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OCEANOGRAPHIC REMOTE SENSING: A POSITION PAPER,(U)
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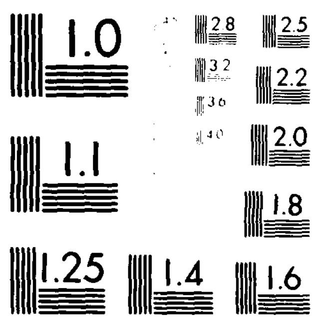

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NAVAL OCEAN RESEARCH AND DEVELOPMENT ACTIVITY

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OCEANOGRAPHIC REMOTE SENSING; A POSITION PAPER,

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Oceanographic Remote Sensing; A Position Paper

INTRODUCTION

Purpose

The purpose of a Navy R&D remote sensing plan should be to set forth the requirements and direction of basic and exploratory research in satellite remote sensing which supports the overall Navy oceanographic research and operational programs. The aim of the plan would be to outline the established requirements, objectives, current and planned research programs necessary to achieve the ultimate goals of improved environmental support to the fleet. While the plan will be primarily directed toward 6.1 and 6.2 programs, appropriate consideration for coordination of 6.3-6.6 requirements should be addressed. The plan should help serve as a single technology and program reference for implementation and planning of Navy related satellite remote sensing programs. Fundamentally, the plan would:

Set forth the manner and rate with which the Navy research program should proceed in order to successfully exploit environmental satellite systems supporting Navy and DOD oceanographic requirements,

Provide guidance to the Assistant Secretary of the Navy for Research, Engineering and Systems (ASNRE&S) and the Chief of Naval Research in overall program planning,

Provide research programs which will support the objective of the Naval Oceanographic and Meteorological Support System (NOMSS) Environmental Satellite Plan for predictions for Naval operations.

The immediate benefits of this plan would be to provide prioritized program direction within the fiscal limitations. It will provide a single source document which will assist program management in implementing remote sensing research projects. Finally it will provide a framework wherein overall remote sensing coordination can be established.

More importantly a well defined remote sensing research program will contribute to the operational fleet needs by:

- Providing input to oceanographic predictions.
- Providing data for acoustic predictions for ASW and ocean surveillance.
- Provide global data for marine atmosphere predictions.

- Provide polar ice data for ASW and mine warfare objectives.

- Lead to improved ocean circulation and sedimentation prediction capabilities for amphibious and mine warfare applications.

The research plan could focus on a specific framework as depicted in figure 1.

Navy forces operating in, on and above the oceans of the world are clearly dependent upon environmental support. Satellite remote sensing requirements necessary to provide that support have been established in the Operational Requirement OR-W0527-OS, "Satellite Measurement of Oceanographic Parameters (SMOP)," 10 Aug 1976; and the Joint Chiefs of Staff memo MSCS 251-76 of 31 Aug 1976, "Revalidation of Military Requirements for Meteorological Satellite Data." The remote sensing research program ultimately must be responsive to those validated operational requirements as well as the research community needs.

Scope

The scope of this paper addresses the following to the extent time permitted:

- Background of remote sensing.
- Current program direction.
- Status of capabilities.
- Program deficiencies.
- Program direction changes.
- Overall program reviews.
- Recommendations.

Figure 1: SATELLITE REMOTE SENSING R&D PROGRAM FOCUS

	1	2	3	4	
KEY THRUST AREAS	Operational: DMSP*, NOSS*, GOES, TIROS-N R&D: NIMBUS, LANDSAT	 Satellite Processing Center	Environmental Prediction Center	Ocean FCST Centers	Fleet Users
KEY R&D AREAS	• Sensor Development • Technology Exchange	• Surface Truth • Physical insights • Algorithms • Data Analysis	• Data ingest • Model development	• Products • Display • Distribution	
KEY LABORATORY INVOLVEMENT	NRL	NORDA NEPRF ONR NUSC NRL	NORDA NEPRF ONR NRL	NORDA NEPRF ONR FNWC	

BACKGROUND

Evolution

The beginnings of remote sensing of the environment from space can be traced back to 1 April 1960 when TIROS-I (Television and Infrared Observational Satellite) was first placed into orbit. The success of this spacecraft subsequently led to two generations of meteorological satellites (the TIROS and ESSA series) which employed vidicon detection systems. These instruments, although they could not be calibrated, produced images that revealed the incredibly detailed and organized structure of the earth's cloud cover, and assured the continuance of the meteorological satellite program.

A significant advance in the technology occurred with the launches of the third generation of polar orbiting satellites -- the ITOS/NOAA and the Defense Meteorological Satellite Program (DMSP) Block-5 series -- in which the vidicon sensors of previous spacecraft were replaced with scanning, high resolution radiometers. The most important advantage of these latter instruments was that they could be calibrated; using the instrument response curves determined prior to launch and the onboard calibration data provided in the down-link, the data could be handled digitally for conversion to absolute measures of the energy received at the sensor in each observing channel. Thus, satellite remote sensing entered the quantitative era where consideration could be given to deriving precise measurements of discrete elements of the phenomena being observed.

The threshold of the fourth generation of operational environmental satellites was recently crossed with the launch of the DMSP Block-5D and the launch of TIROS-N.

