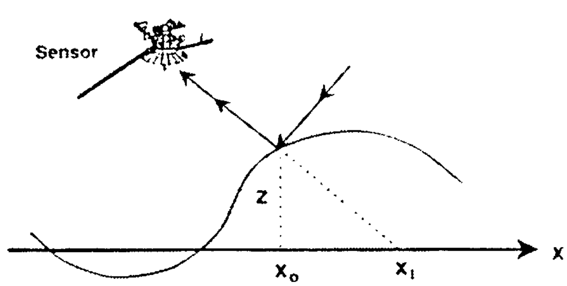


***Figure 21:** X-Band Spotlight SAR Images. This approach is also being tried for SAR imagery, here from the DCS system. Because SAR "sees" the waves in a complicated manner, artifacts such as an apparent turning of the wave direction must be corrected for by using a correct MTF (Modulation Transfer Function).*

Misregistration model



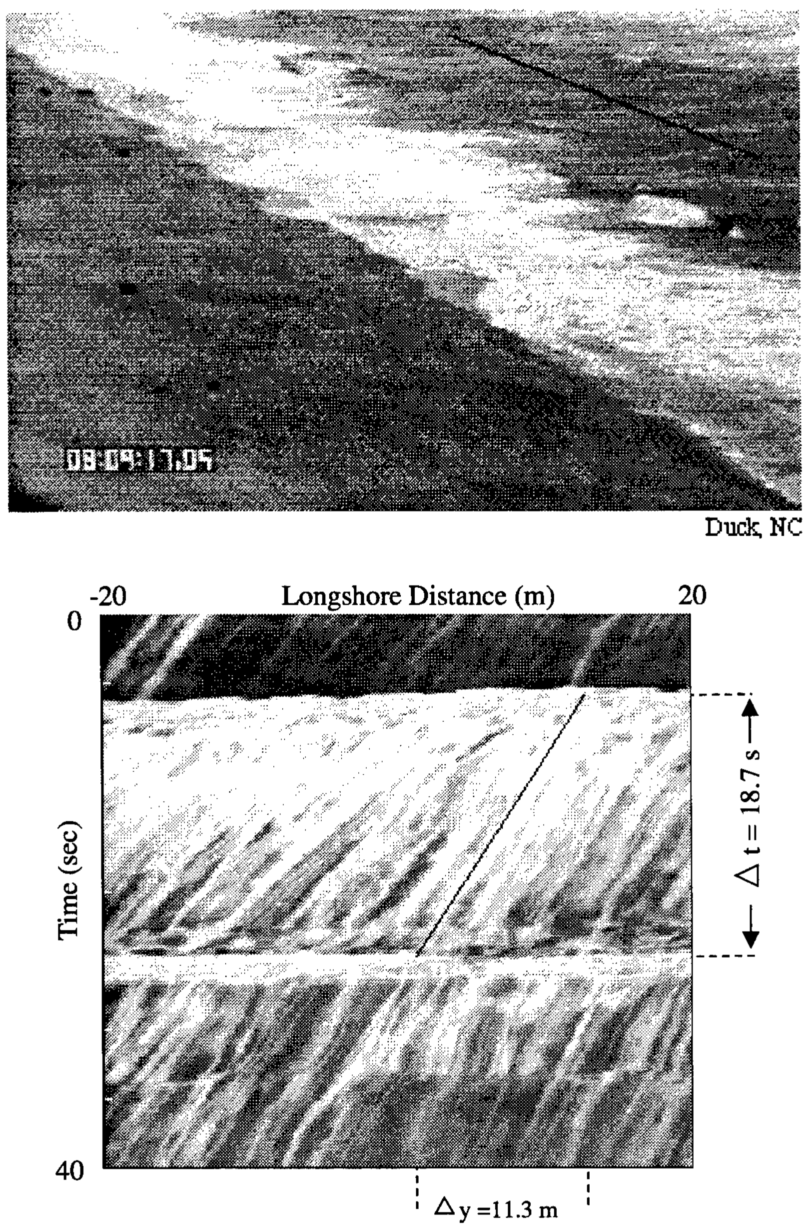
$$x_l - x_o = \cot(\psi)\, z(x_o, y_o)$$

Finite surface simplitude z introduces misregistration between the nominal image plane a projection X_1 and the truce ocean position X_0.

Random misregistration is analogous to jitter. It introduces a random point-to-point phase shift that blurs (rolls off) the high wavenumber transfer functions between ocean slope and measured radiance.

$$\left\langle \exp\left[-i k_x (x_l - x_o)\right]\right\rangle = \exp\left[-\frac{1}{2}(k_x \cot(\psi)\, \sigma_z)^2\right]$$

***Figure 22:** Oblique imaging of finite amplitude waves leads to an apparent mis-registration of the sea surface location by an amount that depends of the wave height and wavenumber. The resulting roll-off in the observed spectrum can be inverted to allow estimation of the wave height. This research is part of the Littoral Remote Sensing program.*



$$\text{Longshore velocity} = \frac{\Delta y}{\Delta t} = 0.60 \text{ m/ sec}$$

Figure 20: *Longshore current/foam drift. Longshore advection of foam can be used to reveal the longshore current. The data from this analysis comes from time stacks (bottom panel) collected using a pixel array that is oriented in the alongshore direction (upper panel). The slope of streaks in the time stack corresponds to the longshore current.*

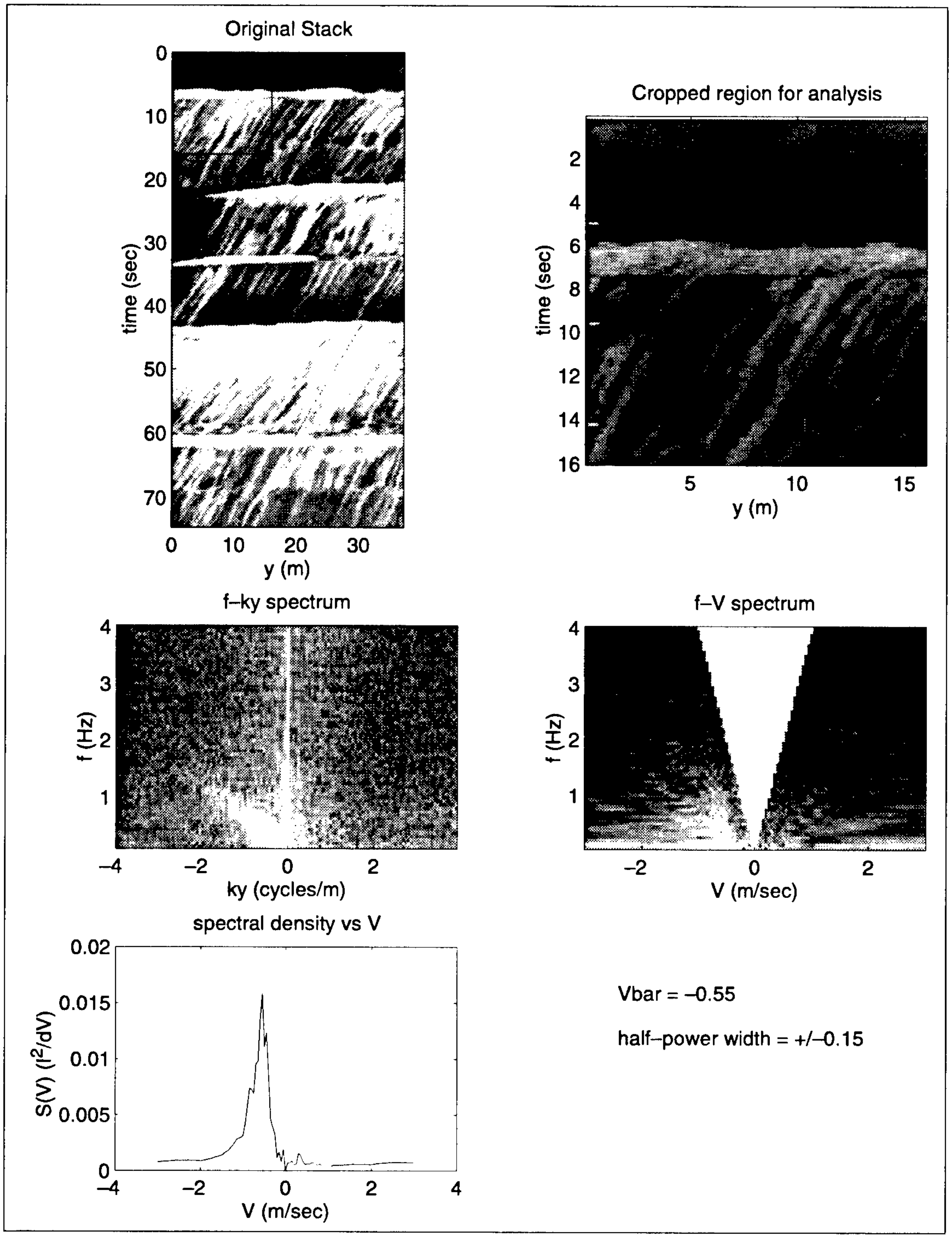


Figure 21: *The key to the research on estimation of longshore currents from foam advection lies in developing a robust estimator along with associated confidence intervals. This is another example of the importance of signal processing rigor in image processing analysis.*

OTHER ISSUES

Other broad issues that are important research topics for our understanding of the nearshore.

- Hard Targets
- Differences Between Beach "Types"
- Modeling Capabilities

SMARTCEN: CURRENT ASSESSMENT AND FUTURE DIRECTIONS

CDR T. McGee

OBJECTIVE

The objective of this paper is to define the functionality of the Next Century Forecast Center and its role in the Navy's Joint Vision 2020. The ideas here are based on experience gained through leveraging the power of Web technology as applied to the METOC mission. Recent operations have definitively proven that in many cases, the communications pathway to our customers is solidly in place, in the remaining cases, it is coming fast. Now is the time to reform our process. Web technology coupled with current modeling and visualization interfaces can be further harnessed to maximize the fidelity of our product line and the effectiveness of our service.

CENTER VISION

Produce and deliver accurate and relevant METOC guidance to a broad customer base. In response to this varied customer base, the next century product line will be abundant and offer a wide selection of products and services ranging from on-demand technical METOC data to complete visualization of the environmental impact on a specific operation. Functionally, the next century center will:

- Perform smart searches of global data resources;
- Assess resources for value and quality;
- Host appropriate resources in a regional server;
- Employ the right resources to produce hybrid forecasts; and
- Communicate the product line with our customers.

The vision's key enablers are communications and Web technologies. The Web has redefined the landscape of available METOC resources and "on line" shared tactical communications have brought unprecedented levels of operational awareness to the supporting echelon. The Next Century Center will employ a global data resource, powerful computational capabilities and emerging communications technologies (whiteboard, web-meetings, shared applications, etc.) to achieve even greater levels of product fidelity and customer service.

The functional elements for the Next Century Center are described below both in terms of existing operational capabilities and targeted technologies.

The Search. Web based information markups and Web crawlers have dramatically increased the resources available to METOC operations. Next century search functions capitalize on this technology with the assistance of advanced searching, sorting, vetting and decision making interfaces to streamline initial information assessment and routing.

The Host. Current operational servers provide a regional node for all applicable METOC information (predominately complex files, e.g., GIF, TIF, PCX, JPEG, BMP, etc.). The next century server will host digital data (geospatial, satellite, ocean sensor and GRIB) as well as complex files. The server operation will be redundant and secure.

