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NAVAL
RESEARCH
ADVISORY
COMMITTEE
REPORT

THE IMPORTANCE OF ENVIRONMENTAL DATA

FEBRUARY 1989

OFFICE OF THE ASSISTANT SECRETARY OF THE NAVY
(RESEARCH, ENGINEERING AND SYSTEMS)
WASHINGTON, D.C. 20350

NAVAL RESEARCH ADVISORY

COMMITTEE

THE IMPORTANCE OF

ENVIRONMENTAL DATA

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EXECUTIVE SUMMARY

The panel conducted a top level analysis of the significance of quantitative knowledge of environmental parameters to naval weapons and naval warfare. While it is readily apparent that all naval platforms and weapon systems are affected to some degree by the environment, the panel reviewed a number of scenarios where the impact of the environment was significant. There are combinations of weapon systems and environmental parameters where knowledge of the environment can result in order-of-magnitude improvements in system performance. However, quantifying exactly how much performance can be gained and what degree of precision of environmental measurements are required must be determined on a case-by-case basis and was beyond the scope of this panel. Adequately characterizing the marine environment in space and time requires the use of remote sensing techniques, both ground-based and space-based. Using remotely sensed data supported by in-situ measurements, ocean/atmosphere models will be able to accurately predict the state of the environment and weapon system performance.

As the trend towards stealth continues to drive the signatures of platforms and weapons deeper into the environment, knowledge of the environment and how it affects weapon systems continues to grow in importance. The importance and utility of environmental knowledge continues to increase until the signature is so deep in the environmental noise that it is beyond detection, even in the most favorable environment. At this point, performance can be improved only through the development of new technologies and better system design. Knowledge of the environment is equally vital in system design.

The panel developed four basic observations.

1. The impact of the environment is not adequately addressed during the research, development and acquisition process. Each new naval and marine system concept should be evaluated to determine the effect of the environment on system performance and what environmental measurements must be obtained to support the system.

RECOMMENDATION: OPNAV (OP-07 and OP-098) and SECNAV (ASN (RE&S)) should vigorously review every Development Options Paper against the probable environmental background before an Operational Requirement is approved (i.e., will the physics and our knowledge of the environment permit the proposed system to operate as advertised).

2. There is no central environmental/oceanographic top level requirement or master plan.

RECOMMENDATION: Oceanographer of the Navy should develop and publish a "Master Plan for Oceanography" for environmental support to future naval planners, battle force commanders and system developers.

3. The more than 20 organizations involved in various aspects of environmental science and effects are not connected by any formalized communication network, leading to duplication of effort and misuse of products.

RECOMMENDATION: The interrelationships of all these organizations should be identified in the Oceanographic Master Plan.

4. The 1984 Naval Research Advisory Committee (NRAC) Panel on Environmental Support to Naval and Marine Forces is an impressive in-depth report that retains much of its validity today.

RECOMMENDATION: The Oceanographer of the Navy and CNR should review the 1984 panel document, and report to the CNO and ASN(RE&S) on the status of implementing the recommendations within the report.

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OBJECTIVE

DETERMINE THE SIGNIFICANCE OF
QUANTITATIVE KNOWLEDGE OF
ENVIRONMENTAL PARAMETERS TO
NAVAL WEAPONS AND NAVAL WARFARE

Terms of Reference
Importance of Environmental Data

This briefing summarizes the findings and recommendations of the Naval Research Advisory Committee (NRAC) 1988 Summer Study Panel on the Importance of Environmental Data. The background statement and specific tasking provided to the panel follow.

1. General Objective. Determine the significance of quantitative knowledge of environmental parameters to naval weapons and warfare.

2. Background. It is widely recognized that ASW techniques and equipment are dependent upon acoustic properties. Therefore, it has been postulated that precise knowledge of the acoustic properties of specific bodies of water could significantly enhance the effectiveness of our Anti-Submarine Warfare (ASW) forces. Similarly, since the atmospheric environment controls the propagation of Radio Frequency (RF) energy, it has been postulated that naval forces can fight more effectively if they can reliably estimate these factors. Lasers and other advanced weapons and sensors are equally influenced by the natural environment.

3. Specific Tasking.

a. Which weapon systems are susceptible to performance modifications caused by the natural environment?

b. How much performance enhancement can be obtained with a more precise measurement/estimate of the natural environment?

c. What degree of precision must be provided for each environmental parameter to enable a measurable improvement in weapons performance?

d. What type(s) of sensors and techniques are necessary to achieve the required level of environmental knowledge?

4. Point of Contact (POC). RADM T. K. Mattingly, SPAWAR, PD-40, 692-2182.

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SPECIFIC TASKING

TASKS	PANEL RESPONSE
● WHICH WEAPON SYSTEMS ARE AFFECTED?	● ALL TO SOME DEGREE - DETECTION SYSTEMS MOST SENSITIVE - WILL PRESENT GO/ NO-GO EXAMPLES
● HOW MUCH PERFORMANCE CAN BE GAINED?	● MAJOR IMPROVEMENTS; MUST BE QUANTIFIED ON A CASE-BY-CASE BASIS ● REQUIRES DETAILED EXAMINATION OF SYSTEM CHARACTERISTICS, ENVIRONMENTAL PARAMETERS, TACTICS AT THE TIME OF SYSTEM APPROVAL & THROUGHOUT DEVELOPMENT CYCLE
● HOW PRECISE MUST THE MEASUREMENTS BE?	
● WHAT TYPES OF SENSORS / TECHNIQUES ARE NEEDED?	● REMOTE SENSING SUPPORTED BY IN-SITU MEASUREMENTS TO PROVIDE GLOBAL, SYNOPTIC COVERAGE ● OCEAN MODELS / PREDICTION SYSTEMS

Specific Tasking

This figure summarizes the terms of reference tasking to this NRAC panel. These tasks bear a similarity to those of the year-long 1984 NRAC study, but were viewed in the current study from a higher level perspective. This is complementary to the previous effort, which was very detailed and comprehensive. The panel first attempted to identify the most critical issues, and quickly homed in on perceived deficiencies in the Navy's organizational structure and procedures related to the impact of the environment, particularly in the Research, Development, and Acquisition (RDA) process. This became a major focus of the study.

There is no question that all naval weapon systems are susceptible to performance degradation by variable and uncompensated environmental features. There is no doubt that real-world weapon performance can be enhanced by improved knowledge and exploitation of the environment. The real issue is one of priorities. The panel addressed this issue by selecting and presenting examples which have the following characteristics:

1. The systems represented are of paramount importance to the Navy;

2. The benefit from adequate consideration of environmental effects may be the difference between mission success and failure;

3. The need for certain specific environmental measurements is clearly indicated by the examples.

Establishment of the quantitative relationships of system performance versus environmental characteristics, as expressed in the terms of reference, should be an on-going process in the developer and user communities of the Navy. It is beyond the capacity of this NRAC panel, in terms of available time and resources, to reach beyond the identification of important parameters, the needs for environmental information, and the improvement in policies and procedures required to integrate them efficiently into the acquisition and fleet operation processes.

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DERIVATIVE ISSUES

- HOW DO LOW OBSERVABLE THREAT TRENDS IMPACT THE NEED FOR ENVIRONMENTAL DATA?
- HOW SHOULD ENVIRONMENTAL DATA BE APPLIED TO THE RESEARCH, DEVELOPMENT, AND ACQUISITION PROCESS ?
- ARE ENVIRONMENTAL DATA BEING PROPERLY USED IN TRAINING, TACTICS, AND FLEET OPERATIONS?

Derivative Issues

Interpretation of the terms of reference specific tasking yielded the derived issues indicated in the graphic. The application of stealth technology to threat platforms and missiles causes their signatures to "sink" deeper into the environment, which tends to frustrate our target detection systems. This evolution must drive our effort to improve the understanding and exploitation of environmental characteristics, and has significantly determined the direction of this study.

The panel did not attempt to thoroughly examine the environmental requirements needed to support future sensor systems that may emerge as threat signatures are suppressed. For example, low frequency magnetic, spatial gradient magnetic anomaly, and bioluminescent sensors were not addressed. It is clear that some of these possible future sensors (e.g., Electro-Optical (EO)) may need more environmental data support than present systems require.

The panel recognized, at the outset, the importance of improving our ability to assess environmental effects on future weapons throughout the acquisition life cycle--from initial concept development through deployment--including impacts on training, tactics, and fleet operations.

PANEL MEMBERSHIP

Member	**Organization**	**Expertise**
Mr. Gerald Cann	General Dynamics	Chairman
Dr. Robert Porter	University of Washington	Vice Chairman
Mr. John Brett	Brett Research Associates	Sensor Technology
Dr. Frederick Bomse	Center for Naval Analyses	Operations/Tactics
Dr. David Hyde	SAIC	Acoustics
Dr. Harvey Ko	Applied Physics Lab, JHU	Electromagnetics
Dr. George Moe	Riverside Research Institute	EO, Non-acoustic ASW
Dr. William Moseley	NORDA	Acoustics
Dr. Juergen Richter	NOSC	EM/EO Propagation
Mr. George Schecter	Battelle Columbus Div.	Combat Modeling
Dr. Robert Spindel	Applied Physics Lab, U of Washington	Acoustics
Mr. William Tolbert	Analysis and Technology	Coastal Environment
CDR Bradley Smith	CNO (OP-701)	Executive Secretary
ASN Sponsor:		
Mr. John Keane	OASN (RE&S)	
Special Advisors:		
RADM Richard Pittenger	CNO (OP-71)	
RADM Craig Dorman	SPAWAR (PD-80)	

BRIEFERS
(IN ORDER OF APPEARANCE)

Briefer	Organization	Topic
RADM C. Dorman	SPAWAR (PD-80)	Research and Development
RADM C. Meinig	NAVSEA (06A)	Environmental Impact On AAW
Dr. J. Sinsky	SPAWAR (PMW-180T)	Environmental Impact on IUSS
Mr. B. Blumenthal	ONR (Code 125)	ASW Environmental Acoustic Support
RADM J. Seesholtz	Oceanographer (OP-096)	Fleet Environmental Support
CAPT J. Jensen	SPAWAR (PMW-141)	Tactical Environmental Support System
Dr. R. Spindel	APL U of Washington	1984 NRAC Study on Environmental Support
Dr. P. Tatro	SAIC	Warfighting Benefits Study
Mr. J. Bardin	SAIC	Warfighting Benefits Study
Dr. J. Richter	NOSC	Electro-Magnetic/ -Optic Propagation
RADM (SEL) P. Cressy	OP-59	ASW in the Gulf Stream
Mr. S. Barker	NAVOCEANO	Magnetics
Mr. R. Feden	OP-962	Oceanographic Requirements
CDR R. Hale	OPTEVFOR	Operational Test & Evaluation

BRIEFERS (Continued)