In these newest systems, changes from the previous generation of spacecraft are evolutionary rather than revolutionary. The DMSP Block-5D spacecraft incorporates a new visible and infrared imager that compensates for changes in resolution along the scan lines. The 15 micrometer vertical sounding instrument carried by the previous Block-5C satellites has been augmented with channels in moisture absorption bands to allow atmospheric moisture profile extraction. Additional improvements have been programmed for the Block 5D-2 vehicles; the digitalization of the IR channel will be increased from 6 to 8 bits and the spectral window will be narrowed to 10.2-12.4 micrometers, thereby greatly improving the instruments' sensitivity to sea surface temperatures. A most significant change is provision for full onboard digitalization of the data and the inclusion of onboard processing capability. This capability effectively precludes contamination by radio frequency noise of the data during transmission from the spacecraft via analog communications channels.

Corresponding upgrades have been incorporated in the TIROS-N vehicles. The Advanced Very High Resolution Radiometer (AVHRR) is a 4-5 channel instrument whose channels have been selected specifically for high resolution quantitative mapping of sea surface temperature. The TIROS-N Operational Vertical Sounder (TOVS) should be a significant improvement over previous sounding instruments. Channels in both the 0.43 and 15.0 micrometer carbon dioxide absorption bands are included in the TOVS, thereby offering the potential of improved vertical and absolute resolution in the retrieved atmospheric temperature and moisture profiles.

The spacecraft and instruments so far discussed were designed primarily for atmospheric sensing; with few exceptions, most of the data from these spacecraft have been processed for meteorological purposes. However, several instruments primarily designed for oceanographic sensing have been flown on recent research satellites. The passive electronically scanning microwave radiometers flown on both NIMBUS-5 and -6 were sensitive to ocean roughness. The multispectral scanner carried onboard the LANDSAT series, while effectively utilized for land resource studies, has distinct capabilities in oceanographic surveillance. SEASAT-A,[1] launched in June of 1978, was a "proof-of-concept" designed specifically for oceanographic remote sensing. The Synthetic Aperature Radar (SAR), the SEASAT-A Scattermeter Sensor (SASS), and the Radar Altimeter (ALT) are a new class of active sensors which offer the potential of providing direct measurements of specific physical oceanographic parameters.

Remarkable advances have taken place in the past twenty years in environmental spacecraft and remote sensing instrumentation, and accelerated advances can be anticipated in the near future with the commencing of space shuttle operation. Paralleling these advances, the ground processing of remotely sensed data has also undergone a remarkable evolution. For a short time following the launch of TIROS-1, the handling of the data from this spacecraft was entirely manual. Pictures were earth-located and -gridded using perspective grids and visual attempts to identify landmarks within the images. From these crude and very labor-intensive beginnings, the technology, aided by advances in computer capacity, has rapidly progressed to a fully automated quantitative science. However, because of the vast amounts of data produced by environmental satellites, consideration of full digital processing has previously been relegated to only the largest of centralized computer facilities. Even with some of the largest computers currently in existence, it has previously not been possible to process all the data produced by even one satellite system (such as the DMSP) on a global scale and in quasi-real time. The advent of minicomputers, microprocessors and special function processors now offers a mechanism for the fuller exploration of the current and expanding remote sensing capabilities on both the research and operational levels.

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[1] The SEASAT-A failed after $\sim$95 days of data collection; data processing and analysis is underway.

All aspects of remote sensing technology have now matured to the point where a reorientation and augmentation of existing resources offers the potential of solving long term problems of the oceanic environment. Whereas the technological potential now exists, the cost of alternative directions greatly exceed the heretofore available resources. Clearly, a central Navy thrust must be defined.

Present Research

The availability of various satellites and sensor systems has provided the research community and the operational Navy, a unique opportunity to make a major advance in providing the fleet with synoptic, dynamic measurements. These instruments, and techniques for their use, are not, however, without their attendant problems. In this regard, increasingly larger portions of the basic (6.1) research programs are being applied to the solution of satellite remote sensing problems as they relate to oceanographic applications.

ONR research is concerned with understanding the environment (which produce and affect the energy fields recorded by the various remote sensors) from the physical, chemical, and biological aspects of the oceans, as well as Arctic research.

NRL research addresses the development and use of remote sensor systems, ocean sciences, and acoustics.

NORDA efforts are directed toward; 1) the evaluation of satellite sensors in providing quantitative input for predicting ocean thermal structure via modeling and; 2) qualitative evaluation of imagery patterns for oceanographic research.

NEPRF develops information extraction algorithms and inversion techniques in the marine atmosphere.

NAVAIR anticipates the development and test of remote sensors for oceanographic and atmospheric applications.

NCSC provides a facility for the test and evaluation of remote sensor systems for coastal - ocean applications.

Considerable research is now in progress within the triservice community addressing many of the problems inherent in relating airborne remote sensing to conventional in situ measurements, and then transitioning to those made from satellites.

Research within the naval community is directed toward determining the capabilities and limitations of the various sensors in measuring significant ocean and atmospheric parameters such as surface winds, sea suface directional spectra, ocean thermohaline structure, coastal processes, Arctic ice conditions, and other related research.