The Production (and Simulation). Products and services have been redefined in terms of current Web server technology which provides both a central, directed shopping site for an infinite range of complex file products and a convenient venue for file manipulation, annotation, display and re-hosting (e.g., Power Point briefs, MPEG animation, etc.). In addition to this powerful technology, the Next Century Center will conduct mesoscale simulations and produce a broad spectrum of METOC products (from complex files and/or mesoscale GRIBs to full-blown animations). Much of the technology for affordable (regionally run) mesoscale simulations is available "off the shelf" today. A next century production tool, which translates simulated data into valuable tactical information, will be required to leverage the combined skill of computational production and expert operators. Final products from such a tool range from hybrid GRIBs (for OA divisions, TDA's, mission planning and rehearsals, etc.) to animated ship routing products.

Production will focus on sensible weather and ocean information – accurately depicting the metrics our human and man-made sensors "feel."

The Communication. The Web is the communication vehicle of today and tomorrow. Web communication has enabled an unprecedented level of shore engagement in fleet operations. Real time customer interaction has spotlighted the "service" aspects of shore METOC operations. Highly capable shore facilities can now efficiently marshal their assets to effectively impact operations afloat. Communication interface capabilities in the Next Century Center will expand to perform product compression and packaging, routing (local hosting, point cast, multicast, trickle broadcast, request servicing, work-flow management, etc.) and distributed communications management (redundancy and hand-off).

CONCEPT OF OPERATIONS

The production cycle is directed and begins with customer communication and interaction. The operational engagement drives a smart search of the global data resource. Both functions are continuous. Complex files and digital data fields are locally hosted and distributed as requested. All available objective aids (synoptic scale numerical guidance) are evaluated for their skill in addressing operationally relevant situations in the AOR. An assessment is made to determine if the available synoptic scale guidance is sufficient to address the operational situation or weather a mesoscale simulation is required. If a mesoscale simulation is required, the optimum synoptic objective aid for each situation is selected to initialize and bound the mesoscale model. Multiple mesoscale simulations (initialized by various objective aids for differing areas and situations) may be run simultaneously as regional operations, model "micro-climates", and/or hardware capabilities dictate.

The production interface, which translates simulated data into valuable tactical information, accepts digital data in raw forms directly from the search or fresh from locally run mesoscale simulations. The four dimensional modeled data (atmosphere and ocean) provides the foundation for product generation. Additional data sources can be selectively ingested into the production interface, including: digital satellite data, geospatial data, oceanographics data, *in situ* measurements, operational response characteristics, etc.

The production interface creates a five dimensional (4D plus rotation) animation of sensible weather (atmosphere and ocean), then enables the expert operator to manipulate sensible weather fields, ship track, annotations, response impact feedback, confidence thresholds (sliders), etc., each designed to maximize the fidelity and value of the products.

Production may be "captured" at any state depending on the "synthesis" required by the customer. For example, Non-METOC capable customers/situations would be "high synthesis." Some may required an interactive capability in which case the product would be a finished fine mesh GRIB, others may only required a visualization (e.g., MPEG). These type of spatial/graphic renderings replace the traditional WEAX and OTSR product. Conversely, METOC "capable" customers are "low synthesis" and may require a wide range of GRIBs (raw and synthesized), complex files, technical METOC data and specialized services.

Finished products are quality assured and forwarded to the communication interface for distribution. Engaged feedback is solicited.

THE VALUE IN THIS APPROACH

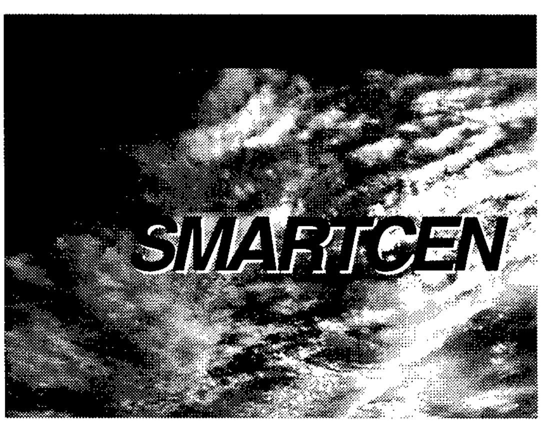
Real and, in many cases, quantifiable value is added in each phase of this process. The essential value being generation of information advantage afloat thus enabling acceleration in the speed of command (Observe, Orient, Decide, Act). Some specific "high value" functions include the information search, quality assessment, information fusion, METOC expert analysis and annotation, and information distribution. This approach has broad applicability to the complete range of Naval support services ashore.

ASSUMPTIONS

- Broad band communications will be in place for a majority of our customers.
- Technologies will emerge to communicate essential informant to "low end" customers (e.g., a marine fire team in the field, Patrol Craft, remote METs, etc.).
- Web technology will continue to grow.
- Computational power will continue on its path of growth and affordability.
- Many required capabilities will emerge in the public domain.

THE BUILDING OF SMARTCENTER

- Customer pull
- Technology push



THE BLUEPRINT FOR CHANGE

- Modern products and services
- Proactive application of commercial technology
- New processes

The capabilities of current COTS and WEB technology have outpaced deliverables from long range system development programs.

Programmed system resources could be better leveraged to provide new tools with an overall bias towards higher COTS system acquisition in the systems/program development mix.

Increased technical capabilities provide the opportunity to improve proce3sses, products and services. Additionally, the optimum organization must be reassessed as these three fundamentals evolve.

This reassessment may involve the requirement for different or additional skills and training.

THE MISSION

- Engage the operating forces.
- Impart aknowledge of the environment.

Our message has value – we must be proactive in our approach – data/information overload in the computer age saturates the users – we must enhance the fidelity of our products and services. Specifically:

- We want to increase the knowledge and understanding of the oceans and the atmosphere and their impact on Navy weapons, sensors and platforms (and people).
- Our assessments and forecast will be accurate.
- Information will be meaningful, relevant and concise (in the language of the warfighter).

THE CYCLE

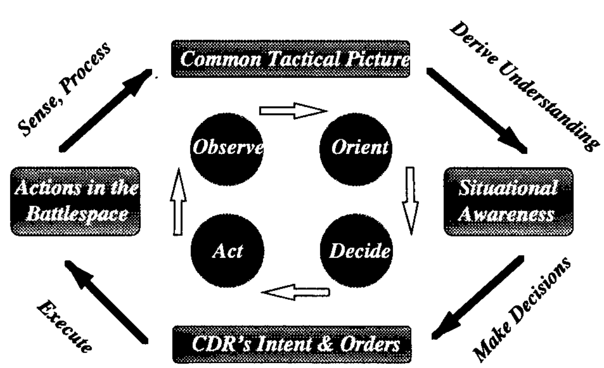


Figure 1. *Where We Fit.*

The Speed of Command:

- Observe
  - Common tactical picture
- Orient C4I
  - Situational awareness
- Decide
  - Commander's intent and orders
- Act
  - Actions in battlespace

The METOC domain is to provide the understanding which forms the basis for the decision maker's situational awareness.

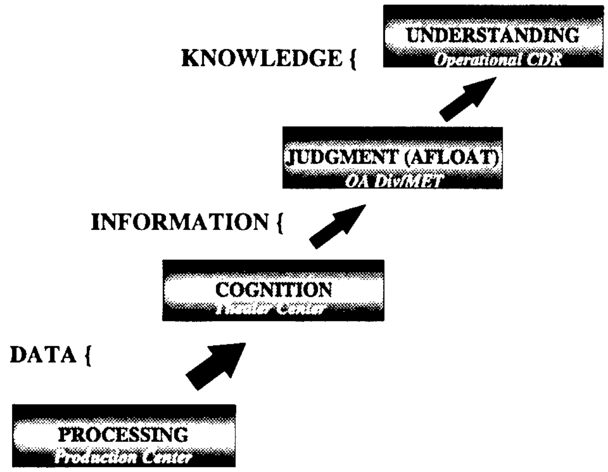


Figure 2. *The Cognitive Hierarchy.*

THE COGNITIVE HIERARCHY

- Processing: Data basing, Dynamics Models
- Data: raw signals
- Cognition: Assessment, correlation, statistical models
- Information: Formatted, plotted, translated
- Judgement: Application, context, awareness and experience
- Knowledge: Correlated, fused, analyzed, displayed
- Understanding: Articulated, synthesized and visualized

The METOC IT system delivers a fused package (levels 1-3, data-knowledge) and/or a composite product.

The final step (understanding) infers an on scene human process where the warfighter develops an awareness.

THE BLUEPRINT FOR CHANGE

- Modern products and services
- Proactive application of commercial technology
- New processes

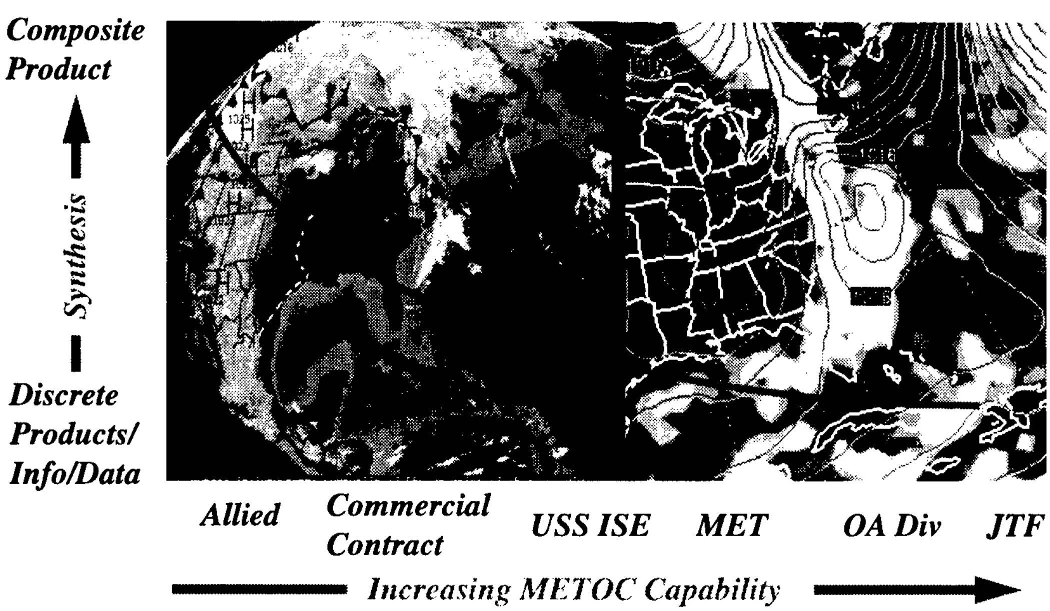


Figure 3. *The Product. This figure depicts the METOC Continuum.*

The capabilities of current COTS and WEB technology have outpaced deliverables from long range system development programs.

Programmed system resources could be better leveraged to provide new tools with an overall bias towards higher COTS system acquisition in the systems/program development mix.

Increased technical capabilities provide the opportunity to improve processes, products and services. Additionally, the optimum organization must be reassessed as these three fundamentals evolve.

This reassessment may involve the requirement for different or additional skills and training.

THE PRODUCT

SMARTCEN recognizes that METOC requirements across a broad spectrum of customer capabilities are highly varied and does not seek to define a specific product.

Conversely, SMARTCEN searches, fuses, assesses, produces, packages and delivers a wide variety of products and services in direct response to the customer's requirements and capabilities.

"Low end" users may require one highly tailored product (e.g., INMARSAT voice warning, etc.). More METOC capable users (knowledge of model tendencies, products, etc.) will build their own composite in context of the operations.

THE SIPRNET LAN

All equipment and software purchased "Off the Shelf" from Local Vendors.

PC Server connected to a SIPRNET backbone with Unix interface to current JMCIS applications.

In addition to the Hardware, Software and Peripherals (Fiber Cable, Connectors, Tools, LAN Cards, Additional RAM, Hubs, etc.) the $40K figure also includes Local PWC construction (Conduit Runs, Additional Power Outlets and Door/Cypher Installation).