Briefer	Organization	Topic
Mr. S. Lackie	ONR	ASW Environmental Acoustic Support
Mr. B. Cole	NOSC	Low Frequency Active/ Critical Sea Test
Mr. T. Higbee	SPAWAR (PMW-180-52)	Critical Sea Test
CDR T. Callaham	COMSUBLANT	Use of Environment in Submarines
CDR F. Wooldridge	SPAWAR 321	Review of TORs/ORs
CDR P. Bishop	NAVEASTOCEANCEN	Environmental Data and the TAO
CAPT J. Hagy	SPAWAR (PMW-144)	Relocatable Over-the-Horizon Radar
Mr. A. Poltorak	SAIC	Directed Energy Weapons
Dr. W. Moseley	NORDA	Past Warfighting Effectiveness Studies
Mr. G. Hebern	NORDA	Tactical Oceanography Program
Mr. R. Wagstaff	NORDA	Directional Ambient Noise
Mr. R. Poore	CNA	NROSS Utility Study
CDR W. Shutt	NEPRF	Environmental Prediction Research
Mr. R. Winokur	OP-096	Shallow Water Acoustics/Arctic
RADM R. Pittenger	OP-71	Environmental Training
Mr. W. Tolbert	Analysis and Technology	Coastal Environment
CAPT R. Hechtman	OP-73	Tactics Development

PERSPECTIVE

- NEXT WAR CANNOT BE A WAR OF ATTRITION AT SEA
- CURRENTLY WE EXPLOIT FIRST ORDER ENVIRONMENTAL EFFECTS
- THE ADVENT OF LOW OBSERVABLES REQUIRES TIGHTENING ALL PERFORMANCE FACTORS
- LOW INTENSITY CONFLICTS / CRISES TEND TO EXACERBATE NEED FOR ENVIRONMENTAL DATA
- COMPREHENSIVE ASSESSMENT OF REQUIREMENTS / CONCEPTS / HARDWARE / TACTICS / TRAINING WITH RESPECT TO PHYSICAL LIMITS IMPOSED BY ENVIRONMENT IS NOT CURRENTLY OCCURRING IN THE RDA PROCESS

Perspective

THE NEXT WAR WILL NOT BE A WAR OF ATTRITION AT SEA. U. S. Navy assets are bounded. At most the fleet will have 600 ships. The number of aircraft and precision guided weapons are also well defined. Therefore, it is extremely important to maximize the success of the first engagement.

CURRENTLY WE EXPLOIT FIRST ORDER ENVIRONMENTAL EFFECTS. The Navy has a large network to collect and disseminate weather and oceanographic data. At this point in time the easy things have been done. Detailed data bases to support future requirements are not available.

THE ADVENT OF LOW OBSERVABLES REQUIRES TIGHTENING ALL PERFORMANCE FACTORS. Quiet submarines and low radar cross-section aircraft/missiles will make fine-grained environmental data very important. As signal to noise decreases for current systems, it will be necessary to factor the environment into concepts, planning, and tactics to defeat these targets.

LOW INTENSITY CONFLICTS/CRISES TEND TO EXACERBATE THE NEED FOR ENVIRONMENTAL DATA. Over the last forty years, many of the limited war crises/conflicts have been in places where U.S. forces have had to operate in coastal waters where acoustic conditions are bad, local bathymetry is unknown, and there are complex RF/Infrared (IR)/EO sea/land interface conditions. An obvious example of this is the recent Persian Gulf experience.

From the perspective of this panel, there appears to be a high payoff from exploiting environmental effects. However, these effects are often quite subtle, and must generally be considered on a case-by-case basis for each weapon system individually. A detailed understanding of such specific issues as propagation paths and optimum frequencies could result in significantly improved acoustic, IR, EO and Electromagnetic (EM) system design and operation.

Comprehensive assessment of requirements/concepts/hardware/tactics/training with respect to physical limits imposed by the environment needs to be a high priority consideration by decision makers prior to major financial commitment to new systems. This is not generally occurring in the RDA process, and the panel identified this as a fundamental flaw in the system.

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IMPORTANCE OF ENVIRONMENTAL KNOWLEDGE

- GLOBAL IN NATURE
- COMPREHENSIVE IN EXTENT

- SYSTEMS DESIGN
- DEPLOYMENT
- OPERATIONS & TACTICS

CONTINUOUS INTERACTION

- WEATHER (OCEAN & ATMOSPHERE)
- GROUND CHARACTERISTICS (SOIL & SEA FLOOR)
- PROPAGATION (ACOUSTIC, EM / EO)

- EXAMPLES
  - RADIO / RADAR PROPAGATION
  - OCEAN ACOUSTICS
  - COASTAL ENVIRONMENT

Importance of Environmental Knowledge

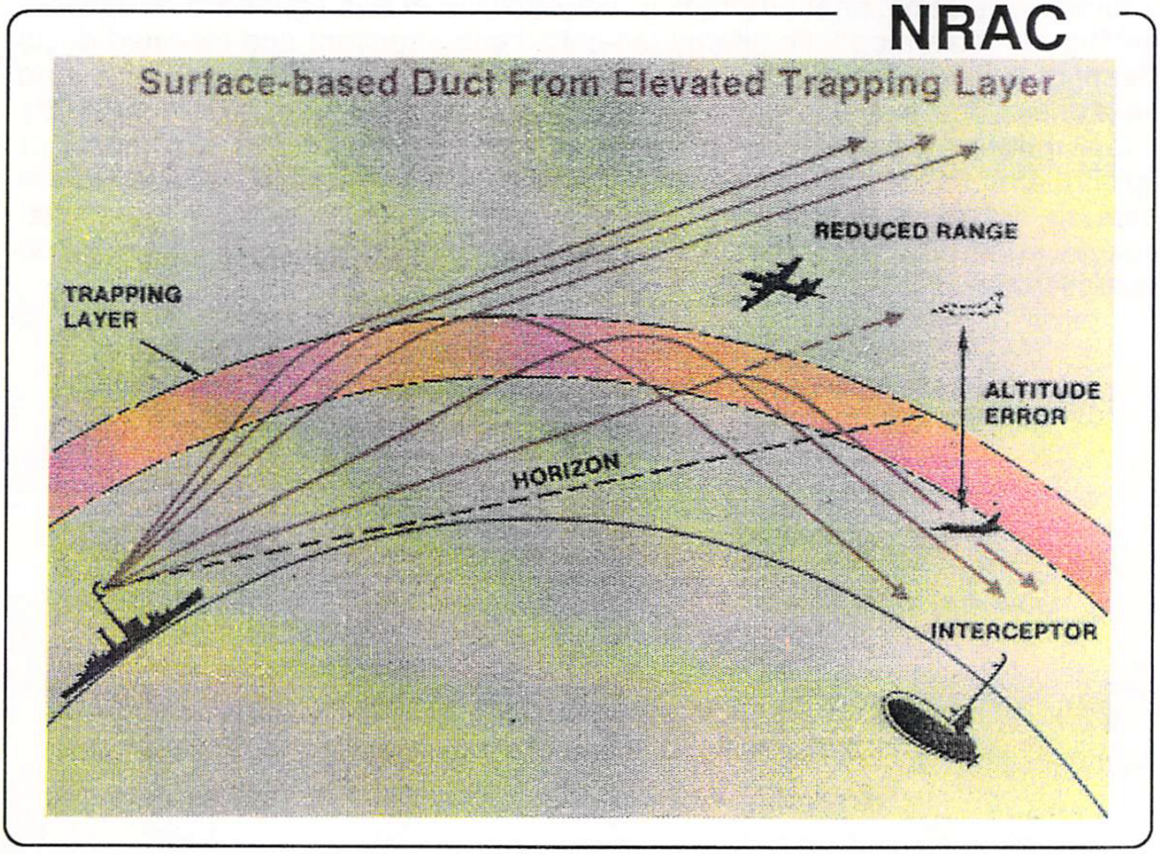
The Navy's requirement for environmental information is global in nature. It not only involves the ocean environment from the tropics to the poles, but also the coastal and land environments. Some of the areas are either not accessible or access to them may be denied.

Environmental knowledge and the proper consideration of its effects are essential throughout the entire acquisition process from basic research through development, test, evaluation, and production. After deployment, operations and tactics must take environmental conditions into account and either mitigate or exploit their effects.

There are many environmental factors that influence naval operations. Most obvious are weather effects and properties of the ocean, both surface and subsurface. Less obvious, but often of crucial importance, are properties of the sea floor and soil characteristics of the adjacent land. Bottom topography of the ocean floor is critical to submarine operations and sound propagation; in shallow water it also affects mining and amphibious warfare. Soil conditions on the beach and the adjacent land may have a significant impact on landing operations. For example, unexpected sand and dust storms may not only reduce visibility for the human eye and electro-optical sensors, but may also render machinery, such as helicopters and tank engines, inoperable. The often highly variable structure of the atmosphere profoundly affects electromagnetic (including electro-optical) propagation. Similarly, underwater acoustic propagation is critically dependent on temperature and salinity changes in the ocean.

There must be a continuous interaction between the collectors and analysts of environmental data and the users in the research through operations process described above.

The following examples illustrate how important the environment can be and how proper consideration of its properties enhances warfare effectiveness.



Propagation Anomalies In The Presence Of A Surface Duct

The first example addresses anomalous radio and radar propagation. This figure depicts a number of propagation effects which are often encountered in a marine environment. A so-called surface-based duct may be formed by colder moist marine air within the first few hundred meters of the ocean surface with drier, warmer air above. The electromagnetic wave fronts may be bent by refraction and propagate beyond the normal radio or radar horizon. The bending of a height finder radar beam may lead to significant errors in determining an airplane's altitude. As recent events in the Persian Gulf have shown, accuracy of altitudes obtained with height finder radars is a critical issue.

The downward refraction of electromagnetic energy may provide over-the-horizon radar coverage or unusually long intercept ranges. Other areas may be less illuminated than under standard propagation conditions and result in a so-called radar hole. A ship's surveillance capability certainly would benefit from having a wider coverage against surface targets but, at the same time, its signals can be intercepted at unusually long ranges and an incoming intruder might exploit a hole in radar coverage. Other propagation phenomena caused by anomalous atmospheric refraction not depicted in this figure are an upward bending of electromagnetic energy (so-called subrefraction) and elevated ducts affecting primarily airborne platforms such as surveillance aircraft and seeker/guidance systems for missiles. All described propagation effects are neither inherently good nor bad, but need to be understood to circumvent or exploit them. Present refractivity measurement and assessment techniques are adequate for most applications; however, there are cases where horizontal changes in refractivity are important. Measurement of those conditions requires presently unavailable refractivity sensing techniques.