Present efforts at the Office of Naval Research and Naval Research Laboratory (ONR & NRL), the Naval Ocean Research & Development Agency (NORDA), the Naval Environmental Prediction Research Facility, (NEPRF), NAVAIR, MARCOR, etc. have progressed to the point where some crude, but workable, environmental prediction models for Naval operations can be successfully driven by satellite remotely sensed measurements.

Enough is known from the research community and the applications of satellite remote sensing to oceanographic measurements to isolate the most significant environmental, software, and hardware impediments to meaningful, synoptic, global real-time remote sensing data as they apply to Navy-Marine Corps planning and operational missions.

The major areas of present concern can be resolved into the following categories:

A. Atmospheric attenuation

B. Instrument resolutions

C. Soft and hardware relating to high data rates and data processing

D. Specific instrument development

E. Lack of complete algorithms which relate sensor outputs and environmental parameters.

F. Data Processing (Relate to C)

An outline for a research program plan addressing the major problem areas is set forth in the next section. It is these problem areas that must be overcome to provide the Navy/Marine Corps with an operational oceanographic satellite remote sensing program.

Deficiencies noted in present fleet application of satellite remote sensing to oceanography are:

1. We are presently unable to correctly infer the vertical thermohaline structure of the ocean from satellite measurements.

2. We do not obtain a complete understanding of the method(s) of generation of, the rate of movement of, nor the longevity of various observable sea surface phenomena, e.g., eddies, thermal fronts, maneuvering current boundaries, etc.

3. We are presently unable to correct for or extract absolute SST from satellite IR and microwave data without some surface control. In certain areas of the world's oceans, we cannot resolve SST differences of as much as $3^{o}C$ because of atmospheric effects.

4. We are unable to measure the horizontal and vertical distribution of TPW (total precipitable water) in the atmospheric column in order to provide proper corrections to IR measurements.

5. We are also unable to measure the atmospheric temperature profile (stability) with sufficient accuracy to allow derivation of surface winds from radar backscatter measurements.

6. No formal method is known for integrating or insuring that results of research projects are fed back into Navy operations (the fleet) via manuals or other technology transfer methods.

7. There is no satisfactory method by which Navy researchers can acquire certain satellite data such as DMSP and some NASA satellite systems.

8. Satellite sensor systems thru the 1988 time frame are inadequate to meet the full naval environmental operational data requirements, e.g., wave directional spectra.

9. Deficiencies exist in the development of algorithms to adequately extract information, derive geometric units, or to control sensor operations.

10. There is a lack of any means of coordinating oceanographic aircraft flights and ocean survey vessels with field research projects.

11. No adequate planning is underway to develop a national program for balanced utilization of buoys, ships, aircraft, and satellites. One is needed that considers and capitalizes on the capabilities of each platform in relation to the specific oceanographic problem and the costs involved.

Outline of Remote Sensing Program Plan

Deep Ocean Remote Sensing

The main Navy requirements and program objectives in this area are:

1) Develop and demonstrate the capability of utilizing satellite sensing to provide numerical input for prediction models of ocean thermohaline structure to depths of acoustic detection significance and;

2) Improve the state-of-the-art in interpreting satellite imagery for ocean features of acoustic detection significance.

The first objective addresses the Naval requirements for quantitative input to a central forecasting facility for global service, i.e., Fleet Numerical Weather Central-Monterey. The second objective is oriented to tactical situations where satellite data is received directly and utilized in near real-time by Weather Centrals and LPH and CVV ships.

a) Numerical Analysis

Table 1 lists those parameters in the priority which is required for input to oceanic thermohaline prediction models. A series of field experiments which encompass simultaneous in-situ surface, sub-surface, aircraft and satellite measurements will be conducted to evaluate and verify the applicability of satellites for providing the data input to these models. Paralleling these investigations, a strong effort to develop and perfect thermohaline prediction models must be accomplished to insure that the remote sensing program is focused, and, of course, that operating models are delivered to FNWC. Oceanographic experiments of this type, which may fully investigate two or three parameters at a time, cost roughly $250K and require one to three years duration. Several of these experiments will be running simultaneously at an estimated expense of $1,000 K/yr. Specialized in-situ data collection hardware and processing software which are required for valid experiments will need to be developed. For certain of these parameters satellite sensors which may meet the stated requirements during cloud free conditions are available. For others, e.g., absolute wind stress vectors, extensive work in both sensor development and field verification will be required. The requirement for an all weather capability (through cloud cover) dictates that sensors which collect data in the microwave portion of the spectrum be developed. This area of the spectrum has historically received the least exposure to oceanographers because of the lack of such sensors aboard satellites. SEASAT-A was to have filled this data gap however it was short-lived ($\sim$95 days) and many field experiments for evaluating microwave data from its sensors were not conducted. A renewed effort investigating active and passive microwave sensors aboard high-altitude aircraft should be immediately undertaken. Should the National Oceanic Satellite System (NOSS) become available in 1983 as it is currently envisioned, microwave and other data will be available for evaluation and operational demonstration. Full Navy support for this national program is recommended.