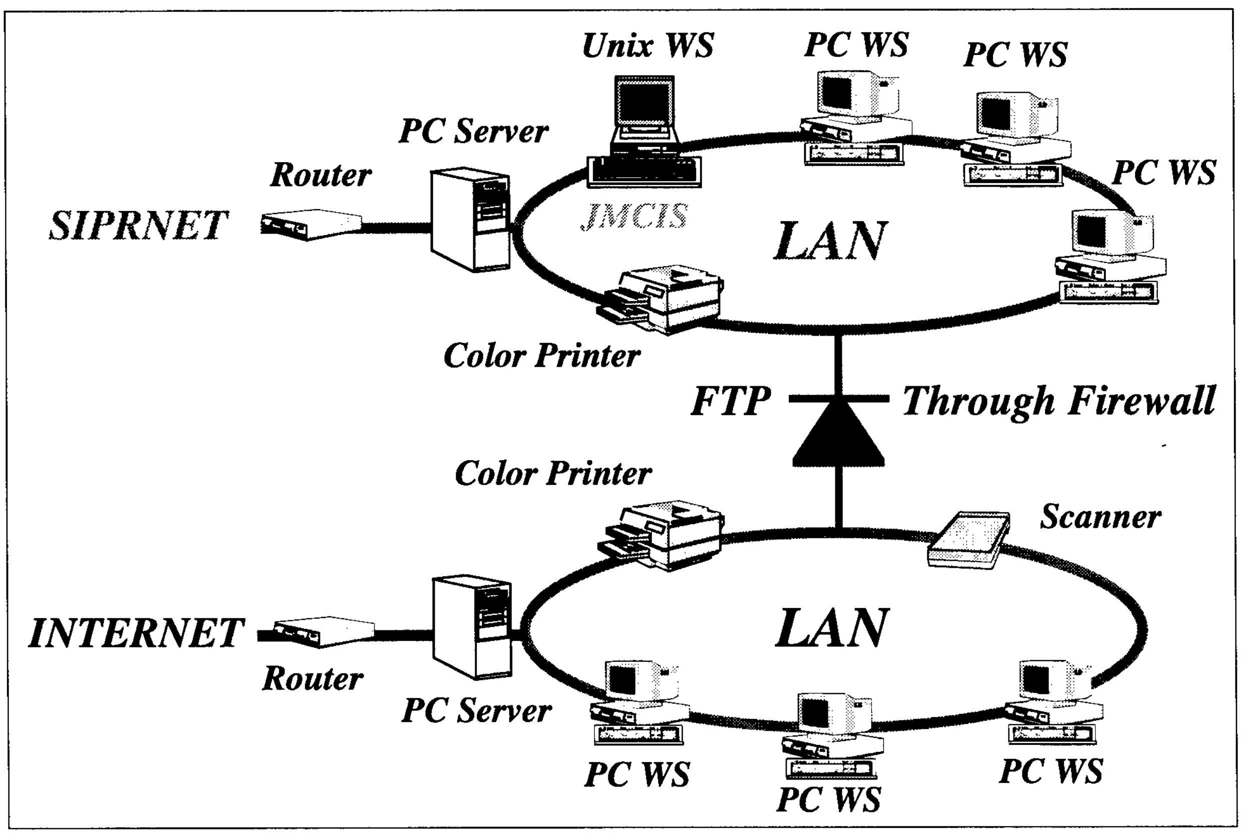


Figure 4. The Architecture.

- (1) PC Server: Dual P-133, 128 Mb RAM 8Gb HD - Windows NT
- (10) PC Workstations: P-200, 32Mb RAM, 2.5Gb RHD - Windows 95
- (3) Large Screen (21 inch) Monitors
- (2) CISCO 2500 Routers
- (2) Uninterrupted Power Supplies
- *(1) TAC-IV UNIX Workstation (for Current JMCIS Applications)

*On loan from SPAWAR PMW-185

THE PROCESS

- From a Production Driven
- To a Customer Response Command

All source, smart data fusion is the centerpiece of the METOC IT system, SMARTCEN. The recurring theme is development of an engaged and customer driven product.

Data fusion from a global resource is a central tenet of SMARTCEN. Data and information from the two production centers (FNMOC, NAVO) continue to provide the baseline for all services.

Web searches, Data synthesis, Smart Information Packaging (Compression) and Local Hosting of METOC Products are the principal advantages of SMARTCEN.

Products and services will be delivered in the time scale of the operator, not the production center.

THE PRODUCTION CYCLE

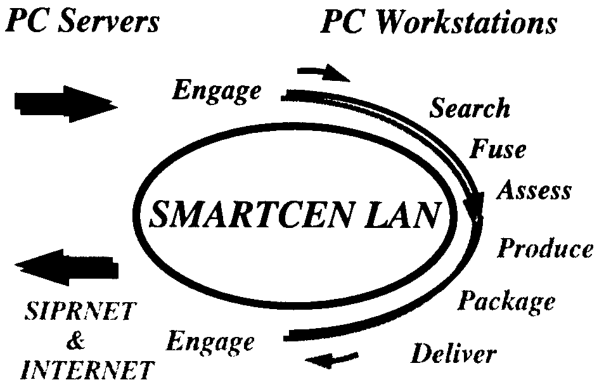


Figure 5 The Production Cycle.

THE CONNECTIVITY

SMARTCEN's technological enables are:

- Powerful and inexpensive (PC) workstations,
- A phenomenal global information resource (WEB),
- A permissive Navy C4I architecture (SIPRNET),
- Electronic "search agent" technology,
- Rapidly developing communications capabilities, and
- EHF, in conjunction with emerging communications router technology, will bring an impressive broadband (T1) path to the Cruiser/Destroyer navy. Amphibs will follow.

This commercial maritime technology in conjunction with experienced fleet forecasters maximizes central site skills and capabilities.

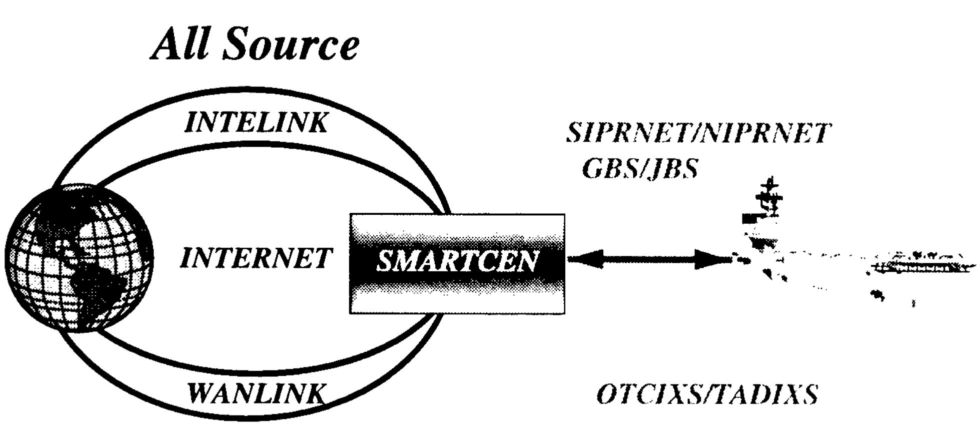


Figure 6 The Connectivity.

THE BOOTSTRAP

- Built by Sailors (Aerographer Mates) and Oceanography Officers.
- 18 days from initial purchase order to operational center.

Prior to the SMARTCEN evolution there were not many computer and even fewer Network savvy folks at the command.

The Sailors stepped up to the plate, opened the books, called the vendor help numbers and bootstrapped themselves to a very significant level of technical competency.

Sailors replaced hard drives with removable hard drives, added 6 Gb Hard Drive Storage to the server, installed 16 Mb additional RAM in each PC Workstation, synchronized modems and repeaters, installed Etherlink Cards, crimped and routed fiber, programmed servers and routers, and aligned crypto. Endemic PC technology and familiar inerfaces eclipse many historic training issues.

THE RESULT

In a mature state, SMARTCEN's connectivity and WEB premise enable it to process much greater amounts of data and information.

Further, the emphasis on customer requirements in conjunction with the evolution of direct customer communication enables SMARTCEN to attain significantly enhanced engagement in the operational mission.

METOC center of gravity shifts from infrastructure toward readiness.:

THE LEGACY

- Presence, Awareness, Accuracy
- . . . Forward from the Sea

This is the legacy we want to leave with the warfighting forces:

- We are there when they need us.
- Our assessments and recommendations are in the context of the operational problem.
- We consistently provide the correct answer articulated in the warfighter's language.

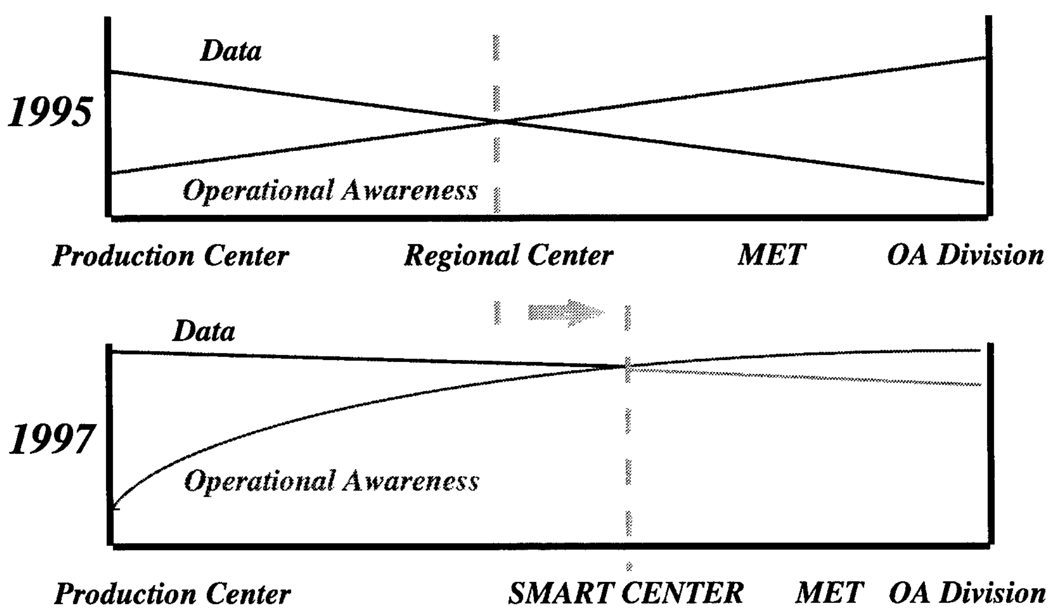


Figure 7. The Result.

THE ADAPTIVE BEACH MONITORING PROGRAM AND GROUND-TRUTHING REMOTE SENSING DATA

Dr. Gerald D'Spain and Dr. William A. Kuperman

The data collected by new civilian remote sensing systems is a potentially rich source of information to help the Navy accomplish its mission. However, a few basic questions first must be addressed to realize its potential to the fullest. For example, exactly what information collected by these systems is of use, and what is its quality? How is this information related to that collected by other methods, including ground-based sensors and existing classified remote sensing systems? If unique information is contained in the data from the new civilian systems, how can it be combined with information from other sources to provide a more complete picture of the operational environment?