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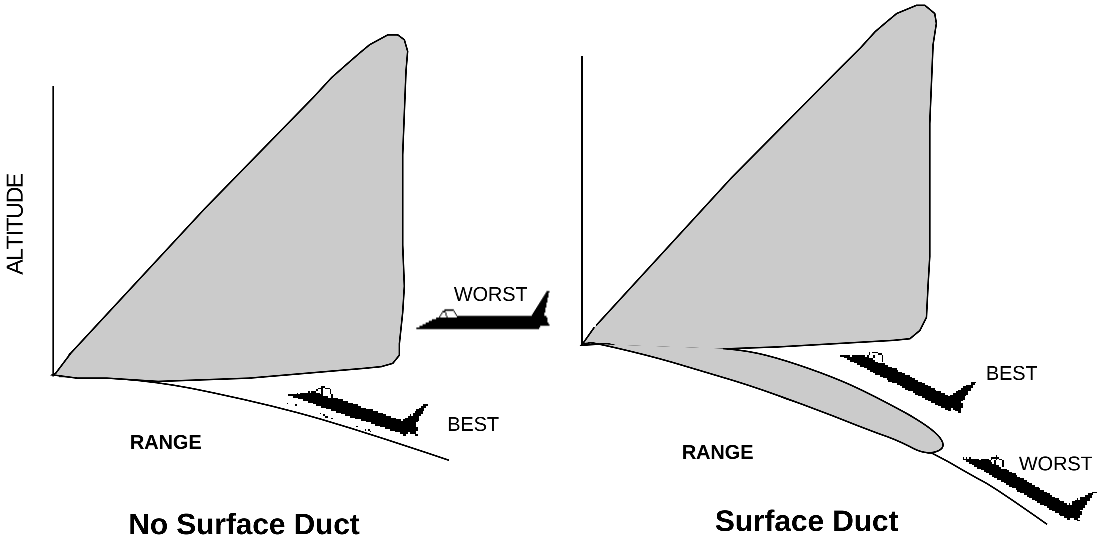
TYPICAL IREPS RADAR COVERAGE DIAGRAMS AND ATTACK AIRCRAFT POSITIONS

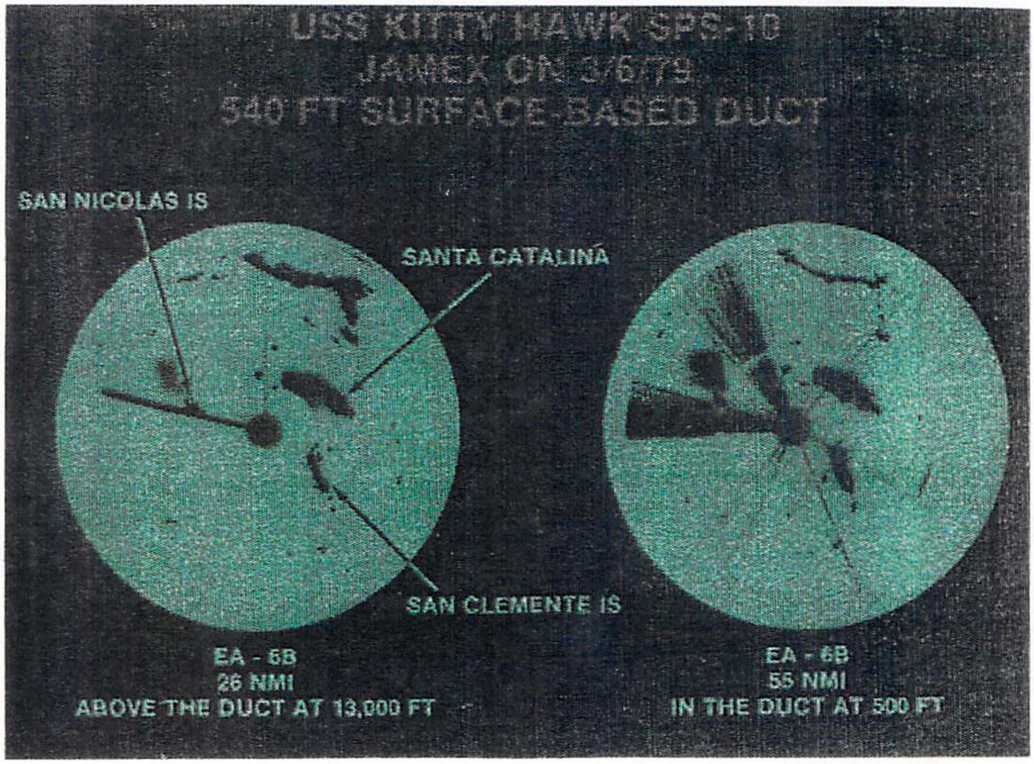


No Surface Duct **Surface Duct**

Tactical Exploitation of Surface Ducts

Tactical exploitation of radar coverage conditions by aircraft carrier based attack and Early Warning (EW) aircraft has been successfully used operationally ever since the Integrated Refractive Effects Prediction System (IREPS) was introduced on carriers in 1978. IREPS produces a number of propagation assessment products and Tactical Decision Aids (TDAs) based on vertical refractivity profiles derived from radiosondes or measured directly by airborne microwave refractometers installed on E-2 aircraft.

The figure depicts a TDA for attack aircraft flying against an enemy radar. The left side shows schematically the hostile radar detection envelope under standard atmospheric propagation conditions. In this case, the best flight altitude for the attacking aircraft is just above the surface in order to stay undetected as long as possible. In the presence of a surface based duct, the enemy radar experiences extended detection ranges often far beyond the normal radar horizon. The low flight altitude commonly used would lead to an early detection at distant ranges and provide the radar platform under attack ample warning and time to counter the attack. IREPS calculates and provides to the pilot the best flight altitude in the less illuminated area above the duct and, thereby, maximizes the time the attacking aircraft remains undetected. Similar TDAs have been developed for EW aircraft equipped with jammers. In this case, jamming effectiveness is significantly enhanced when the jammer is flown in the duct.



Jamming Effectiveness Under Ducting Conditions

An impressive example of jamming effectiveness is shown in this figure which consists of two photographs of the Plan Position Indicator (PPI) of the SPS-10 radar aboard USS KITTY HAWK during a fleet exercise. The PPI on the left shows the ship's radar located at the center of the circle. The presence of a surface duct is apparent by radar returns outlining the California coastline to the north and some of the islands that are beyond the normal radar horizon. An EA-6B jamming aircraft flying at an altitude of 13,000 feet, 26 nautical miles (nmi) from the carrier jams the ship's radar successfully only over a narrow azimuthal angle. In the PPI to the right, the jammer aircraft has moved away to more than twice the original distance, but has also descended to an altitude of 500 feet above the water. Under standard propagation conditions, the EA-6B would be far beyond the normal radar horizon and unable to jam the radar. However, being within the surface duct, the aircraft is now effective in jamming the ship's radar not only, as in the previous case, through its main lobes, but also through the side lobes resulting in much wider azimuthal sector jamming.

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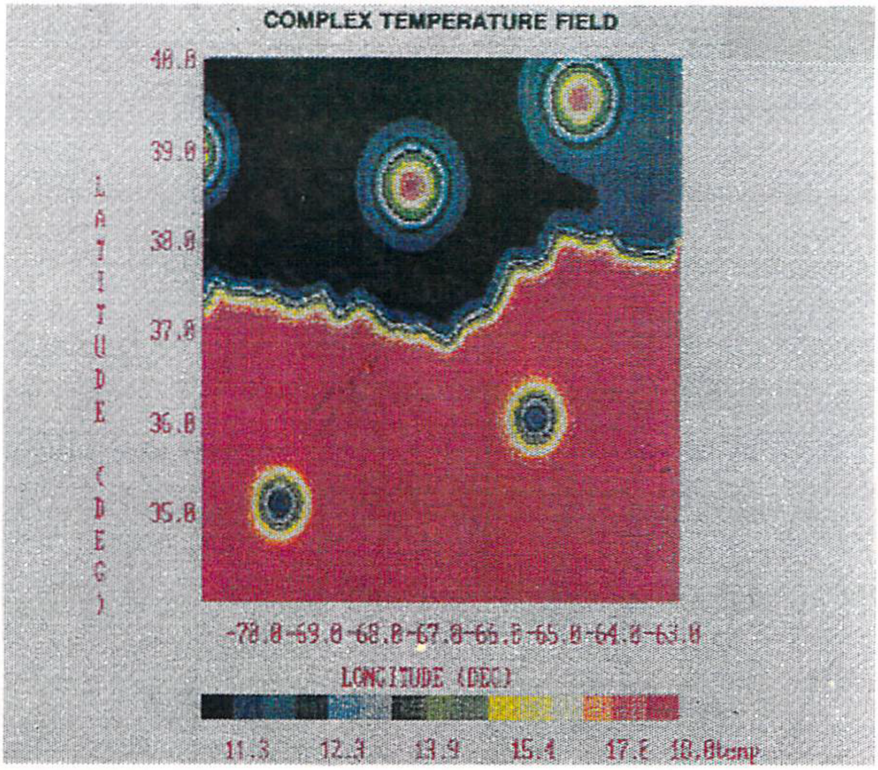
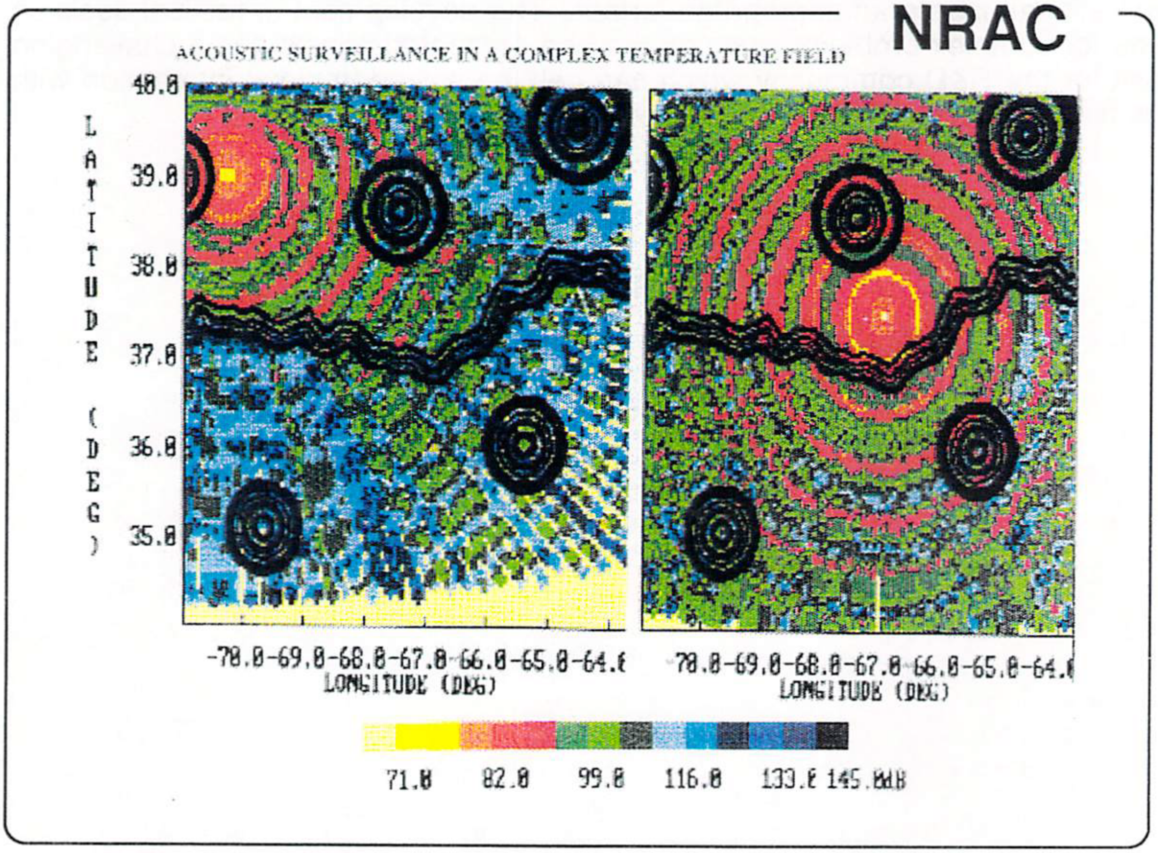