b) Imagery Interpretation

One must recognize that 5 to 10 years will be required to begin to utilize environmental satellites for numerical analysis and predictions as outlined above. (A major thrust would shorten this duration). In the interim, satellite imagery in the thermal IR, and visible portions of the spectrum are available to operating Naval units. Although these data are provided primarily for meteorological applications, they also are being used, in a rudimentary fashion, for oceanographic interpretations. We believe it is correct to capitalize on, and support the further use and development of this budding imagery interpretation capability for oceanic objectives. Further, scheduled advances in shipboard and field installation instrumentation will allow for some degree of quantification and enhancement of the thermal and visible data. To support this effort, training in the form of classroom sessions and manuals should be developed and provided. The training syllabus will be composed of the results of the research projects being conducted. The oceanographic research papers and reports resulting from R&D efforts should be also formatted as case histories for training manuals. A continuing effort in this area at a scope of $250K per year should be implemented.

The primary Navy groups engaged in utilizing satellites for deep ocean R&D are NRL Codes 7006, 7100, 7900, 8100, 8300 and 5300; ONR Code 480, NORDA Codes 330 and 320, NEPRF Satellite Data Processing, and Display and Tactical Applications Departments, NUSC Code 311.

Marine Atmospheric Corrections

Remote sensing of the oceans from space cannot be conducted independent of the intervening atmosphere. The greatest impediments to surveillance of the ocean surface from space are the contaminating effects of clouds and atmospheric water vapor. In the visible and infrared portions of the electromagnetic spectrum, the effects can range from total obscuration by clouds to partial obscuration by the presence of water vapor (where the degree of obscuration is a function of the net amount of water vapor contained along the slant range path of the sensor). Even at microwave frequencies, clouds and water vapor have a contaminating effect and the observations must be corrected for, at least, cloud liquid water content. Aerosols and atmospheric trace gases cause contamination but these effects are secondary to the effects of clouds and water vapor.

The presence of clouds in the sunlit portion of the earth can be readily detected through the use of high resolution detectors in the visible portion of the spectrum. Even at night the locations of contaminating clouds can be determined by examining the spatial variability of measurements made in a thermal IR channel.

The water vapor problem requires additional research before it can be resolved. Several avenues of approach are suggested. The first is to define the scale (both spatially and temporally) of atmospheric water vapor. This will entail deplcyment of sensitive instruments on aircraft. Second, is to evaluate the extent to which existing and planned indirect optical sounders are capable of measuring the atmospheric moisture structure. The third, is to develop new sensors (channels) to better measure this parameter. Consideration should be given to additional channels for passive detection as well as active LIDAR and microwave systems.

The water vapor problem is critical in the broad spectrum of oceanographic remote sensing endeavors. Research in this area has been neglected and deficiencies in knowledge are restricting programs in ancillary areas, e.g., E-O weapons, meteorological analysis, airborne surveillance. The highest priority in this subject area should be assigned to resolving this problem.

The cognizant organizations with capability in this area are NRL, NEPRF and ONR.

Coastal Remote Sensing

Research in coastal oceanographic processes will continue to address the physics of shelf water circulation and the distribution of energy at the shoreline. Understanding the physical principles of water and sediment circulation and the generated surface manifestations is requisite to isolating the significant parameters or combinations of parameters that must be measured by the remote sensors in order to delineate and monitor the movements and rates of change of these surface configurations.

Research needs for remote sensing of shelf dynamics evident through the evolution of satellite remote sensing research are:

1. A significant increase in the spatial resolution of the satellite remote sensors is necessary. It would be particularly beneficial to have sensors with a zoom capability.

2. An all weather, day/nite capability is also of extreme importance to coastal environmental research. This requirement necessitates use of radio frequency sensors, which, paradoxically, have the poorest spatial resolution.

3. The availability of suitably equipped remote sensing aircraft for field research experiments is a critical need within the Navy.

4. A dedicated coastal environmental test site area would greatly enhance cost-effective research and the correlation and calibration of satellite data with in situ ocean data.

5. Remote sensor(s) should be developed that relate specifically to the unique conditions of the shallow water or shelf conditions. Present systems do not have the proper bandwidths or center wavelength for instance, nor do they have the proper number of channels in the required narrow bandwidths.

6. Greater flexibility in the programming of ocean research vessels is required for support of coastal field research projects.

7. Access to presently available processed satellite remote sensor data must be increased.

Arctic Remote Sensing

The objective of the remote sensing sub-program pursued by the Arctic Programs Office of ONR is to develop methods of deriving quantitative ice parameters from aircraft and satellite borne remote sensors as well as remote data buoys, and to demonstrate their use in determining, understanding, and predicting the characteristics of sea ice. The program includes research efforts to obtain and analyze both data from remote sensors and from in situ measurements of sea ice parameters, and to establish quantitative relationships between the two. The program is expected to provide new insights to the nature and significance of sea ice dynamics and processes; methods to determine the state of constancy or change of the ice masses; and will contribute to aspects of climate research by providing inputs to climate models. The long range goal of this program is to determine and characterize remote sensing methods and sensor combinations capable of measuring ice properties at the necessary temporal and spatial frequencies to meet both research and operational needs in the Arctic.