To determine the quality of the data collected by new civilian remote sensors, and simultaneously provide a way of calibrating these data, comparisons with data from other sources collected at the same time and place are required. This process of ground-truthing can best be accomplished by taking advantage of the expertise developed in existing Navy-sponsored research programs. One such program, focusing on the shallow water littoral zone, is the Marine Physical Laboratory's Adaptive Beach Monitoring (ABM) program. The objective of this program is to determine the capabilities of small on-shore and off-shore seismoacoustic arrays along with directional wave and current sensors to provide the amphibious force commander with a covert monitoring capability of shore-based as well as near-shore enemy forces, near-shore current and wave dynamics, and beach surf conditions. Included in the program is the study of the near-shore ocean physics affecting the recordings from on-shore and off-shore seismoacoustic arrays.

At present, one method of obtaining intelligence on enemy disposition and movement in preparation of an amphibious landing is through the use of remote overhead sensors (i.e., satellite or air-breathing). These sensors also provide information on the environmental conditions such as surf activity that are critical to the success of the mission. However, these systems have limited on-station time and their data can be significantly degraded by weather. The goals of the ABM program are to determine the benefits of supplementing the intelligence gathered by overhead sensors and/or special forces' personnel with the information obtained from covertly deployed on-shore and off-shore sensor nodes composed of seismoacoustic sensors and directional wave and current sensors. This fusion of information is the same process as required in using data from new civilian remote sensing systems for Navy mission-critical support.

In the nearshore experiments conducted to date in the ABM program, a large variety of seismoacoustic and environmental data acquisition systems have been deployed. The seismoacoustic systems measured simultaneously the offshore underwater seismoacoustic field, the land seismic field, and the air acoustic field. The underwater sensor systems include:

- Two 64-element hydrophone line arrays deployed in a mutually orthogonal orientation on the ocean bottom at ranges of 1.6 km and 3.4 km offshore;
- Small-aperture, two-dimensional arrays composed of up to 13 ocean bottom seismometers (OBS), at ranges of 1 km to 4 km offshore. Each of the OBS's measure simultaneously the three components of ocean bottom ground motion as well as underwater acoustic pressure;

- A line array of four pairs of hydrophones placed directly in the surf zone to measure the generation and transmission of sound by the breaking waves;
- A sensor pod also placed directly in the surf to measure the effective changes in underwater sound speed and sound absorption due to the entrainment of air by the breaking waves; and
- Receiver moorings at a variety of locations outside the surf zone to measure ground motion and/or water particle motion along with underwater acoustic pressure as a function of range offshore.

The land-based ground motion sensors used in the experiments include:

- A 24-element vertical-component geophone array deployed in both linear and two-dimensional configurations;
- Five 3-component geophones buried across the beach; and
- Two buried miniature accelerometers.

For measurement of the land air acoustic field, the following systems have been deployed:

- Both a 6- and a 12-element miniature microphone array;
- A directional microphone within a parabolic dish pointed at the surf zone; and
- Two miniature microphone sensor pods for measuring acoustic pressure and acoustic pressure gradients.

This large variety of sensor systems has been required to properly characterize the generation of, propagation within, and coupling between the seismoacoustic fields in three complicated media, the ocean, the land, and the atmosphere.

A correspondingly large variety of ancillary environmental information also have been collected, including basic weather data (e.g., wind speed and direction, air temperature, relative humidity, atmospheric pressure) water temperature and salinity (to derive ocean sound speed), ocean bottom bathymetry, directional ocean surface wave spectra, tide activity, and ocean currents. These environmental data, as well as other sources of information, e.g., videotapes recorded from cameras scanning the beach and surf zone, nearby highway vehicle activity, earthquake origin times and epicentral locations, and on-land human activity logs, have been vital to the proper interpretation of the seismoacoustic data.

Several interesting results have come out of the analysis of the experimental data in the ABM program. First, land vehicle activity on the beach clearly can be detected and tracked using data from underwater hydrophone arrays located at least as far as 3.4 km offshore. To illustrate this capability, Figure 1 shows the beamforming output over the frequency band of 30 to 70 Hz as a function of time during the transit of four tracked vehicles down the beach. In this case, the hydrophone array was 1.5 km offshore in 12 m water. Signal beam levels exceed background levels by 30 dB at times, suggesting that the vehicles could be tracked from much farther offshore ranges (order 10 km). These results derived from the underwater acoustic data agree with the vehicle tracks obtained from visual observations. Additional land-based signals that have been detected in the offshore underwater acoustic data are those due to the operation of

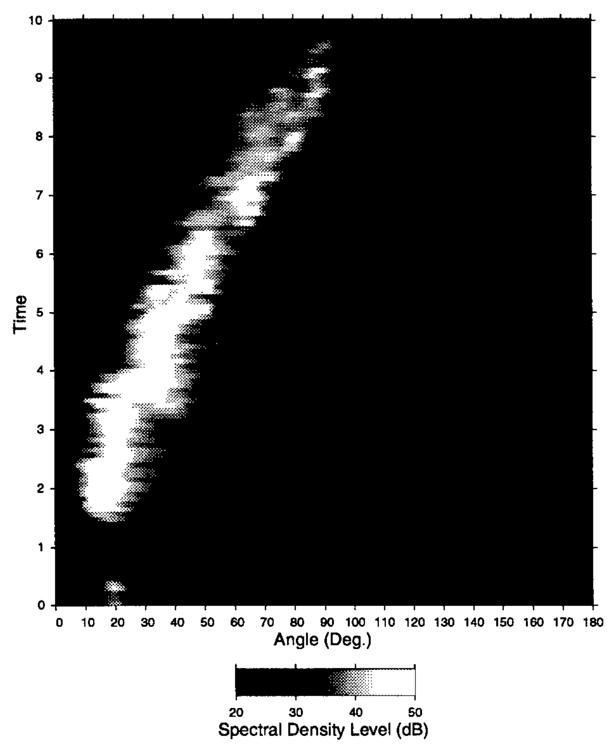


Figure 1: *ABM 96 SRP NS ARRAY JD 323 22:40. Adaptive Beamformer 30-70 Hz – AEL Positions for 61 Elements.*

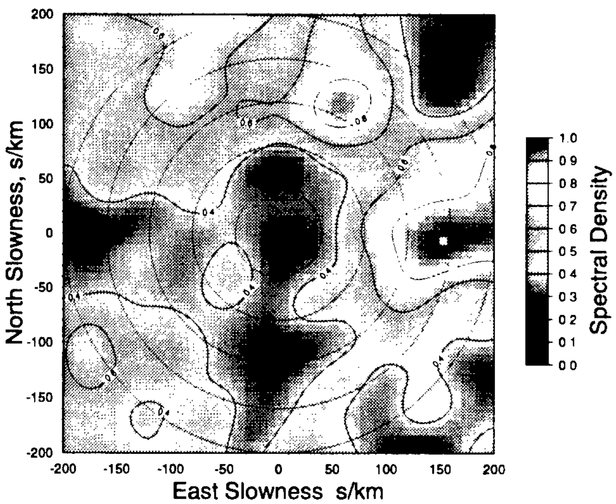


Figure 2: *0.0625 - 0.2 Hz Noise*

water pumps as far as 17 km inland, and to sanitation pumps on an offshore island 70 km distant.

The key to understanding the characteristics of the coupling between the land sources and the underwater acoustic field have been the recordings of controlled, small land detonations by the offshore underwater seismoacoustic sensors. Simultaneous recordings of these land detonations by the land seismic sensors have been used to invert for compressional and shear wave velocities in various ground conditions on and near the beach. Small controlled detonations also were conducted on the seafloor and the arrivals recorded by the OBSs have been used to determine the ocean bottom shear velocity structure as a function of depth. The OBS data also have been used to derive highly resolved ocean surface wave directional spectra. An example result is shown in Figure 2, where ocean swell is arriving simultaneously from due west (large red spot to the east on the right hand side of the plot) and from the south-southwest. Therefore, seismoacoustic arrays can be used both for making important environmental measurements as well as detecting and tracking seismoacoustic sources of interest to amphibious operations

A focus in the ABM program has been on surf activity since it plays a major role in amphibious operations. Measurements within the surf zone have shown that directly under a breaking wave, the effective sound speed can be reduced to values smaller than the 350 m/s speed in air due to the large volume of air entrained in the wave breaking process. The lower plot in Figure 3 shows the effective sound speed in the surf zone as a function of time. Once a large wave breaking event occurs (one min into the plot), a period of 3 to 5 min is required for sufficient degassing of the water column to occur and allow the sound speed to again reach the nominal 1500 m/s value typical of ocean conditions. Concurrently, the introduction of air bubbles into the water column causes hugh increases in the attenuation of sound, as the upper plot in Figure 3 shows. At those times when the bubble density is greatest, sound attenuation at the higher frequencies exceeds 150 dB/m.

Besides the effect on sound speed and attenuation, the process of wave breaking creates sound within the surf zone. The broadband nature of the generated sound permits the active portion of the wave breaking to be tracked over time with just

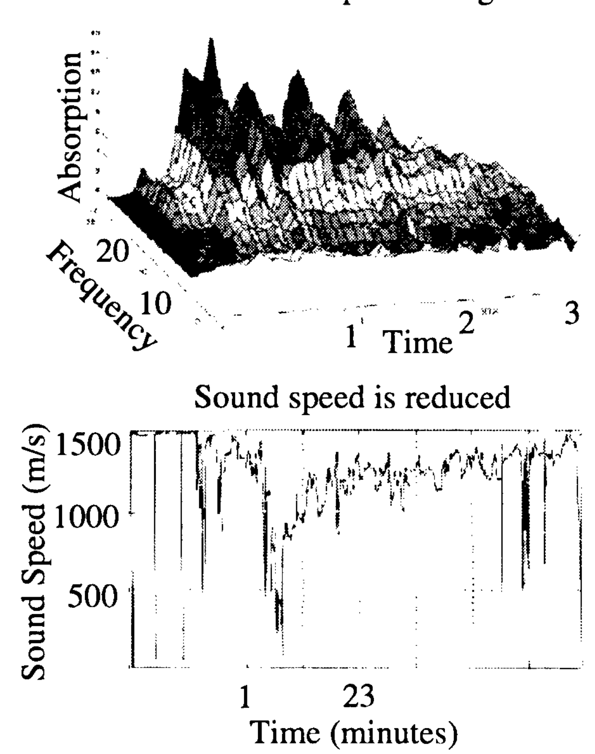


Figure 3: *The effect of breaking surf on acoustic transmission. Affects last for 3-4 minutes after breaking.*

two hydrophones. Future work with these results will involve the correlation of the wave breaking regions with ocean currents and bottom bathymetric features, two critical pieces of information for amphibious operations. However, for the low surf conditions experienced in these experiments, and because of the high attenuation caused by the presence of bubbles, the sound generated by breaking surf does not contribute significantly to the sound levels measured outside the surf zone. Figure 4 displays the hydrophone time series and corresponding spectrum of a wave breaking event at four locations across the surf zone. Although the received signal is large within a few tens of meters of the wave, the sound has nearly decayed to background levels after propagating a few hundred meters. Efforts to detect the sounds created by the surf at ranges of 1 km or greater offshore have not been successful. In fact, at distances of only a few hundred meters from the surf zone, a larger contributor to the background ocean ambient noise is the breaking of short-wavelength capillary waves modulated by incoming swell. This contribution has a diurnal dependence due to the diurnal variation in the onshore wind flow, i.e., the onshore wind speed is greatest in the afternoon and dies off in the early morning hours due to differential heating of land and sea.