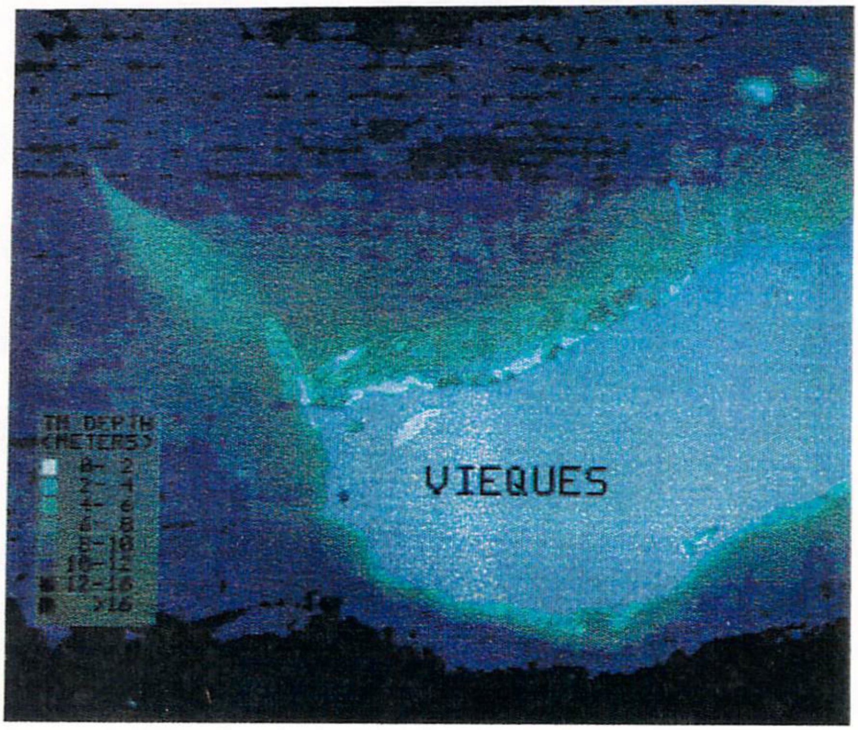
Complex Temperature Field

The second example addresses the undersea surveillance problem the Navy faces in an ocean environment that is characterized by a complex sound velocity field. This figure depicts a computer-generated slice of the ocean temperature distribution at a depth of 200 meters, geographically located in the Gulf Stream region of the North Atlantic. The temperature field is derived from satellite-measured ocean surface temperature data, satellite-measured altimetry, and ocean circulation models with directly sensed inputs of opportunity and produced by the ocean thermal interpolation system scheduled to be part of the Tactical Environmental Support System (TESS). The temperature distribution shows two important features: two water masses with different temperatures separated by a narrow transition or frontal region; and, embedded in the respective water masses, eddies that are either warmer or cooler than their surroundings. This picture is typical of the Gulf Stream, but is not restricted to this specific area. Other important ocean areas display similarly complex temperature and circulation structures.



Acoustic Surveillance in a Complex Temperature Field

This figure illustrates the surveillance problem encountered in a complex temperature environment. On the left side of the figure, a receiver is located at a latitude of 39 degrees North and a longitude of 70.5 degrees West at a depth of 100 meters. The color pattern represents signal levels at a frequency of 500 Hz from a source also at a depth of 100 meters. If, for example, signal levels in excess of 99 dB (green, red, yellow) are necessary for target detection, there are large blue areas that could contain targets that would escape detection. Specifically, the warm eddy at 38.7 N and 67.5 W causes shadowing of the region toward the east, and the front itself produces abrupt changes in signal level. Receiver location for optimal coverage is not intuitively obvious; it can be objectively determined using appropriate ocean and acoustic models and procedures. The right side of the figure shows the signal level field for the receiver relocated to 37.5 N and 67 W. The geographic area under consideration is now almost entirely covered by the receiver, increasing the surveillance effectiveness significantly. Optimal placement of surveillance receivers is important for systems like Surveillance Towed Array Sonar System (SURTASS) and can be accomplished by a complex process involving remotely and directly sensed data, ocean circulation models, interfaced with acoustic models and the timely presentation of the information to the operational user in an appropriate format. The development of tactical decision aids for complex problems such as the one presented constitutes a challenging task for the R&D community which can only be solved in close interaction with the fleet user.



Bathymetry from Satellite Imagery

LANDSAT 4 Thematic Mapper images have been used in research projects to determine bottom bathymetry in clear water to depths of 25 meters. This figure shows the multispectral image of a 15-kilometer by 15-kilometer region centered on the western part of Isla De Vieques in the Caribbean. Computer processing of each 30-meter square pixel of the image in several spectral bands, together with archival calibration point soundings from the area, produce a remotely sensed map of the ocean bottom.

This "bottom image" is displayed in the next figure as a color image where each different shade of blue represents a different water depth scaled in meters. The accuracy of the technique provides water depths with an average error of less than two meters. The color image indicates the severe complexity of bathymetry in coastal areas. Similar processing of these images can yield trafficability information.

Accurate near-shore bathymetry/trafficability is of high value to hazard-free navigation and to amphibious assault planning. Remote sensing techniques such as these are crucial for the coastal regions where the proprietary country generally denies access to all other countries. These research capabilities need to be transitioned to operational capabilities and all water types (not just clear water) capabilities need to be developed.

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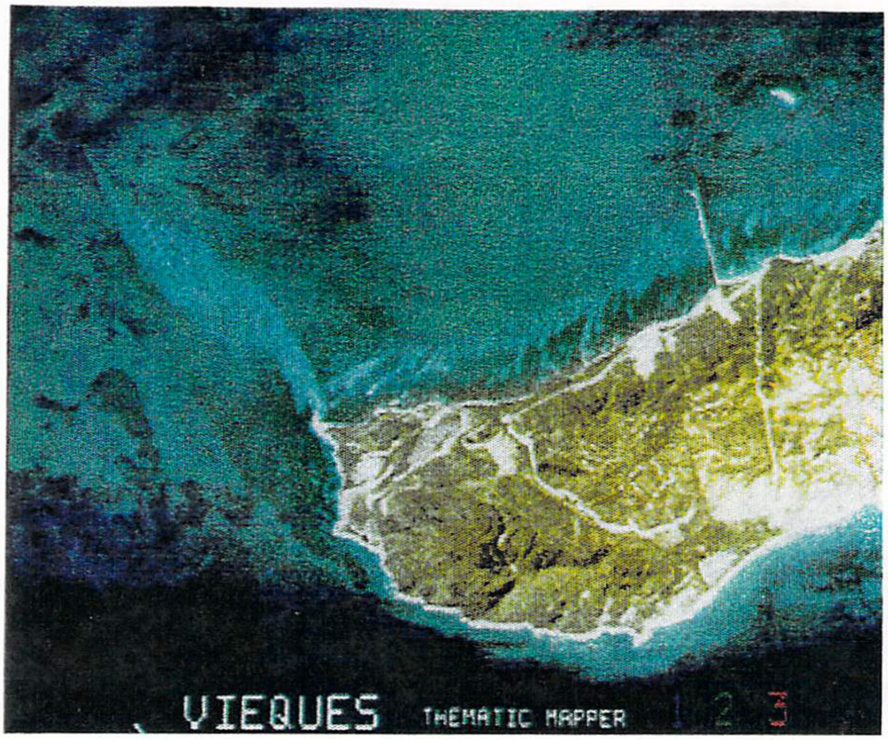

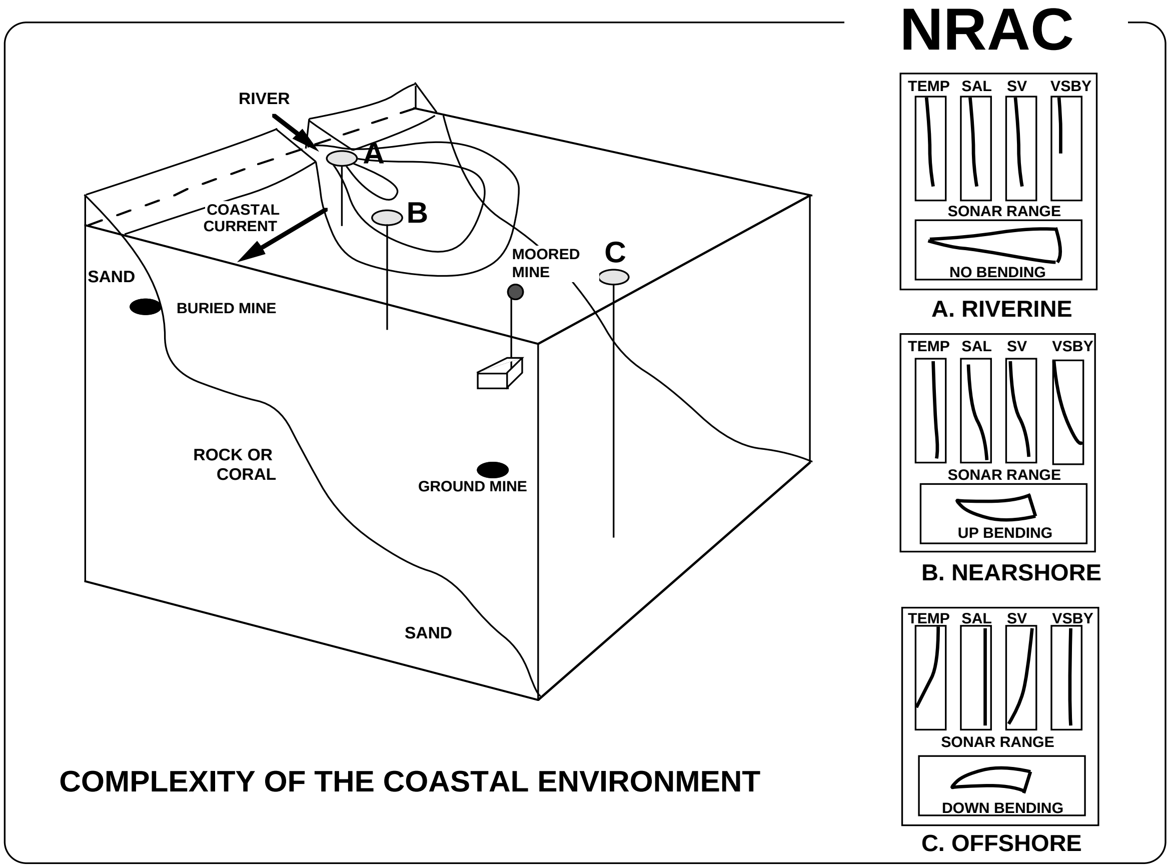

Complexity of the Coastal Environment

The third example depicts the spatial complexities of the coastal environment and some of the problems encountered in attempting to operate in these shallow waters. Adding to this complexity is the fact that many of these parameters change with time (minutes, to hours, to days).