Present deficiencies in remote sensing of sea ice are:

Lack of capability to:

a. measure sea ice thickness directly.

b. accurately measure ice roughness, ridge heights.

c. discriminate between ages of sea ice (first year, second year, multi-year) over wide areas at fine resolutions and over varying conditions of freeze up, melt, etc.

d. accurately measure the amount of drift, degree of convergence or divergence within the pack ice.

e. accurately measure the amount of snow cover over sea ice.

f. accurately measure the size and location of leads and polynyas in sea ice.

g. obtain measurements of sea ice using remote sensors under day/nite, all-weather conditions.

Broadly stated, the research needs of the arctic program are to:

a. develop methods, including algorithms, to quantitatively relate remote sensor measurements to sea ice characteristics and processes.

b. determine the optimum frequency, polarization and resolution for making all-weather microwave measurements of sea ice.

c. determine the optimum mix of remote sensors to provide that information on sea ice characteristics and dynamics necessary for research and operational purposes.

d. develop methods of processing, enhancing, interpreting, and interrelating the measurements of sea ice from the various remote sensing systems employed.

Sensor Development

The sensor is sine qua non for satellite remote sensing applications. All applications require measurement of geophysical (oceanographic, atmospheric, terrestrial) parameters with specified precision, accuracy, frequency, resolution and timelines of observation. As discussed above, specific applications (coastal, arctic, deep-ocean, etc...) impose varying stringencies of measurement to meet specific application needs.

There is a broad range of scientific and engineering maturity for sensors applicable to oceanic problems. It is essential that the capabilities of existing sensors be well documented, and appropriate development efforts be initiated where measurement deficiencies exist. Sensor documentation must include statements of measurement precision, accuracy and resolution. Algorithms for reduction of sensor output signals to characterization of geophysical parameters must be provided. Data reduction algorithms must include engineering calibration factors, and appropriate correction terms from utilization of other data (complementary sensors, external data fields). Initial proof-of-concept validation experiments will be conducted as carefully-designed "surface truth" field tests. Full validation of geophysical algorithms will be conducted as part of the disciplinary field experiments which have been cited above.