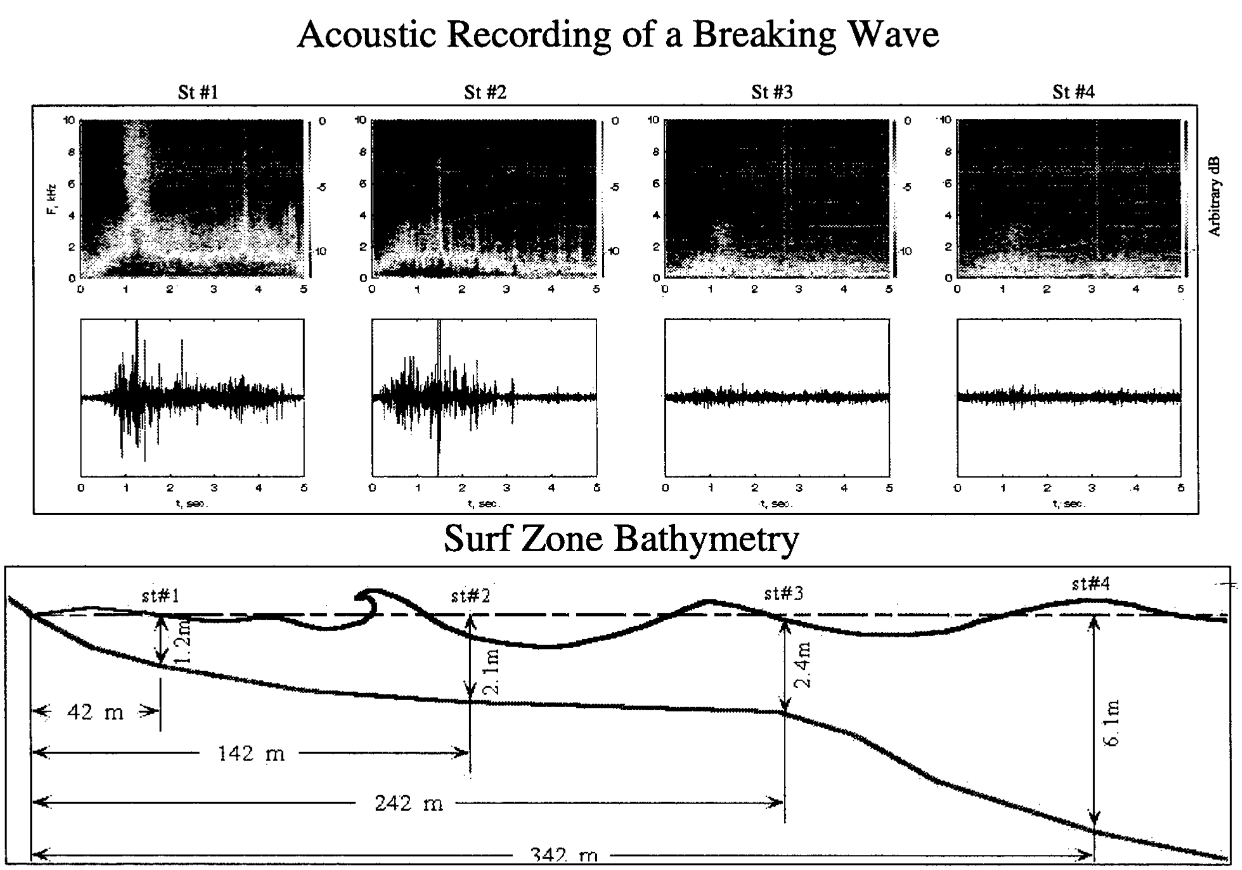


Figure 4. *Simultaneous Frequency Spectrograms and Time Series of the sound generated by a breaking wave recorded at four stations across the surf zone. Spectrograms were calculated from the 5 second time series shown with a Fourier window length of 0.1 seconds and an overlap of 0.05 seconds. The spectrograms display the acoustic power transmitted to the array over a frequency range of 0.1 - 10 kHz. The positions of the high frequency transducers at 100 m intervals across the surf zone are displayed. The transducers were mounted approximately 0.5 m from the bottom in the depths shown. Note the strong attenuation across the surf zone for the wave breaking near station #1.*

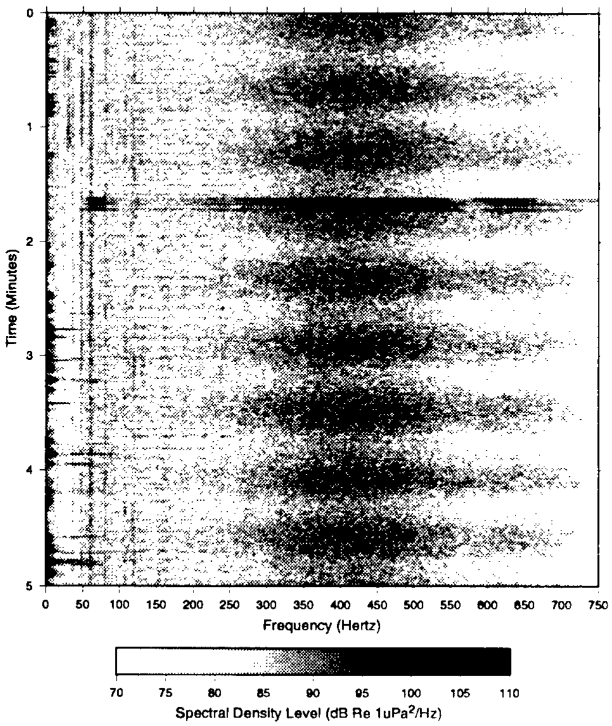


Figure 5: *ABM SRP NS Array Single Element Gram, JD 152 Start time of tape is 01:43 GMT, Element 8 with Zero Offset.*

At farther distances offshore, the dominant contributor to the underwater acoustic noise field from 50 Hz to 5000 Hz is the sound created by biological activity. For example, Figure 5 shows a 5-min spectrogram from one element of the bottom hydrophone array at 3.4 km offshore recorded early in the evening at the beginning of summer off the Southern California coast. Prominent aspects of the plot are the broadband horizontal stripes that last for 20 sec or so and occur at regular 30-35 sec intervals. Spectral energy is concentrated in the 300-550 Hz band and peaks at 90 to 100 dB re 1 uPa2/Hz between 400 and 450 Hz. These cycling sounds are choruses created by fish, believed to be two species of the croaker (Sciaenidae) family, and last all night long during the spring and summer months. At times, an individual fish comes within several meters of an array element so that its sequence of 5-15 knocks can be distinguished above the background din. Some of these fish knocking sequences show arrivals corresponding to seismic interface excited by the fish at the ocean-sediment interface. The dispersive character of these interface waves have been used to invert for the shear wave properties of the uppermost part of the ocean bottom. The values of about 40 m/s thus obtained agree quite well with those measured in the laboratory by other techniques. In addition, the shear wave structure obtained from the inversions of the fish sounds and the OBS ocean bottom detonation data are consistent with each other.

As an aside, ocean bottom seismic interface waves have played another important role in the ABM results. That is, they allow inert mine deployments to be detected, i.e., by the "thud" generated upon impact on the ocean bottom, even though the splash and other sounds of entry and descent through the water column are masked by noise created by the deployment ship. The thud's arrival can be clearly detected in the presence of the loud deployment ship noise because of the much slower propagation velocity of the interface wave compared to that of sound in water.

Future work in the ABM program will involve further development of this underwater seismoacoustic "remote sensing" technique and ground-truthing it with the ancillary environmental information. The use of data from overhead remote sensing systems also will require the same kind of ground-truthing effort. Hopefully, unique information will be present in the data from the overhead systems so that data fusion from various sensor types will provide even clearer pictures of the environmental and operational settings.

The Principle Investigators of the ABM project at Scripps Institution of Oceanography are L. Dorman, G. D'Spain, W. Hodgkiss, W. Kuperman and K. Melville.

FULL FIELD PROCESSING FOR SOURCE LOCALIZATION AND OCEAN TOMOGRAPHY

Dr. Arthur B. Baggeroer

SUMMARY

Full Field Processing (FFP) is an acoustic imaging techniques which can be used for both localizing sources and tomographic estimation of environmental parameters. The technique takes advantage of the ray/mode interactions of an acoustic field observed across an array of sensors. For source localization it can be considered a generalized beamformer, while for tomography it exploits the full spatial and temporal structure of the field instead of just the travel times as done in current ocean tomographic methods. There must be a very close connection among the oceanography, acoustics and the signal processing for successful use of FFP; consequently, accurate environmental models are critical.

For source localization its compelling advantage is that FFP leads it an estimate of both range and depth of a source instead of just bearing. In addition, it reduces the well known signal gain degradation due to multipath interference. For tomographic problems it exploits the full field which can improve performance. The fundamental issue is the coherence of the acoustic propagation needed to exploit FFP. The following material indicates:

- Examples of FFP applied to both source localization and tomographic methods and
- A summary of some of the important research issues involved in making FFP an operationally useful approach to both problems.

OVERVIEW OF THE OBJECTIVES OF FULL FIELD PROCESSING

Source localization and tomography problems can be addressed. Narrow band FFP, usually termed Matched Field Processing, exploits the phase delay interference pattern across an array while the use of active broadband signals exploits group delays as well.

Objectives of Full Field Processing:

Localize a source of estimate environmental parameters using full field acoustic propagation models.

- Generalized form of beamforming using Green's functions versus plane wave models and usually adaptive methods.
- Matched field processing:
  - Localize a source given an environmental model.
- Matched field tomography:
  - Estimate environmental model parameters given a source location.
- Simultaneous matched field processing and tomography.
- Narrowband versus broadband methods:
  - Exploitation of relative phase across an array versus additional use of travel time information.

SHALLOW WATER ENVIRONMENT

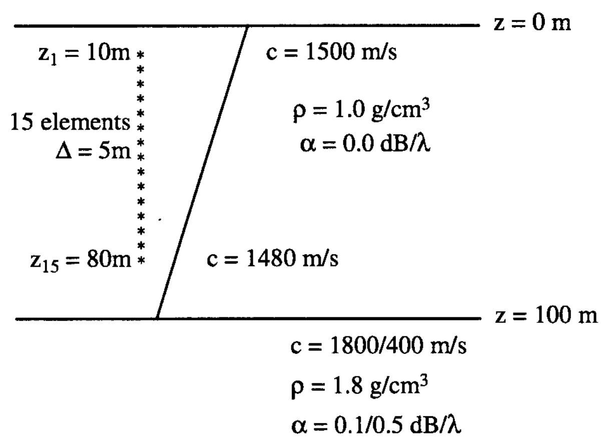


Figure 1: *Example of a downward refracting, shallow water environment for narrowband full field processing example.*

SOURCE LOCALIZATION PROCESSING

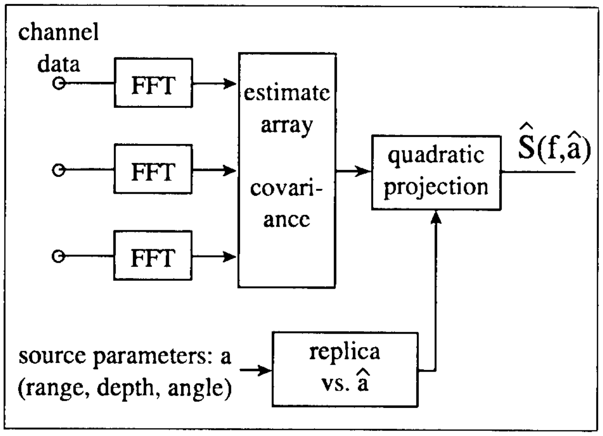


***Figure 2:** Processing method for full field processing. The data are narrowband filtered using FFT's and then used to form a data matrix. The replica signal computed from the environmental model is then used to estimate source location and/or environmental parameters.*