Navy missions conducted primarily in coastal waters include mine warfare, amphibious warfare, and special warfare. Each of these warfare areas faces unique environmental problems that can have severe impacts not only on mission success but on the very survival of the forces involved. For example, in amphibious warfare, depth of the water is a critical parameter and the location of near shore bars and obstructions is essential to the operation of any displacement hull craft. While this requirement may change with the introduction of Landing Craft Air Cushion (LCAC), displacement hulls will be used in the foreseeable future to resupply the initial assault.

In mine warfare, bottom type is essential to the mine planting as well as to the countermeasures effort. It is estimated that up to half of the ground mines laid in coastal waters (depths less than 200 feet) will bury, and as technology is making mines more sweep resistant, hunting becomes our only countermeasures option. Yet today we do not have an effective means to detect, locate and neutralize buried mines. While we have developed models to predict where, when, and how mines bury, such models are virtually useless since we cannot provide the essential input data, primarily sediment characteristics. The threat of the buried mines can have dire consequences to all Navy operations, e.g., block the ingress/egress of Navy platforms to home ports, curtail North Atlantic Treaty Organization (NATO) resupply operations, and disrupt amphibious assault operations. A means to rapidly survey coastal sea bottoms is critical to all fleet operations.

Special warfare operations are uniquely affected by the operational environment as both men and equipment are directly exposed to its influence. A primary mission of these forces is to map and measure bars and obstructions that might interfere with amphibious landing and to locate and neutralize very shallow water mines. Nevertheless, the environment itself is the greatest deterrent to the success of these missions. Poor underwater visibility, the very high probability of mine burial, as well as currents and surf conditions, severely impact the ability of SEAL teams to succeed in their assigned tasks.

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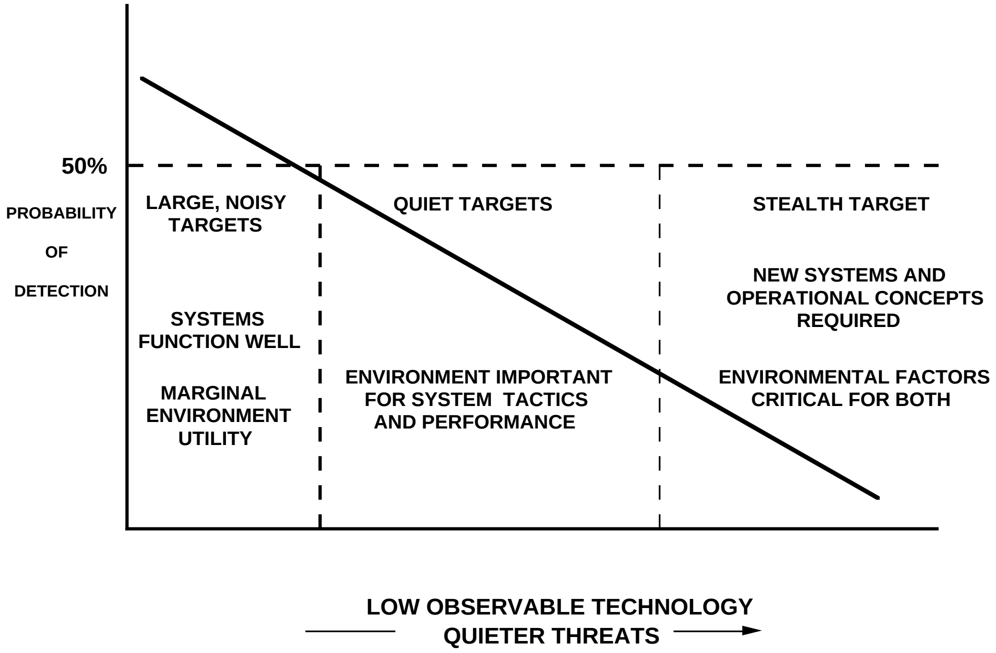
VALUE OF ENVIRONMENTAL DATA



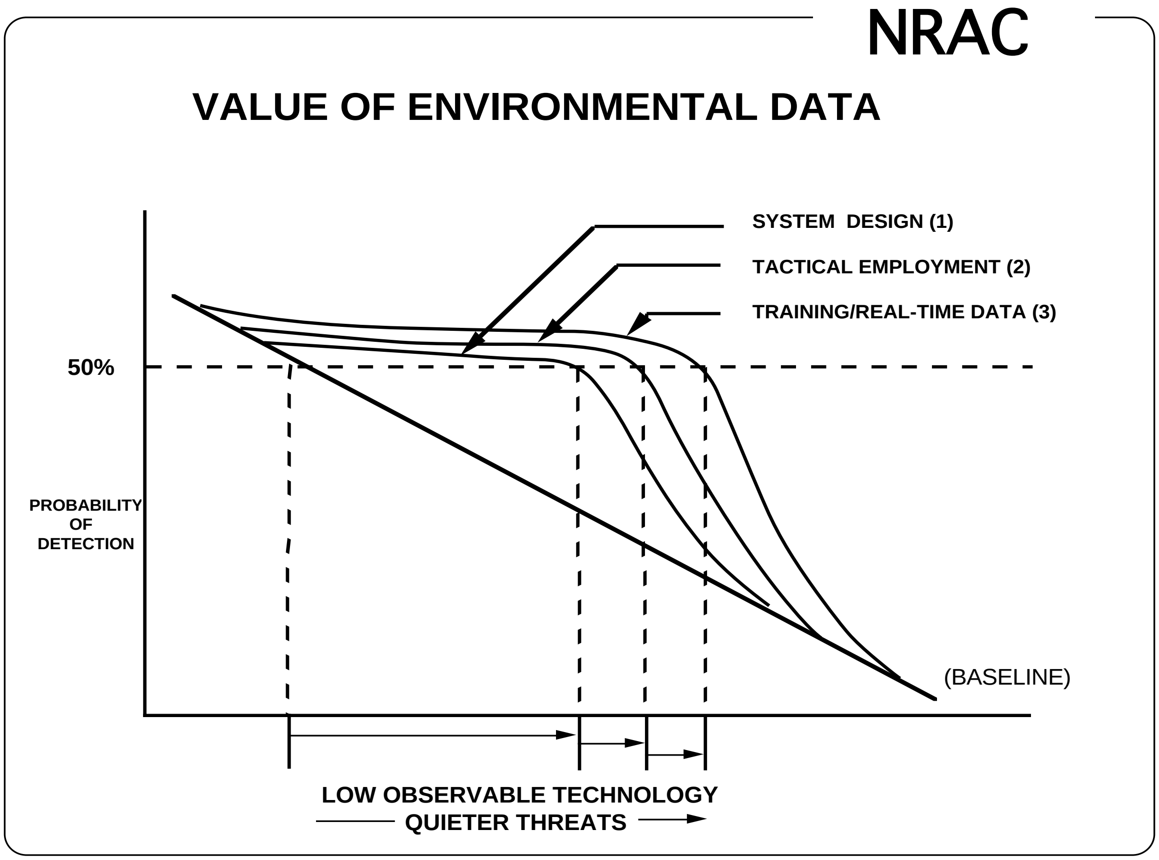
Value of Environmental Data

The impact of environmental data on improved performance of a system depends on the ratio of target signal to background fluctuations as perceived by the system.

When the target signal is extremely strong and stands out above the background, the system functions well and knowledge of the environment provides only marginal system performance improvements.

For the case where the target signal is quiet and is often obscured by the ambient background fluctuations, it is very important to exploit the environmental data to improve system performance, platform development strategy, and tactics during engagement. Proper use of environmental data can make the difference between operational failure and success.

When the target becomes extremely stealthy, and the target signal is masked by the background fluctuations, new systems and new operational concepts are required. Environmental factors will be critical in the design and development of improved new systems and tactics which maximize system performance.



Value of Environmental Data

Low observable technology is being used to produce quieter, more formidable threats. The techniques of employing environmental data to counter the quieting and successfully overcome stealthier threats are threefold.

(NOTE: In this graph, success most often occurs when the system performance curve is above 50 percent probability of detection. Failure most often occurs when the system performance falls below 50 percent probability of detection.)

The baseline curve represents present system performance capability which begins to fail as quieter threats are engaged. The first usage of environmental data is to help design improved systems which better exploit the environment. An example in this category is the array gain improvement achieved by SURTASS over arrays which suffer from nearby bottom interference. The system design improvement which gives the operator the right tool is illustrated by curve (1). Note that much quieter threats can be detected with the improved tool.

Tactics of force employment and asset positioning which take advantage of accurate environmental data to put the platforms and sensors in the proper place with the correct orientation to achieve successful engagement represent the second usage of environmental data. When combined with improved systems, this technique yields the system performance curve (2). An example in this second category is the Tow

Direction Array Performance System which has been employed to achieve significant performance improvements for SURTASS.

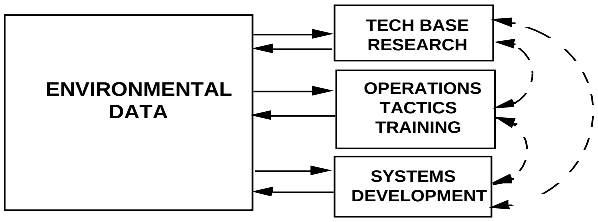
The third technique involves environmental training and real-time environmental data to operationally select the proper sensor modes and weapon presets. When an expert operator, informed of the up-to-date situation, uses improved tools at the right place and time in the most effective fashion, then curve (3) results. Examples of correct sensor mode selection have improved detection ranges from direct path (often only a few nautical miles for sonar) out to Convergence Zone (CZ) ranges (35 to 70 nautical miles). Once again quieter threats can be engaged.