Figure 2: Major Earth-Observation Satellite Programs

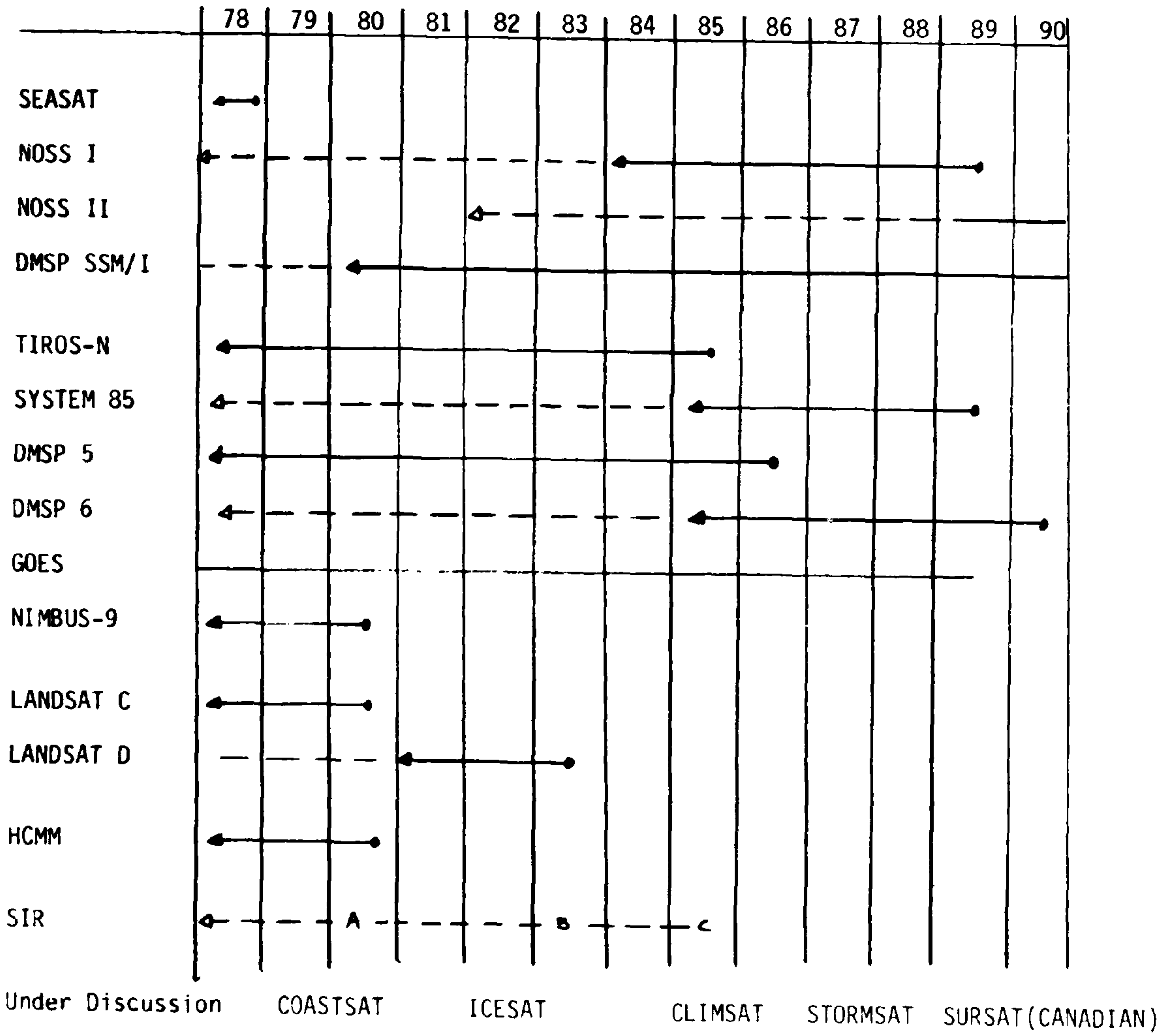

Figure 2 shows the major national earth-observation satellite programs in operation or being planned thru 1990. The Navy must evaluate each of these programs with respect to satisfaction of stated requirements, identify deficiencies, and, where necessary, institute R&D projects to satisfy those requirements.

Limitations in national resources have driven current space policy toward combined civil and DOD programs. In order to properly utilize data from these programs, the Navy must participate as a full partner in sensor selection, algorithm development and technical monitoring of all emerging programs from which data are to be derived.

Where deficiencies exist, the Navy must take the lead in cooperative (civil and DOD) sensor development programs. Basic research (6.1) programs will be conducted in parallel by DOD and NASA to establish fundamental principles for design of new sensors. Scientific exchange at the 6.1 level will take place thru the normal peer review process. Exploratory development (6.2) programs will be generally characterized as aircraft experiments using "bread-board" concepts of sensors. Scientific and technical exchange at the 6.2 level should be accomplished through structured inter-agency reviews.

Advanced sensor development (6.3) in the SHUTTLE era will take place at the component level whereby prototype sensors are fabricated as part of joint-agency programs and are evaluated as space experiments. On a case-by-case basis, interagency memoranda of agreement will be drawn up which define the "lead" agency for each experiment, and which define the roles of each cooperating agency.

Complementary 6.1 research programs will be carried out by the civilian agencies and are necessary for exploration of alternatives to sensor design concepts. Similarly, parallel 6.2 programs will provide extended data to sustain trade-off analyses, develop data reduction algorithms, and validate sensor performance over a wide range of environmental conditions. Because of high costs, and the technical maturity at the 6.3 level, single cooperative SHUTTLE projects are appropriate to meet national and Navy objectives.

It is beyond the scope of this document to provide a complete listing of tasks appropriate to the Navy sensor development effort. The character of the specific tasks (work units) depend upon the technical maturity for measurement of each of the parameters listed in Tables 2,3,4,5 above. The following examples characterize the sensor development tasks for representative parameters.

Infrared sensors provide high-resolution measurement of <u>sea surface temperature</u> under clear-sky conditions. Radiation transfer equations permit correction for transmission thru the real (water vapor) atmosphere provided that appropriate measurements of the atmospheric profiles and cloud cover are available. Thus, practical operational algorithms for absolute determination of SST with infrared sensors can be specified where requisite supplementary data are available and uncertainties of measurement can be stated where data are lacking.

Microwave sensors have shown the potential for all weather measurement of SST. Significant work remains to be done to validate geophysical data reduction algorithms over a wide range of environmental conditions. A major 6.3 effort is required to solve engineering problems (antenna aperture, scanning techniques, multiple beams) to obtain the precision, accuracy, and resolution needed to fully meet Navy operational requirements for future systems (1986 time-frame).

Basic research of the fundamental physics of electromagnetic scattering from the ocean surface is necessary to model sensor performance for measurement of directional wave spectra. Sensor options include synthetic aperture radar, ocean wave spectrometer, dual frequency scatterometer, interferometers, and surface control radars. Inherent data rates are of the order of 150 Mbsec. There are fundamental problems in obtaining adequate surface truth measurements for evaluation of airborne sensor performance. Significant research efforts are necessary to develop practical sensors, communications, and data processing techniques (algorithms) to provide the reliability of measurements needed to satisfy Navy requirements.

Theoretical analyses and laboratory measurements have demonstrated broadening of oxygen molecular resonance lines as a function of temperature and pressure. Conceptual studies have shown that suitably-designed, range-gated, microwave spectral sensors have the potential for measuring atmospheric temperature and pressure profiles. If these profiles can be obtained with sufficient precision and resolution (horizontal and vertical), they may be used as direct input for dynamic numerical atmospheric and oceanic forecast models. The importance of these measurements justify a major 6.1 effort for evaluation of the potential for development of a barometric pressure sensor to be implemented in the next generation of satellites (ca 1986).