TOWED ARRAY

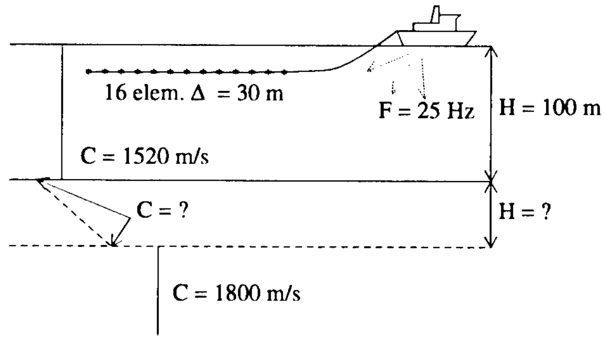


***Figure 3:** Example of using a towed array with a narrowband signal to estimate bottom properties. The ship radiates a narrowband signal and the FFP estimates the speed of the upper and lower sediment speeds in a two layer bottom. Speeds are usually estimated with wideband signals and travel time by refraction; FFP suggests an alternative approach using narrowband signals.*

SEDIMENT SPEED/TOWED ARRAY

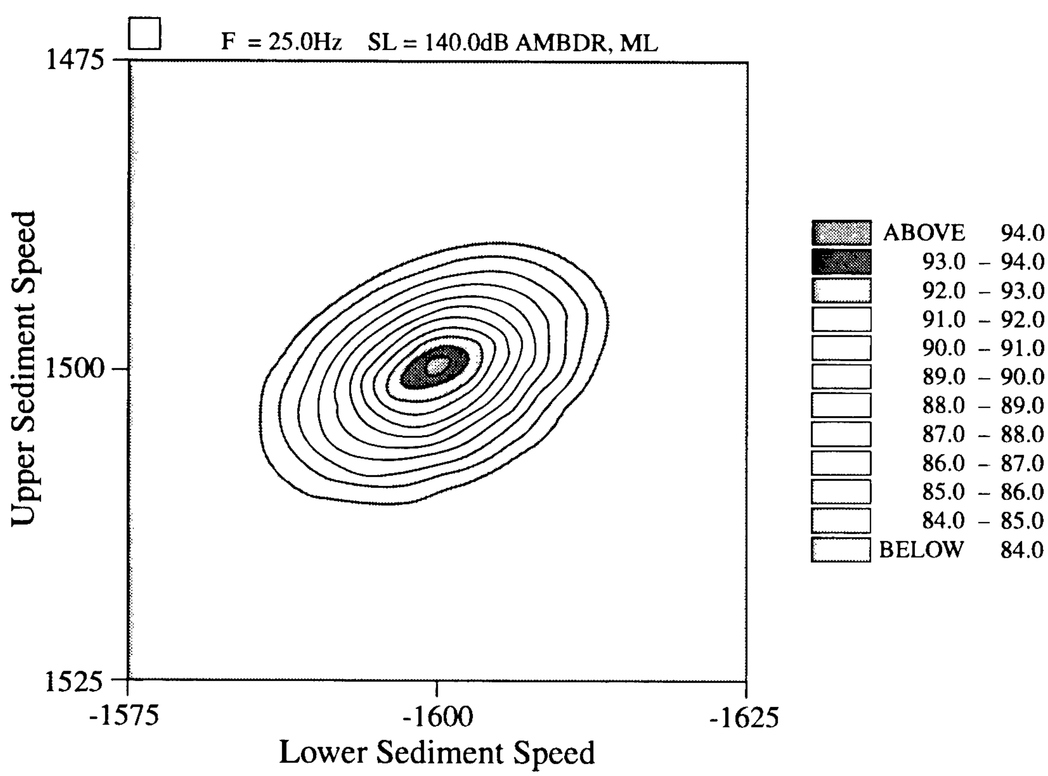


***Figure 4:** Cramer-Rao bounds on the estimates of the sediment speeds using FFP. The tilt in the ellipse indicates the coupling between the parameters. This is an example of using FFP for environmental parameter estimation.*

The following summarizes FFP, its potential application to Navy problems and some of the current research topics. FFP is being pursued actively by many ONR investigators as an advanced method for both ASW and environmental modeling.

- FFP exploits the full acoustic field.
- FFP requires close interaction of signal processors, acousticians and oceanographers.
- Most useful for vertical or endfire arrays where the field inhomogeneity is greatest.
- Several successful experiments using FFP.
- Some aspects already useful:
  - Vertical array applications (shallow and deep)
  - Large aperture and multiline towed arrays
- FFP potentially useful for complicated array geometries, e.g., 2D curtain arrays, towed arrays in a turn.
- FFP is especially sensitive to four sources of replica mismatch;
  - Environmental mismatch – unknown parameters for propagation codes
  - Scattering mismatch – characterization for random phenomena
  - System mismatch – calibration, sensor position
  - Stochastic mismatch – sample covariances for adaptive methods
- Many research issues remain for FFP to be a robust sonar system such as those built on plane wave signal models.
- Active Russian literature with both theory and experiments, e.g., home page on the WWW.

CURRENT RESEARCH ISSUES

- Broadband processing
  - FFP experiments to date based on narrowband models.
  - Broadband processing done by incoherent combination versus frequency (optimum if source is wide sense stationary).
  - "coherent" algorithms in literature are incorrect since they destroy phase coherence versus frequency.
  - Broadband important for active systems and transients for passive systems.
- Noise
  - Literature for the full field vertical structure of ambient noise does not exist.
  - There is no FFP theory for the beampattern design, i.e., tapering and sidelobe control, to mitigate against strong jamming; adaptive methods now required.
  - Vertical coherence models needed for adaptive beamforming.
- Doppler
  - Experiments have been for fixed/fixed or flow source/receiver geometries.
  - Doppler compensation for long integration time is complicated; replicas depend upon x, y, z. v_x, v_y, and are time varying; no experiments to date with full doppler compensation.
  - Incoherent Doppler compensation successfully implemented by Russians.
  - Doppler is a robust search parameter and should not be neglected because it is now complicated to implement.
- Source models
  - Almost all FFP literature based upon point source models.
  - Sources are many wavelengths long.
  - Potential source of signal gain degradation.
- Covariance matrix estimation and adaptive methods
  - FFP often uses adaptive methods for sidelobe control.
  - Adaptive methods estimate covariance of acoustic environment.
  - Estimates are "dof" (degrees of freedom) deficient.
  - Radar literature → 3 x the number of sensors, so adding sensors paradoxically can degrade performance.
  - Impressive gains in radars for adaptive systems.

ACOUSTIC TELEMETRY

Dr. Arthur Baggeroer

SUMMARY

Ocean acoustic telemetry is difficult because of the reverberant, bandlimited characteristics of the underwater channel. Absorption limits the bandwidth to several kilohertz and multipath propagation and Doppler spreading due to ocean processes and source/receiver motion make coherent, high bandwidth expansion signaling methods problematic. For example, state-of-the-art acoustic modems have a bit rate to bandwidth ratio of roughly unity while for commonly used computer modems the ratio is 5 – 10. One can easily demonstrate that the channel capacity of the underwater channel will never support exceptionally high rates for applications such as remote beamforming except at very close ranges with a line of site path; nevertheless, acoustic modems have many very important applications in C4ISR where data rates are often modest. The important aspect in the design of an acoustic telemetry system is that it must incorporate the characteristics of the underwater channel. The propagation physics are typically much more important than data communications using electromagnetics.

Acoustic telemetry once was limited to analog systems such as the underwater telephone. In the late sixties digital methods were advanced for applications such as well head control for oil fields, very low bit rate command/control to submerged UV's and some scientific instruments. The first digital systems were designed and built in the seventies taking advantage of the advances in the emerging digital technology. The first fully digital system capable of operating in highly reverberant environments such as shallow water was built by MIT and Woods Hole with funding from the

ACOUSTIC TELEMETRY CHANNEL CHARACTERISTICS

- Bandlimited: bit rate proportional to bandwidth:
  - Acoustic telemetry: $R \approx W$
  - Digital modems: $R \approx (5 - 10)\ W$
- Reverberant: leads to intersymbol interference (ISI)
  - Spread spectrum methods: low data rates or high bandwidth.
  - Requires channel equalizers: computationally demanding.
- Time varying: fading nulls signal dropouts
  - Long code durations for nulls: complex decoders.
  - Diversity with multiple frequency and beams.
- Moving source/receivers require timing synch.
- Many similarities to cellular phone technology.
- Energy limits for autonomous systems.

Acoustic telemetry channel characteristics. Bandwidth, reverberation and Doppler spreading are the important features of the underwater channel which now limit bandwidth expansion ratios, the ratio of bit rate to bandwidth, to relatively low levels compared to terrestrial applications such as digital modems.

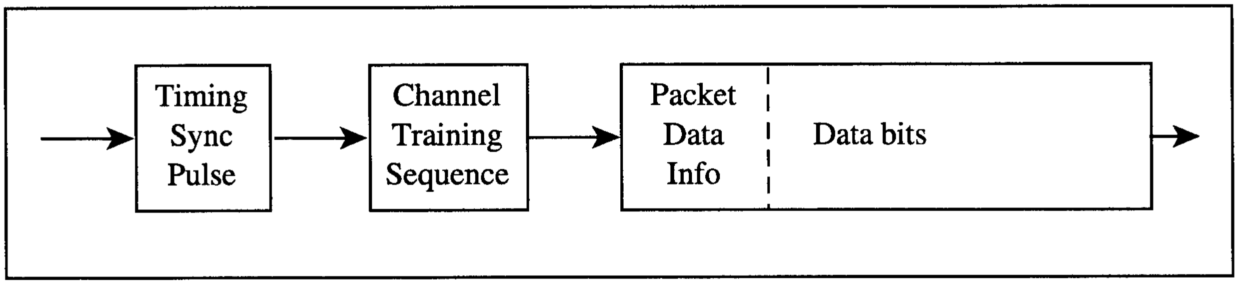


Figure 1. Typical acoustic telemetry signal sequence. The typical message sequence for an acoustic telemetry system contains: 1) a timing synchronization pulse such as a Barker code to establish a time reference for the receiver; 2) a channel training sequence where a signal known to the receiver is sent to initialize the adaptive equalizer and 3) the message itself. The message may contain packet data information if it is operating in a packet mode in either point to point or a network configuration.

NOAA Seagrant program. Data rates of 400 bits/sec with error probabilities of 10^{-2} were achieved for a 2 km path. The performance of current systems is now a data rate of 5 kbits/sec with error probabilities of 10^{-6} which has been achieved by the use of adaptive equalization, coherent signaling and coding. Longer ranges lead to lower rates, but the needs of most C4ISR applications can be met if one employs an acoustic node network much as is used for terrestrial systems. Acoustic telemetry is now receiving a lot of support both commercially and by the Navy. Advances will continue since there is much to draw upon by existing work using modern digital communication techniques.

TABLE 1: CURRENT DATA RATES (WITH TUNING)

RANGE	DATA RATES	CARRIER FREQS
100 m Direct path	100 kbs (1 image/sec)	500 kHz
0.1 - 5 km	5 - 10 kbs (2-5 pages/s)	10 - 50 kHz
5 - 100 km	1 kbs	1 kHz

The table indicates data rates and the carrier frequency used for some experimental acoustic telemetry. These are not now off the shelf and have required some on site tuning by the designer to match the propagation conditions.