As the threat employs even better stealth techniques, the cycle begins again because new system and operational concepts will be required. We must employ environmental data at the early stages of system design as well as throughout the life cycle and operation of the system. Further, we must understand that the most effective use of environmental data recognizes the involving of system parameters, threat characteristics, tactics, training, and the environment itself.

NRAC

USE OF ENVIRONMENTAL DATA FROM RESEARCH TO OPERATIONS

- DIFFERENT ACTIVITIES USE ENVIRONMENTAL DATA IN DIFFERENT WAYS
- NO ONE ACTIVITY PROVIDES COMPLETELY ADEQUATE INFORMATION TO OTHER ACTIVITIES
- CONNECTIVITY BETWEEN ACTIVITIES IS INADEQUATE
- EACH ACTIVITY NEEDS APPROPRIATE SPECIALISTS TO EFFECTIVELY INTERACT WITH OTHER ACTIVITIES
- FLEET OPERATORS NEED BETTER PRODUCTS, DELIVERY, AND TRAINING
    - ACCURATE, TIMELY TACTICAL DECISION AIDS (e.g., TESS)
    - EMBEDDED INTO WEAPON SYSTEM IF POSSIBLE



Use of Environmental Data

Environmental data are obtained in a variety of activities. For example, the tech base community develops a basic understanding of oceanographic and atmospheric phenomena. Other tech base investigators may develop the understanding of the physics of acoustic and electromagnetic wave propagation. This information is combined into predictive models for weather, oceanographic processes and wave propagation. This may be done, for example, at the Naval Environmental Prediction Research Facility. Once the models have been developed, they may be used, perhaps at the Fleet Numerical Oceanography Center (FNOC), to integrate inputs from a great number and variety of sensors to produce products suitable for delivery to the operations community.

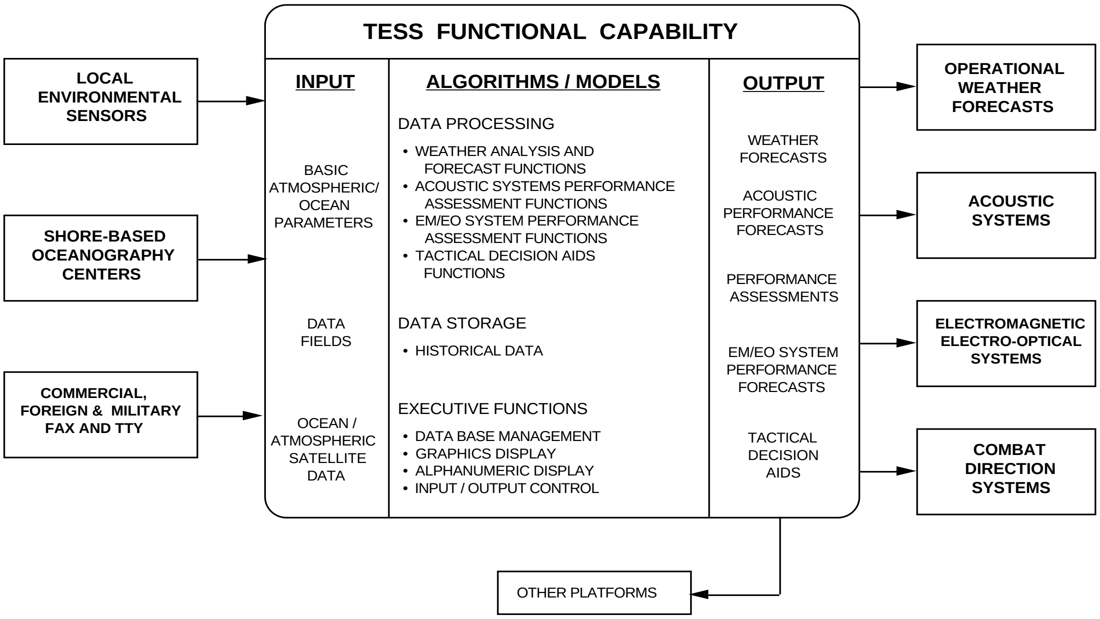
In the operations community, the environmental data may be used to assess and optimize weapon system and sensor performance, assess vulnerability, decide tactics, or simply minimize fuel consumption. The timeliness and form in which the environmental data products are provided is extremely important.

Systems development activities must consider the impact of a variable environment on system performance in the design phase and require environmental inputs during planning and execution of tests and demonstrations. System performance models, validated by tests, are a valuable tool in the design optimization process and provide focus for directed R&D.

Thus, it is clear that environmental data are required by different activities for different reasons and used in different ways. Because of this fact and the time spent on focused developments, rarely does one activity provide a product that precisely suits the needs of another activity. Therefore, each activity needs appropriate specialists and efforts that interact with the other activities to promote better connectivity and product value.

NRAC

TACTICAL ENVIRONMENTAL SUPPORT SYSTEM (TESS)



LOCAL ENVIRONMENTAL SENSORS

SHORE-BASED OCEANOGRAPHY CENTERS

COMMERCIAL, FOREIGN & MILITARY FAX AND TTY

TESS FUNCTIONAL CAPABILITY

INPUT

BASIC ATMOSPHERIC/ OCEAN PARAMETERS

DATA FIELDS

OCEAN / ATMOSPHERIC SATELLITE DATA

ALGORITHMS / MODELS

DATA PROCESSING

- WEATHER ANALYSIS AND FORECAST FUNCTIONS
- ACOUSTIC SYSTEMS PERFORMANCE ASSESSMENT FUNCTIONS
- EM/EO SYSTEM PERFORMANCE ASSESSMENT FUNCTIONS
- TACTICAL DECISION AIDS FUNCTIONS

DATA STORAGE

- HISTORICAL DATA

EXECUTIVE FUNCTIONS

- DATA BASE MANAGEMENT
- GRAPHICS DISPLAY
- ALPHANUMERIC DISPLAY
- INPUT / OUTPUT CONTROL

OUTPUT

WEATHER FORECASTS

ACOUSTIC PERFORMANCE FORECASTS

PERFORMANCE ASSESSMENTS

EM/EO SYSTEM PERFORMANCE FORECASTS

TACTICAL DECISION AIDS

OPERATIONAL WEATHER FORECASTS

ACOUSTIC SYSTEMS

ELECTROMAGNETIC ELECTRO-OPTICAL SYSTEMS

COMBAT DIRECTION SYSTEMS

OTHER PLATFORMS

Tactical Environmental Support System (TESS)

It is especially important that the information provided to the fleet operators be accurate, timely, and presented in a form they can and will use. This means the raw data must be digested to the maximum extent possible, using models to produce the specific products/forecasts actually needed. Adequate communications must be provided, and onboard graphical displays and tactical decision aids are necessary. TESS provides this link.

The Tactical Environmental Support System (TESS) is a delivery system which, in its future versions (TESS(3) and beyond), will link an operator at a sophisticated computer graphics workstation on a ship in the fleet to data from local and worldwide environmental sensors, as well as to regional oceanographic centers and global computational centers such as FNOC.

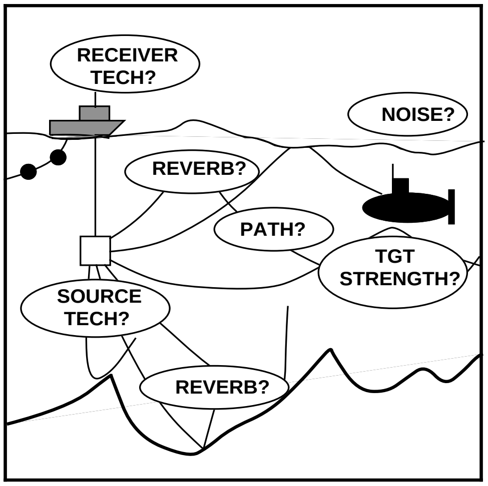
TESS incorporates models to provide an on-site local predictive capability and tactical decision aids. TESS is the final link in a system that exemplifies the direction the Navy must go in providing environmental data to the fleet, and should be strongly supported.

Ideally, the capability would be embedded in some systems. Then environmental variability would be automatically taken into account by the weapon system itself (e.g., height-finder radar which automatically corrects for atmospheric bending).

NRAC

EARLY INSERTION OF ENVIRONMENTAL EFFECTS INTO THE DEVELOPMENT PROCESS

- CRITICAL SEA TEST PROVIDES EXAMPLE
- ATD FOR LOW FREQUENCY ACTIVE ACOUSTICS



ENVIRONMENTAL ISSUES

- SURFACE AND BOTTOM REVERBERATION
- VOLUME AND BIOLOGICAL SCATTERING
- SURFACE AND BOTTOM LOSS
- FREQUENCY AND ANGLE SPREADING

SYSTEM DESIGN/PERFORMANCE MODELING

- CLUTTER ECHO
- TARGET CROSS SECTION
- ARRAY GAIN
- PROPAGATION PATH LOSS
- DOPPLER PULSE PROCESSING
- GEOGRAPHICAL ENVIRONMENTAL VARIABILITY

Early Insertion of Environmental Data

Consideration of the environment early in the system development process is essential. A good example is the Critical Sea Test (CST), an advanced technology development project for low frequency active acoustic systems.

The CST series of at-sea experiments is intended to measure environmental data and to evaluate systems issues pertaining to acoustic propagation paths and path losses, surface and bottom reverberation, and acoustic noise. Issues pertaining to receiver systems technology include pulse design, doppler processing, and array gain. Source issues include power and directionality. CST measurements will also help assess the impact of variability of the environment on the performance of low frequency active systems.

The CST program also illustrates the complexity and level of effort needed to consider environmental effects at the front end of the development cycle. CST is a needed and comprehensive experiment, but it will not provide all answers for highly environmentally sensitive systems such as low frequency active.