TABLE 1: NEEDED PARAMETERS FOR THERMOHALINE MODELS

PRIORITY	PARAMETER	ACCURACY	RANGE	HORIZ. RESOL.	FREQUENCY	AREA SIZE
1	REL. SST	.25°C 0.5°C	10°C 35°C	5 KM 30 KM	3 HR 12 HR	200 x 200 KM OCEAN BASIN
2	ABS. WIND STRESS VECT.	0.2 DYNES/CM^2 0.25 DYNES/CM^2	0-20 DYNES/CM^2 0-20 DYNES/CM^2	5 KM 30 KM	3 HR/15° 12 HR/45°	200 KM x 200 KM OCEAN BASIN
3	ICE COVER	% COVER % COVER	10% 10%	5 KM 30 KM	3 HR 12 HR	200 KM x 200 KM OCEAN BASIN
4	REL. SURFACE TOPO	3 CM 5 CM	1 METER 2 METERS	5 KM 30 KM	24 HR 72 HR	200 x 200 KM OCEAN BASIN
5	NET HEAT FLUX	10 CAL/CM^{2}DAY 20 CAL/CM^{2}DAY	5-100 5-100	5 KM 30 KM	12 HR 24 HR	200 KM x 200 KM OCEAN BASIN
6	ABS. SST	.5°C .5°C	0-35°C 0-35°C	5 KM 30 KM	3 HR 12 HR	200 KM x 200 KM OCEAN BASIN
7	INSOLATION	2 CAL/CM^2/DAY 5 CAL/CM^2/DAY	5-500 5-500	5 KM 30 KM	12 HR 24 HR	200 KM x 200 KM OCEAN BASIN
8	TURBIDITY	0.1-10 mg/l .005 mg/l	0.2-50 mg/l .01-0.7 mg/l	5 KM 30 KM	3 HR 12 HR	200x200 OCEAN BASIN
9	ABS. AIR TEMP	0.5°C 1.0°C	-50°C to 40°C -50°C to 40°C	5 KM 30 KM	3 HR 12 HR	200 KM x 200 KM OCEAN BASIN
10	BAROM. PRESSURE	5 MILLIBAR 5 MILLIBAR	960-1020 MB 960-1020 MB	5 KM 30 KM	3 HR 12 HR	200 KM x 200 KM OCEAN BASIN
11	RAIN	1 MM/HR 1 MM/HR	1-100 MM/HR 1-100 MM/HR	5 KM 30 KM	3 HR 12 HR	200 KM x 200 KM OCEAN BASIN
12	REL. HUMIDITY	5% 5%	0-100 0-100	5 KM 30 KM	3 HR 12 HR	200 KM x 200 KM OCEAN BASIN

TABLE 1: NEEDED PARAMETERS FOR THERMOHALINE MODELS (cont.)

13	CURRENTS	CM/SEC (10%) CM/SEC (20%)	4-400 4-400	5 KM 30 KM	3 HR/15° 12 HR/45°	200 KM x 200KM OCEAN BASIN
14	SEA STATE HEIGHT	50 CM 50 CM	0-15 METERS 0-15 METERS	5 KM 30 KM	3 HR 12 HR	200 KM x 200 KM OCEAN BASIN
15	SALINITY	0.05 ppt 0.1 ppt	0-40 ppt 0-40 ppt	5 KM 30 KM	3 HR 12 HR	200 KM x 200 KM OCEAN BASIN

Table 2

NAVY OCEANOGRAPHIC OPERATIONAL REQUIREMENTS FOR ENVIRONMENTAL DATA MEASUREMENTS FROM SATELLITES*

PARAMETER		DATA RECEIPT RATE (HRS) FREQUENCY	TIMELINESS	RESOLUTION HORIZONTAL (KM)	RESOLUTION VERTICAL (M)	DEPTH (M)	MEASUREMENT PRECISION	MEASUREMENT ABSOLUTE ACCURACY	MEASUREMENT RANGE	COVERAGE WINDOW (W) OR GLOBAL (G)
SEA SURFACE TEMPERATURE		12	3	10	-	-	0.25°C	0.5°C	2 to 35°C	G
		72	12	25			0.8°C	1.0°C		
SEA VERTICAL TEMPERATURE PROFILE		12	3	10	2	300	0.25°C	1.0°C	2 to 35°C	G
		72	12	100	10	50	1.0°C	2.0°C		
WAVES	HEIGHT	3	0.5	1	-	-	0.3M	0.3M	1-20M	G/W
		12	3	25			10%	10%	1-8M	
	AMPLITUDE COMPONENT	3	0.5	1	-	-	0.3M	0.3M	1-20M	
		12	3	25			0.7M	0.7M	1-8M	
	WAVELENGTH COMPONENT	3	0.5	1	-	-	5%	5%	1-1000M	G/W
		12	3	25			15%	15%	50-500M	
	DIRECTION	3	0.5	1	-	-	10°	10°	0-360°	G/W
		12	3	50			30°	45°	0-360°	
SEA ICE	COVER	24	12	25/0.5**	-	-	10%	12%	0-100%	G/W
		120	24	25			25%	30%	0-100%	
	THICKNESS	24	12	2	-	-	0.25M	0.5M	0-25M	G/W
		120	24	50			2M	2M	30-M	
	AGE	24	12	10	-	-	6 mos.	6. mos.	1-36 mos.	G/W
		120	24	50			12 mos.	12 mos.	1-36 mos.	
ICEBERG & LEADS		24	3	0.015	-	-	-	0.5KM	-	W
		48	3	0.1				2KM		

* Block Identification - Top represents a tactical site with direct satellite readout.
- Bottom represents a central processing site for numerical processing.