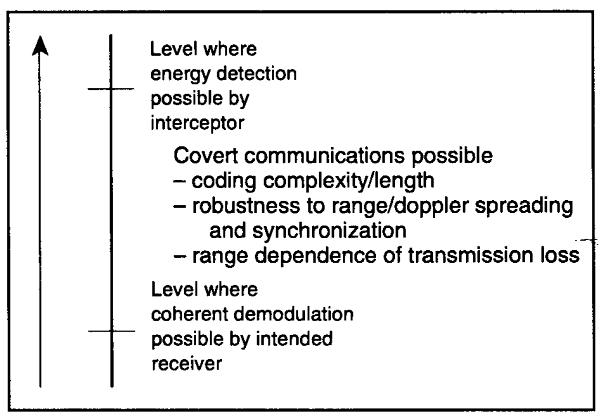


Figure 2. *Covert communications. Covert communications, or low probability of intercept, are often needed for C4ISR applications. This is challenging since the system must operate with power levels low enough that the signals cannot be detected using simply energy detection methods, yet the level must be high enough that coherent signaling is possible. Note secure communications is not an issue since the cryptographic methods can be used for acoustic telemetry without modification.*

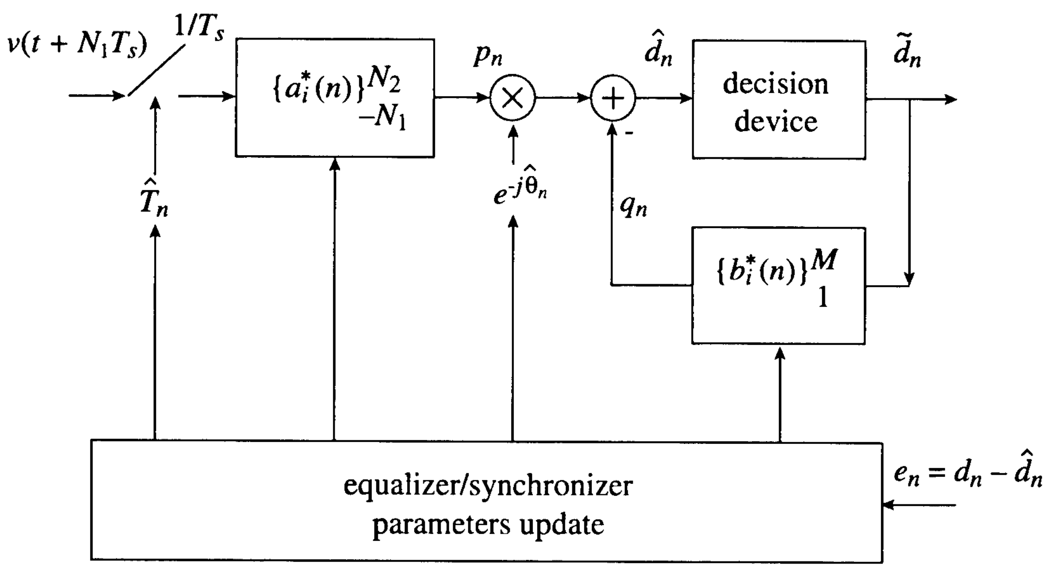


***Figure 3.** The structure of a typical adaptive equalizer which is an important component in current coherent acoustic telemetry systems. The purpose of the equalizer is to compensate for the multipath and Doppler spreading introduced by the channel. Intersymbol interference is a major problem with these channels. The equalizer must be periodically reinitialized because they tend to lose track of the impulse response of the channel as it changes due to source/ receiver motion and propagation effects. From Stojanovik, M., Catipovik, J. and Prokis, J., "Phase Coherent Digital Communications for Underwater Acoustic Channels",* Journal of Oceanic Engineering, *v.19 (1), January, 1994.*

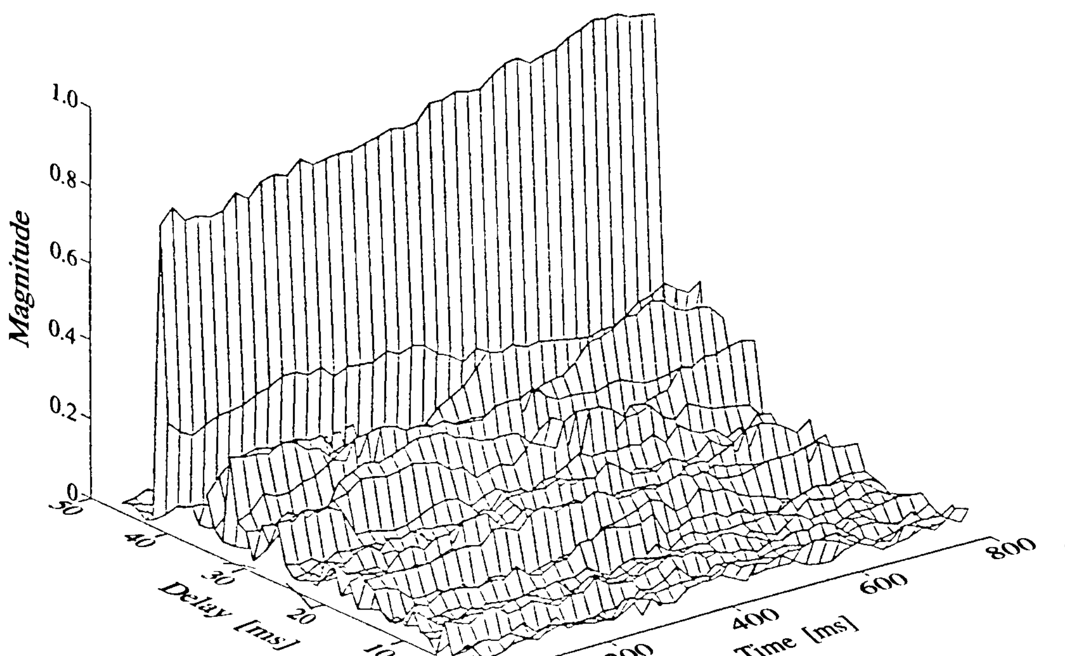


***Figure 4.** An example of a sequence estimated impulse responses for propagation across a path in the Woods Hole harbor. The left access is the impulse response while the right is the sequence number. In this channel there are some lower level arrivals followed by a large one. The cumulative effect of the lower arrivals lead to intersymbol interference. The time varying character of the channel is indicated by the change in amplitude among the different paths versus sequence. This is a relatively benign channel compared to most because both source and receiver are fixed.*

PLANS FOR EOS AND AVAILABILITY OF EOS DATA

Dr. Jeffrey Dozier

MTPE SCIENCE PRIORITIES

SEASONAL-TO-INTERANNUAL CLIMATE VARIABILITY

- Provide global observations and scientific understanding to improve determination and forecasting of the timing and regional extent of transient climate anomalies.

LONG-TERM CLIMATE CHANGE

- Provide global observations and scientific understanding of long- term climate variations and trends and the mechanisms and factors that determine them.

ATMOSPHERIC CHEMISTRY AND OZONE

- Provide global observations of changes in stratospheric and tropospheric ozone, for the purpose of detection as well as scientific understanding of their causes and consequences.

LAND USE/ LAND COVER CHANGE AND GLOBAL PRODUCTIVITY

- Document and understand the trends and patterns of changes in land use/ cover, biodiversity, and global land and ocean primary production.

NATURAL HAZARDS

- Apply unique MTPE remote sensing science and technologies to characterization and risk reduction from natural disasters such as earthquakes, fires, floods, and droughts.

MONITORING VIA LONG-TERM SYSTEMATIC OBSERVATIONS

- Pre-operational missions addressing the requirements of specific Earth observation applications areas.
- **What** is the climate doing?
- Natural variability; evolution of anthropogenic forcings.
- Fixed set of observables (radiation, precipitation, SSTs, etc.).
- Global coverage on large scales.
- Long-term, continuous measurements.
- Requires validated, reliable technology.

PROCESS STUDIES AND BASIC RESEARCH OBSERVATIONS

- Research/demonstration missions with the emphasis on advancing understanding of Earth system processes.
- **Why** is the climate behaving as it is?
- Understanding, closing cycles, . . .
- Variables of interest evolve with observations and increased understanding.
- Local coverage on small scales.
- Episodic, opportunistic observations.
- Some technical risk can be tolerated.

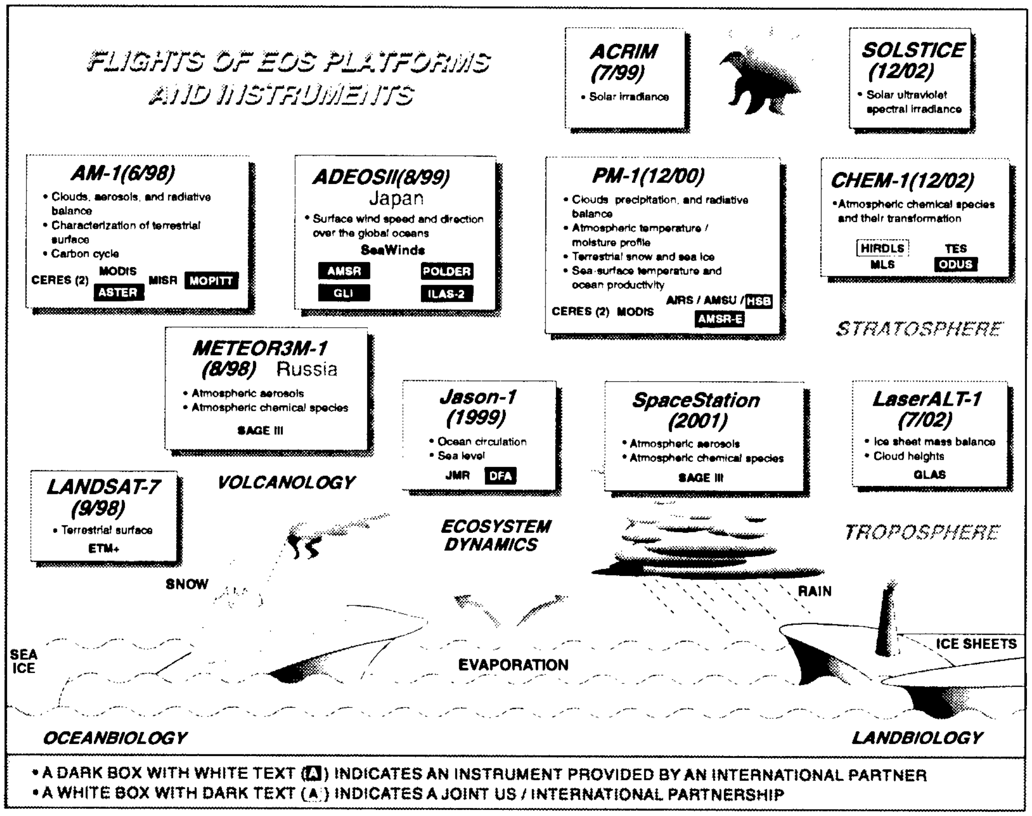


Figure 1: Flights of EOS Platforms and Instruments.