NRAC

REMOTE SENSING

- **MAJOR ISSUE IN THE NAVY FOR MANY YEARS**
  - ONLY WAY TO MEASURE GLOBAL, SYNOPTIC ENVIRONMENTAL FIELDS
- **EXAMPLES OF USES**
  - WEATHER
  - SOUND SPEED FIELD
  - ATMOSPHERIC REFRACTIVITY
  - SHALLOW WATER BATHYMETRY IN DENIED AREAS
- **SENSOR EXAMPLES**
  - **SATELLITE AND AIRCRAFT**
    - RADAR ALTIMETER - SEA SURFACE HEIGHT, WAVEHEIGHT,
    - DIRECTION, LENGTH
    - MICROWAVE AND IR RADIOMETERS - SEA SURFACE TEMPERATURE
    - MICROWAVE SCATTEROMETER - GLOBAL WIND FIELD
    - SYNTHETIC APERTURE RADAR (SAR) - ICE & COASTAL MAPPING
    - MICROWAVE SOUNDER - WATER VAPOR
  - **EARTH-BASED**
    - OCEAN TOMOGRAPHY - SOUND SPEED FIELD
    - SHIPBORNE LIDAR - ATMOSPHERIC REFRACTIVITY
    - OVER-THE-HORIZON RADAR - SEA STATE

Remote Sensing

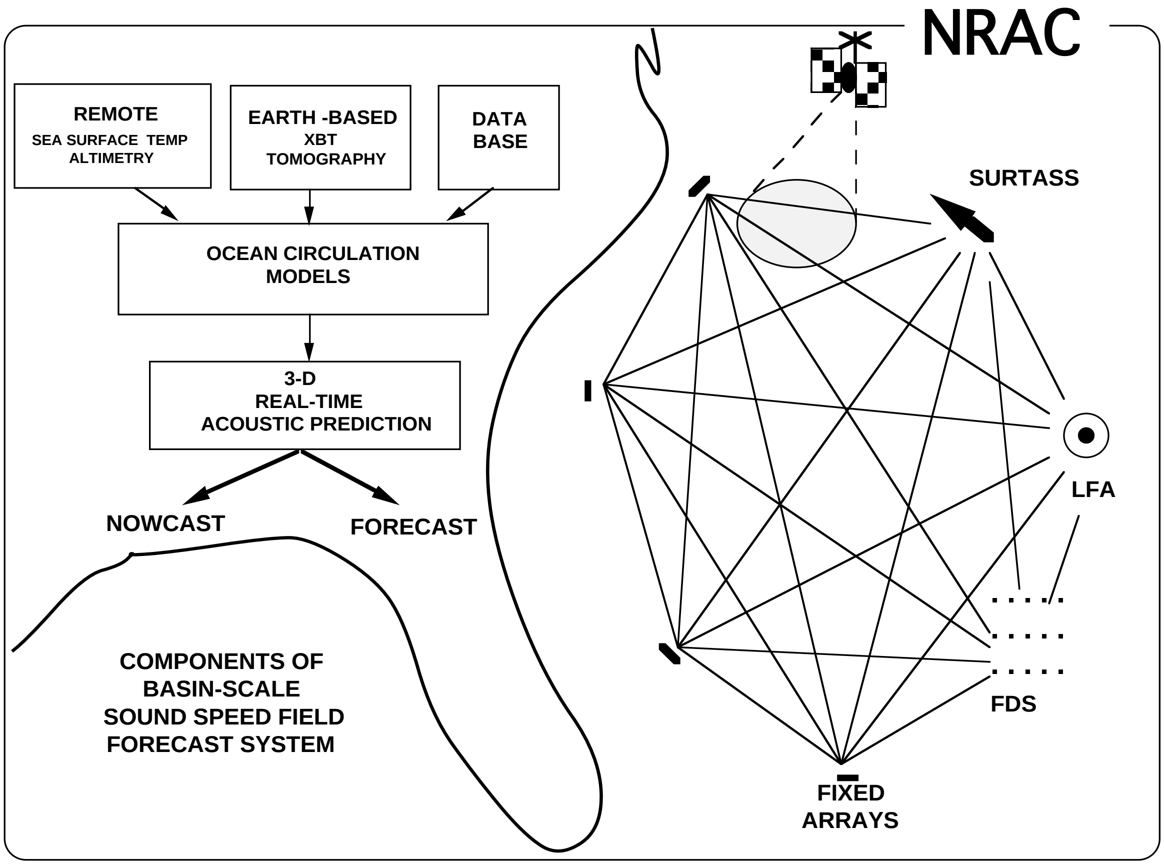
Remote sensing by satellite, aircraft, and earth-based sensors has been an important issue for the Navy for many years. It is widely recognized that global and synoptic coverage are applicable to naval operations and tactics, and that future systems can be optimized to take advantage of these data. The Navy Remote Ocean Sensing Satellite (NROSS) was proposed as a cooperative program with National Aeronautical and Space Administration (NASA) and National Oceanographic and Atmospheric Administration (NOAA) to support these needs. The failure to fund NROSS was partly a consequence of a poorly defined connection between the data collected and the specific requirements of naval systems. It was hard to justify NROSS on an operational basis, because the applications of the data that would have been collected were still being researched.

This panel took a close look at remote sensing from an integrated viewpoint, where some measurements were made by satellite, some by aircraft and some by earth-based systems. We focused on future environmental data requirements to meet the challenge of low observability. It is our opinion that remote sensing, especially from space-based systems, is essential to the Navy, but the cost may be too high to justify a dedicated Navy satellite. Therefore, we recommend that the Navy place a high priority on working cooperatively with other national and international agencies to obtain satellite environmental data needed for its systems, and that the Navy commit itself to supporting its own programs to integrate data collection into its operational needs.

The satellite is not the only remote sensor platform the Navy needs. Other examples include the shipborne laser radar (LIDAR) which can measure atmospheric parameters important to local weather prediction, including radar ducting. Airborne sensors can be used to measure shallow water bathymetry. Some applications require the integration of a wide variety of environmental data collected from diverse sensors. The oceanic sound speed field, critical to the efficient and effective employment of active and passive surveillance systems, ASW sonars and other fleet assets, requires satellite remote sensors, earth-based remote sensors, and in-situ ocean measurements.

Satellites and aircraft employ radar altimeters for measuring sea surface height, waveheight, wave direction and wavelength. Microwave and infrared radiometers have been well developed for measuring sea surface temperature. The microwave scatterometer can measure wind speed and direction. Synthetic aperture radars give high resolution views of the earth and can be used for mapping ice and denied coastal regions. Microwave sounders have been used to measure water vapor.

Ocean tomography is an example of an earth-based, wide-area oceanographic sensing technique which remotely maps the oceanic sound speed field. Over-the-horizon radar can measure sea state.



Sound Speed Forecast

To meet the threat of low observability, the Navy is developing new surveillance systems which include low frequency active systems as well as distributed passive systems. The Navy has recognized that the performance of these systems will depend upon detailed knowledge and integration of the environmental effects. The CST, for example, has been designed to measure environmental parameters that are crucial to the design and ultimate performance of low frequency active sonars. A system to map the three-dimensional oceanic sound speed field will require the integration of various environmental parameters as well as numerical models.

The objective of the environmental system is to provide nowcasts and forecasts to optimize surveillance system performance. It will require sea surface temperature and sea surface height derived from satellite radiometers and altimeters. Coupled with this will be earth-based, wide-area sensing of the sound speed field by such means as acoustic tomography, as well as a few opportunistic Expendable Bathythermograph (XBT) measurements. In addition, archived climatological data will be an important element to interpolate between remotely sensed parameters. These data drive ocean circulation models which in turn are used by three-dimensional acoustic prediction models.

It is our view that satellite and earth-based sensors will be integrated in both time and space with Navy surveillance assets. Some elements are already in place which can be used as a tomographic receiver network. Low Frequency Active

(LFA) sonar can possibly double as a tomographic source. Sea surface temperature is now routinely measured by satellite. Models are under development. Data bases, although not always adequate, do exist; however, there are elements that are not in place, as shown in the next figure.

NRAC

STATUS OF REMOTE SENSING FOR SOUND SPEED FIELD PREDICTION

PREDICTION CAPABILITIES

- OCEAN MODELS CANNOT USE ALL NECESSARY DATA
- OCEAN CIRCULATION MODELS NOT FULLY DEVELOPED
- NOWCASTS AND FORECASTS IN EARLY PHASE OF DEVELOPMENT

SENSORS

- TOMOGRAPHIC SENSING OF SOUND SPEED STRUCTURE NOT FULLY DEVELOPED
- ALTIMETERS:

SATELLITE	ALTIMETER	OWNERSHIP	LAUNCH
GEOSAT	HI - RES	US	ON ORBIT
ERS-1	LOW - RES	11 EUROPEAN + CANADA	LATE 1990
TOPEX/ POSEIDON	VERY HI-RES	US / FRANCE	1992
JERS-1	TBD	JAPAN	1993-94
EOS	VERY HI-RES	US	2000

RECOMMENDATIONS:

- MAINTAIN ROBUST REMOTE SENSING MODELING PROGRAMS
  - MAKE NAVY A SMART BUYER AND A SMART USER
- SUPPORT COOPERATIVE INTERAGENCY/INTERNATIONAL SATELLITE PROGRAMS
- EXPLOIT EXISTING SYSTEMS TO PROVIDE OCEAN SCALE SOUND SPEED FIELD

Status of Remote Sensing for Sound Speed Field Prediction

There are major pieces of an integrated environmental system for measuring the ocean sound speed field that need to be acquired. Ocean circulation models are not fully developed. Further, even in those that do exist, there is inadequate provision for incorporating remotely sensed environmental data. The coupling of the ocean circulation model to the acoustic prediction model is not complete. And finally, the ability to nowcast and forecast ocean sound fields is immature.

Present sensors also have their shortcomings. While the XBT is a well-developed technology, tomographic sensing of the sound speed field is only in the advanced research phase. The Navy does recognize the potential of the latter technology and is supporting it.

The satellite altimeter is a critical sensor for which there is no Navy plan since the demise of NROSS. There is one altimeter now flying on GEOSAT, but its mission is complete and it is now living on borrowed time. Between now and the year 2000 there are four satellites which are projected to fly with altimeters, but a high resolution altimeter will not be available until 1992. If one discounts year 2000 launches, the U.S. has an interest in only one, and it shares that interest with France.

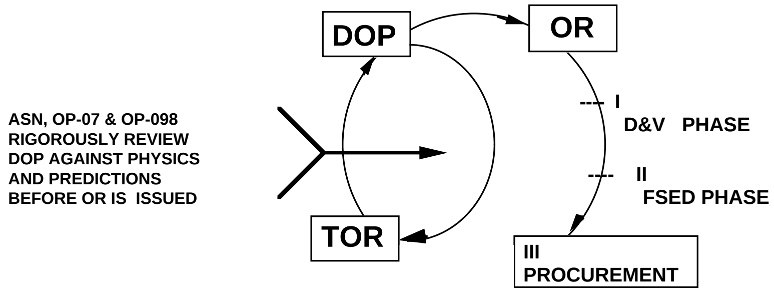
To overcome these deficiencies, the panel recommends that the Navy pay close attention to the international satellite scene and support initiatives to fly altimetric sensors. Further, it is imperative that the Navy maintain its commitment to its own internal environmental modeling and prediction efforts. It is important for the Navy to be in a position to capitalize on the availability of satellite environmental data and it can only do so if it has developed the means to integrate these data into prediction schemes applicable to its unique operational needs. In addition, the Navy should make every effort to exploit the capability of its operational systems to assist in acquiring the environmental data that these systems need.

NRAC

OBSERVATION #1 ENVIRONMENTAL FACTORS IN RDA PROCESS

- **OPNAVINST 5000.42 SAYS ALL NAVY RDA PROGRAMS** *"SHALL CONSIDER"* **ENVIRONMENTAL FACTORS THROUGHOUT THE DEVELOPMENT AND ACQUISITION PROCESS.**

THE RDA PROCESS



ASN, OP-07 & OP-098
RIGOROUSLY REVIEW
DOP AGAINST PHYSICS
AND PREDICTIONS
BEFORE OR IS ISSUED

DOP
OR
TOR
I D&V PHASE
II FSED PHASE
III PROCUREMENT

THE MOST CRITICAL STAGE OF SYSTEM DEVELOPMENT AT WHICH ENVIRONMENTAL FACTORS AS THEY WILL AFFECT SYSTEM PERFORMANCE MUST BE CONSIDERED IS BEFORE MILESTONE I. THE VIEW OF THE PANEL IS THAT THE EXECUTION OF THIS INSTRUCTION IS INADEQUATE.

- **RECOMMENDATION:**

  OPNAV (OP-07 AND OP-098) AND SECNAV (ASN(RE&S)) SHOULD VIGOROUSLY REVIEW EVERY DOP AGAINST THE PROBABLE ENVIRONMENTAL BACKGROUND BEFORE AN OR IS APPROVED (i.e., "WILL THE PHYSICS AND OUR KNOWLEDGE OF THE ENVIRONMENT PERMIT THE PROPOSED SYSTEM TO OPERATE AS ADVERTISED?")

Observation #1

It is the panel's position that each new naval and marine system concept, as well as current systems, should be evaluated to determine the effects environmental conditions have on system performance, and what environmental measurements need to be obtained to support the system. If the needed measurements are not available, then a method and plan to obtain such measurements should be included in the development plan for the weapon system.

The panel noted that OPNAVINST 5000.42 was written to accomplish the above; however, we were not able to determine how that instruction is implemented or what organization has the responsibility to ensure compliance. It is the panel's view that a formalized check should be added to the RDA process to ensure that environmental considerations are included in each DOP, and that OP-098 should be the responsible organization with coordination performed by OP-07 and ASN(RE&S).

NRAC

OBSERVATION #2 PLANNING DOCUMENTATION

- **NO CENTRAL ENVIRONMENTAL / OCEANOGRAPHIC TOP LEVEL REQUIREMENT OR MASTER PLAN**
    - STRATEGY, WAR PLANS
    - TACTICS, DOCTRINE, CONCEPTS OF OPERATIONS
    - EMBEDDED TACTICAL DECISION AIDS
    - OFFLINE TACTICAL DECISION AIDS
    - OTHER USER PRODUCTS
    - MODELS
    - DATA BASE MANAGEMENT / COLLECTION
    - INTERNATIONAL, INTERAGENCY, MILITARY AND
    - SECTOR COOPERATIVE EFFORTS

- **RECOMMENDATION:**

  OCEANOGRAPHER OF THE NAVY SHOULD DEVELOP AND PUBLISH A "MASTER PLAN FOR OCEANOGRAPHY" BLUEPRINT FOR ENVIRONMENTAL SUPPORT TO FUTURE NAVAL PLANNERS, BATTLE FORCE COMMANDERS, AND SYSTEM DEVELOPERS.

Observation #2

The panel noted the absence of accepted documentation which would provide structure, direction, purpose and understanding to the environmental community and to users of environmental data. We recommend that the Oceanographer of the Navy develop and publish an Environmental Oceanographic Master Plan which will delineate present environmental support efforts and will serve as a blueprint for future efforts and outputs.

The Master Plan should address:

1. A detailed listing of environmental factors and possible effects on system design, deployment, performance, training, tactics and strategy;

2. Data collection, forecasting, and transmittal systems for each environmental factor listed above, including accuracy, resolution and timeliness of the data;

3. A list of environmental and effect models which are available to the user community for system development, training, and tactics;

4. Future plans to improve on the accuracy, utility, timeliness and scope of 1 through 3 above, including system description and requirements;

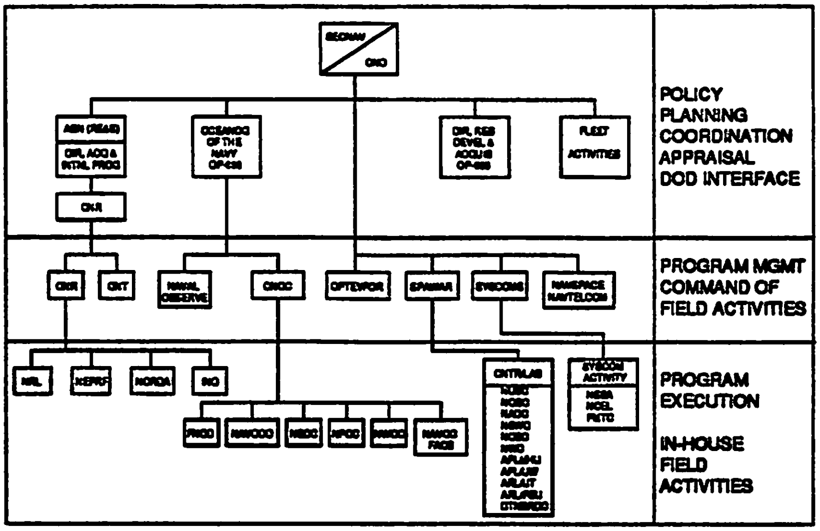
5. The organizational support and lines of communication for 1 through 4 above, including other agency cooperation, both national and international.

NRAC

OBSERVATION #3 ORGANIZATION

- **WHERE IS THE FOCUS OF OCEANOGRAPHIC AND ENVIRONMENTAL MATTERS IN THE NAVY?**

NAVY ACTIVITIES INVOLVED IN ENVIRONMENTAL OR OCEANOGRAPHIC MATTERS



- **RECOMMENDATION:**
  THE INTERRELATIONSHIPS OF ALL THESE ORGANIZATIONS SHOULD BE IDENTIFIED IN AN OCEANOGRAPHIC MASTER PLAN.

OBSERVATION #3

The panel observed that more than 20 Navy organizations are involved in various aspects of environmental science and effects. Their activities are directed by four different commands with no apparent formalized communication network focus among the many organizations. Such a diverse organizational structure has led to duplication of effort, and misuse of the products by the many organizations.

The panel recommends that, as part of the Environmental Master Plan (Observation #2), the Navy develop an organizational approach which defines the interrelationships of the listed organizations.

NRAC

OBSERVATION #4 1984 NRAC PANEL ON ENVIRONMENTAL SUPPORT TO NAVAL AND MARINE FORCES

- **THE PANEL REVIEWED THE 1984 NRAC PANEL'S REPORT ON THE ENVIRONMENT AND WAS IMPRESSED WITH THE DEPTH AND COMPLETENESS OF THAT REPORT.**

- **RECOMMENDATION:**

  THE OCEANOGRAPHER OF THE NAVY AND CNR SHOULD REVIEW THE 1984 REPORT AND REPORT TO THE CNO AND ASN (RE&S) THE STATUS OF IMPLEMENTING RECOMMENDATIONS CONTAINED THEREIN.

Observation #4

As part of its investigation, the panel reviewed the report of the 1984 NRAC panel on "Environmental Support to Naval and Marine Forces," and was impressed with the depth and completeness of that effort. Most of that report and its conclusions are still valid and current today. The panel found the recommendations of the 1984 report pertinent to this investigation.

The 1984 report recommended, for example, that robust, secure and high priority communication circuits be established for environmental support information. It recommended that an SSN be assigned the exclusive mission of gathering arctic environmental data. It placed a high priority on satellite observations using NROSS. It suggested that an OPNAV review of environmental support requirements and limitations be incorporated into major system acquisitions. It made specific suggestions concerning the acquisition of supercomputer facilities for FNOC and Naval Ocean Research and Development Activity (NORDA). The NROSS program has been cancelled, and an SSN has not been assigned to arctic data gathering. Satellite remote sensing should still be a high priority Navy activity (see below), and data to support arctic operations are still needed.

Therefore, the panel recommends that the Navy revisit the 1984 report. In particular, the CNR and the Oceanographer of the Navy should review the status of the 1984 panel recommendations and report the results to the CNO and the Secretary of the Navy.

SUMMARY

- **Top Level Review**

- **Identified System Level Issues**

- **Embed the Environment into the Acquisition**

Process

- **Remote Sensing is Important and Requires Top Level Attention**

GLOSSARY

ATD	Advanced Technology Demonstration
ASN(RE&S)	Assistant Secretary of the Navy for Research, Engineering, and Systems
ASW	Anti-Submarine Warfare
CNOC	Commander, Naval Oceanography Command
CST	Critical Sea Test
CZ	Convergence Zone
D&V	Demonstration and Validation
DOP	Development Options Paper
DTNSRDC	David Taylor Naval Ship Research and Development Center
EM	Electromagnetic
EO	Electro-Optical
EW	Early Warning
FAX	Facsimile
FNOC	Fleet Numerical Oceanography Center
FSD	Fixed Distributed System
FSED	Full Scale Engineering Development
ICAPS	Integrated Command ASW Prediction System
INO	Institute of Naval Oceanography
IR	Infrared
IREPS	Integrated Refractive Effects Prediction System
LCAC	Landing Craft Air Cushion
LIDAR	Laser Radar
LFA	Low Frequency Active
NADC	Naval Air Development Center
NATO	North Atlantic Treaty Organization
NAVOCO	Naval Oceanographic Office
NAVTELCOM	Naval Telecommunications Command
NASA	National Aeronautical and Space Administration
NCSC	Naval Coastal Systems Center
NEOC	Naval Eastern Oceanography Center
NEPRF	Naval Environmental Prediction Research Facility
nmi	Nautical Mile
NOAA	National Oceanographic and Atmospheric Administration
NORDA	Naval Ocean Research and Development Activity
NOSC	Naval Ocean Systems Center
NPOC	Naval Polar Oceanography Center
NRAC	Naval Research Advisory Committee
NROSS	Navy Remote Ocean Sensing Satellite
NSWC	Naval Surface Weapons Center
NUSC	Naval Underwater Systems Center
NWC	Naval Weapons Center
NWOC	Naval Western Oceanography Center
OPTEVFOR	Operational Test and Evaluation Force
OR	Operational Requirement
OTHR	Over-The-Horizon Radar
PPI	Plan Position Indicator
R&D	Research and Development
RCS	Radar Cross-Section
RDA	Research, Development, and Acquisition
RF	Radio Frequency

SURTASS	Surveillance Towed Array Sonar System
SV	Sound Velocity
TESS	Tactical Environmental Support System
TDA	Tactical Decision Aid
TOR	Tentative Operational Requirement
TTY	Teletype
VSBY	Visibility
XBT	Expendable Bathythermograph