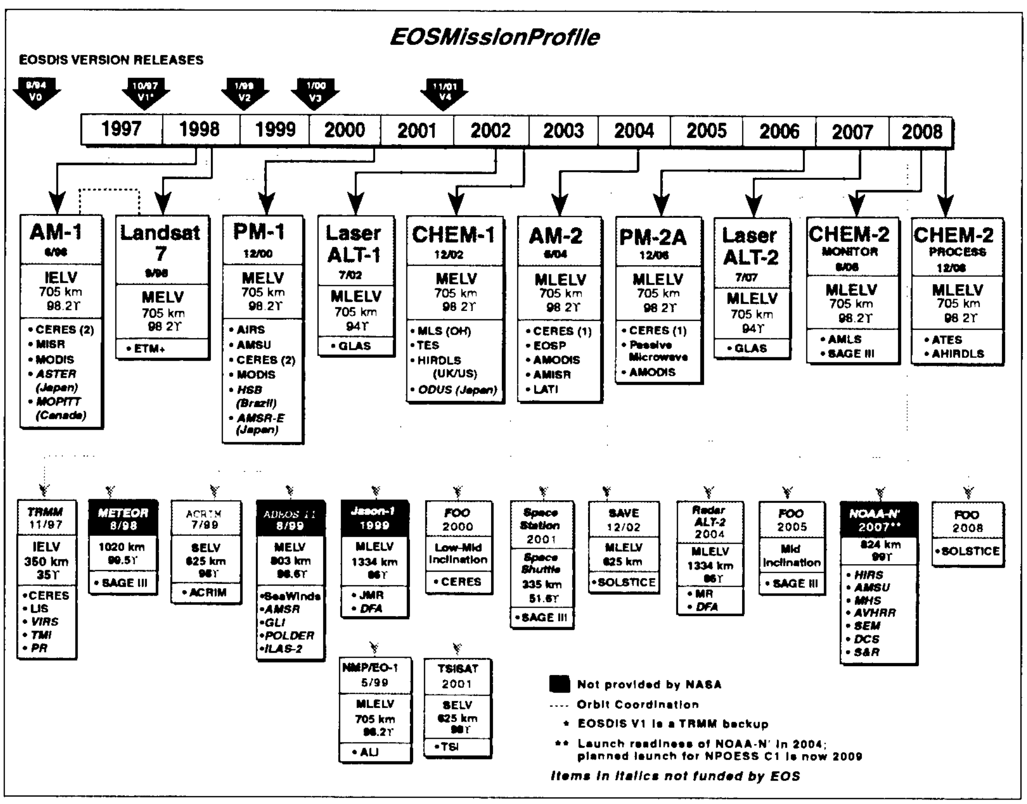


Figure 2. EOS Missile Profile.

Table 8: Measurements to Meet MTPE Scientific Priorities

MTPE Science Research Plan Requirement	Seasonal-to-Interannual Climate Variability	Long-Team Climate Variability and Change	Atmospheric Ozone	Land Cover and Land Use Change	Natural Hazards
Forcing/Feedback Factors:					
• **Total Solar Irradiance**	Secondary	Primary	Not Applicable	Not Applicable	Not Applicable
• **Spectral Irradiance**	Secondary	Secondary	Primary	Not Applicable	Not Applicable
• **Surface UV Irradiance**	Secondary	Secondary	Primary	Secondary	Secondary
• **Earth Radiation Budget**	Primary	Primary	Not Applicable	Secondary	Not Applicable
• **Global Cloudiness**	Primary	Primary	Secondary	Secondary	Secondary
Oceans:					
• **Surface Temperature**	Primary	Primary	Not Applicable	Secondary	Secondary
• **Surface Wind Field**	Primary	Secondary	Not Applicable	Not Applicable	Primary
• **Surface Topography**	Primary	Primary	Not Applicable	Not Applicable	Not Applicable
• **Ocean Color**	Primary	Primary	Not Applicable	Primary	Not Applicable
• **Temperature Profile**	Primary	Primary	Not Applicable	Not Applicable	Not Applicable
• **Salinity Profile**	Secondary	Primary	Not Applicable	Not Applicable	Not Applicable
• **Coral Reef Attributes**	Not Applicable	Primary	Not Applicable	Not Applicable	Not Applicable
Atmosphere:					
• **Global Temperature/Moisture Profiles**	Primary	Primary	Primary	Primary	Primary
• **Stratospheric Temperature**	Secondary	Primary	Primary	Not Applicable	Not Applicable
• **Polar Stratospheric Clouds**	Secondary	Primary	Primary	Not Applicable	Not Applicable
• **Aerosols/Aerosol Precursors**	Secondary	Primary	Primary	Secondary	Not Applicable
• **Chemically Active Trace Gases**	Not Applicable	Secondary	Primary	Not Applicable	Not Applicable
• **Radiatively Active Trace Gases**	Secondary	Primary	Primary	Secondary	Not Applicable
• **Ozone Total and Profile**	Secondary	Primary	Primary	Not Applicable	Not Applicable
• **Global Precipitation**	Primary	Secondary	Not Applicable	Secondary	Secondary
• **Winds**	Primary	Primary	Primary	Secondary	Primary
• **Sea Level Pressure**	Primary	Not Applicable	Not Applicable	Not Applicable	Not Applicable
• **Physical/Biochemical Fluxes**	Secondary	Primary	Not Applicable	Primary	Not Applicable
• **Lightning**	Secondary	Secondary	Primary	Secondary	Not Applicable
Land Surface:					
• **Soil Wetness/Moisture**	Primary	Primary	Not Applicable	Primary	Primary
• **Wetland Extent**	Secondary	Primary	Not Applicable	Primary	Not Applicable
• **Vegetation Function/Structure**	Secondary	Secondary	Not Applicable	Primary	Not Applicable
• **Volcanic Effects**	Secondary	Not Applicable	Not Applicable	Secondary	Primary
Land Surface (Continued):					
• **Fire Intensity/Location**	Secondary	Secondary	Secondary	Primary	Primary
• **Surface Temperature**	Primary	Primary	Not Applicable	Primary	Not Applicable
• **Surface Topography/Slope**	Secondary	Secondary	Not Applicable	Primary	Primary
• **Worldwide River Discharge**	Secondary	Not Applicable	Not Applicable	Primary	Primary
• **Potential Evaporation**	Primary	Not Applicable	Not Applicable	Primary	Primary
• **Space-Time Strain Variability**	Not Applicable	Not Applicable	Not Applicable	Primary	Primary
Cryosphere:					
• **Sea Ice Extent, Concentration**	Primary	Primary	Not Applicable	Not Applicable	Primary
• **Ice Sheet Topography**	Not Applicable	Primary	Not Applicable	Primary	Not Applicable
• **Snow Cover/Water Equivalent**	Primary	Primary	Not Applicable	Primary	Secondary
• **Ice Sheet Surface Behavior**	Primary	Primary	Not Applicable	Primary	Secondary
Geophysical Factors:					
• **Earth Gravity Field**	Primary	Primary	Not Applicable	Not Applicable	Secondary
• **Magnetic**	Not Applicable	Not Applicable	Not Applicable	Not Applicable	Not Applicable
• **Global Plate Kinematics**	Not Applicable	Not Applicable	Not Applicable	Not Applicable	Primary
• **Terrestrial Reference Frame**	Secondary	Secondary	Not Applicable	Not Applicable	Primary

MONITORING VIA LONG-TERM SYSTEMATIC OBSERVATIONS

- Total solar Irradiance (broadband)
- Earth radiation budget (top of atmosphere)
  - Fluxes of shortwave, longwave and net radiation
- Cloud properties
- Sea surface Temperature
- Ocean surface winds (speed and direction)
- Oceanic circulation (sea surface topography)
- Ocean color
- Temperature and moisture profiles
- Aerosols
  - Troposphere and stratosphere
  - Type, optical depth, spatial and temporal coverage, single scattering albedo
- Stratospheric chemistry
  - Ozone concentration
    - Total ozone content (high horizontal resolution)
    - Vertical profile (vert. res. ~ 3 km)
  - Trace gas profiles
    - H_2O, ClO, NO_2, HCl, HF
  - Stratospheric temperature
  - Solar UV spectral irradiance
  - Polar stratospheric clouds
  - Aerosol profile
- Tropospheric Chemistry
  - Ozone profile
- Precipitation accumulation (rate)
- Snow cover (extent)
- Sea Ice (distribution, extent and concentration)

PROCESS STUDIES AND BASIC RESEARCH OBSERVATIONS

- Earth radiation budget: atmospheric column (vertical distribution of cooling/heating processes, surface fluxes of shortwave, longwave and net radiation).
- Cloud properties (vertical distribution of cloud particle size and optical depth).
- Ocean surface winds (speed and direction)
  - Passive remote sensing technique development
- Oceanic circulation (high precision gravity field, oceanic heat and fresh water storage and transport, sea surface salinity and energy fluxes).
- Ocean primary productivity (ocean color).
- Sea surface salinity.
- Aerosols (precursor chemical species, formation and transformation processes).
- Greenhouse gas concentrations (i.e., CH_4, CFCs, etc.).
- Stratospheric Chemistry
  - Trace gas profiles
    - HNO_3, NO, CFC-11, OH, HO_2, BrO, OClO
- Tropospheric chemistry
  - Ozone precursor gases
    - NO, NO_2, CO, HNO_3, CH_4
  - Lightning
- Tropospheric winds
- Soil moisture
- Sea ice (age, albedo, salt content, melt ponds, thickness)
- Ice sheets and glaciers (precision, topographic mapping, surface deformation and field of ice sheets and glaciers, time dependent components of gravity field of ice sheets and glaciers).
- Snow cover (albedo, water equivalent)

ABOUT THE COVER: **TOPOGRAPHY OF THE EARTH**

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In the Oceans, detailed bathymetry is also essential for understanding physical oceanography and marine geophysics. Currents and tides are controlled by the overall shapes of the ocean basins as well as the smaller sharp ocean ridges and seamounts. Because erosion and sedimentation rates are low in the deep oceans, detailed bathymetry reveals the mantle convection patterns, the plate boundaries, the cooling/subsidence of the oceanic lithosphere, the oceanic plateaus, and the distribution of off-ridge volcanoes. Finally biological processes are largely controlled by ocean depth and terrain. Current global digital bathymetry maps (e.g. ETOPO-5) lack many important details such as a 400 km-long ridge in the South Pacific that rises to within 135 m of sea level. Moreover, they are contaminated by long-wavelength errors which prevent accurate identification of seafloor swells associated with mantle plumes.

This new bathymetric map of the oceans (3-10 km resolution) was developed by combining all of the available depth soundings collected over the past 30 years with high resolution marine gravity information provided by the Geosat, ERS-1/2, and Topex/Poseidon altimeters [Smith and Sandwell, 1997, Sandwell and Smith, 1997]. In addition small areas of the bathymetric map are based on high resolution coverage from the Digital Bathymetric Data Base – Variable Resolution (DBDBV Version 1.0). These areas include: Mediterranean Sea, the Black Sea, the Red Sea, the Persian Gulf, the East Pacific Ocean (longitude 140W, latitude 29N-45N), and the Baltic Sea longitude (15E-25E 30N-48N).

Land topography, from the recently released GTOPO-30 model, is also shown to highlight the relationships between onshore and offshore structures. The land and bathymetry data bases were merged using a very high resolution coastline to control the zero elevation contour.

DATA SOURCES:

Measured and Predicted Seafloor Topography (http://topex.ucsd.edu):

Smith, W.H.F. and D.T. Sandwell, Global Seafloor Topography from Satellite Altimetry and Ship Depth Soundings, submitted to *Science*, April 7, 1997.

Sandwell, D.T. and W.H.F. Smith, Marine Gravity Anomaly from Geosat and ERS-1 Altimetry, *J. Geophys. Res.*, v. 102, no. B5, p. 10039-10054, 1997.

DBDB-V:

Data Base Description for DBDB-V, Version 1.0, Naval Oceanographic Office, March, 1996.

DoD Directive 8320.1, DoD Data Administration, Draft, 26 September 1992 (NOTAL).

Naval Oceanographic Office Data Model, Hydrographic/Bathymetry, Deaft, latest applicable version.

GTOPO-30

(HTTP://EDCWWW.CR.USGS.GOV/LANDDAAC/GTOPO30/GTOPO30.HTML):

- GTOPO30 is a global digital elevation model (DEM) with a horizontal grid spacing of 30 arc seconds (approximately 1 kilometer). GTOPO30 was derived from several raster and vector sources of topographic information. For easier distribution, GTOPO30 has been divided into tiles which can be selected from the map shown above.

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The Scripps Institution of Oceanography (SIO) was funded by the Office of Naval Research to investigate whether data from Civilian research systems could be exploited to improve Navy operational missions. This report covers the activities and some recent results that indicate civil systems are a critical asset that could readily be applied to provide information essential to current Navy problems, such as characterization of the littoral zone, ship monitoring and tracking.

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