** Fine horizontal resolution required for special operations.

TABLE 3

NAVY MARINE ATMOSPHERIC OPERATIONAL REQUIREMENTS

FOR ENVIRONMENTAL DATA MEASUREMENTS FROM SATELLITES*

PARAMETER		DATA RECEIPT RATE (HRS)		RESOLUTION		DEPTH (M)	MEASUREMENT			COVERAGE WINDOW (W) OR GLOBAL (G)
		FREQUENCY	TIMELINESS	HORIZONTAL (KM)	VERTICAL (M)		PRECISION	ABSOLUTE ACCURACY	RANGE	
CLOUD COVER** (including smoke, haze and smog)		On Call	0.08	0.5	-	TO DETECT ALL CLOUD LEVELS	-	0.5KM	-	W
		0.5	0.25	1				1.0KM		G/W
WIND	SPEED	3	0.25	10	-	-	5%	2M/SEC	1-75M/SEC	G
		12	3	25			20%	4M/SEC	1-25M/SEC	
	DIRECTION	3	0.25	10	-	-	5°	10°	0-360°	G
		12	3	25			10°	22.5°	0-360°	
VERTICAL TEMPERATURE PROFILE		1	0.5	10	30	0-60,000	1.0°C	10%	-70to50°C	W
		3	1	100	300					G/W
VERTICAL MOISTURE PROFILE		1	0.5	10	30	0-60,000	0.3MM	10%	-	W
		3	1	100	300					G/W
VISIBILITY***		1	0.25	10	-	0-7,500	-	-	-	W
										G/W
PRECIPITATION		On Call	0.25	1	-	-	0.3MM/HR	-	-	W
		3	1	5						G/W
SURFACE TEMPERATURE		1	0.5	10	-	-	0.5°C	0.5°C	-40°to60°C	G/W
		3	1	10			1.0°C	1.0°C		

* Block Identification - Top represents a tactical site with direct satellite readout
- Bottom represents a central processing site for numerical processing

** Visual and IR imagery

*** Discrimination between dense/thick/fog/mist with respect to poor/moderate/good/excellent

TABLE 4

NAVY TERRESTRIAL OPERATIONAL REQUIREMENTS

FOR ENVIRONMENTAL DATA MEASUREMENTS FROM SATELLITES*

PARAMETER	DATA RECEIPT RATE (HRS)		RESOLUTION		DEPTH (M)	MEASUREMENT			COVERAGE WINDOW (W) OR GLOBAL (G)
	FREQUENCY	TIMELINESS	HORIZONTAL (KM)	VERTICAL (M)		PRECISION	ABSOLUTE ACCURACY	RANGE	
GEOID	Continuous	-	25	-	-	1CM	10%	-	G**
SNOW/ICE COVER	3	0.5	10	-	-	5CM	-	-	G
OVER LAND	6	1.5	45						
SOIL MOISTURE	On call	0.25	2	-	-	10%	8CM	-	G
	6	1.5	10						

* Block Identification - Top represents a tactical site with direct satellite readout
- Bottom represents a central processing site for numerical processing

** One time global coverage

Table 5
NAVY NON-VALIDATED OPERATIONAL REQUIREMENTS
FOR ENVIRONMENTAL DATA MEASUREMENTS FROM SATELLITES*

PARAMETER		DATA RECEIPT RATE (HRS)		RESOLUTION		DEPTH (M)	MEASUREMENT			COVERAGE WINDOW (W) OR GLOBAL (G)
		FREQUENCY	TIMELINESS	HORIZONTAL (KM)	VERTICAL (M)		PRECISION	ABSOLUTE ACCURACY	RANGE	
SALINITY		12	3	10	2	300	1.0PPT	10%	-	G
		72	12	25	10	50				
OCEAN SURFACE CURRENTS	DIRECTION	12	3	10	-	-	10°	10°	-	G
		72	12	25			30°	45°		
	SPEED	12	3	10	-	-	0.5M/SEC	0.5M/SEC	-	G
		72	12	25			1.0M/SEC	1.0M/SEC		
WATER MASS IDENTIFICATION **		12	3	10	-	-	-	-	-	G
		72	12	25						
OCEAN TIDES		12	3	10	-	-	-	-	-	G
		24	6	25						
NEAR SHORE CURRENTS	DIRECTION	3	0.5	10M	1	30	10°	10°	-	W
		12	3	10M						G/W
	SPEED	3	0.5	10M	1	30	0.5M/SEC	0.5M/SEC	-	W
		12	3	10M						G/W
LITTORAL SEDIMENT TRANSPORT		3	0.5	10M	10	-	-	-	-	G/W
		12	3	10M						
NEAR SHORE BATHYMETRY***		ON CALL	0.25	25M	1	0-200	-	-	-	G
		-	-	300M						
WATER LEVELS		ON CALL	0.25	10	-	-	10%	0.15M	-	W

* Block Identification - Top represents a tactical site with direct satellite readout.
Bottom represents a central processing site for numerical processing.

** Color, plumes, fronts, and suspended sediments.

*** Once global coverage is obtained, the measurements are only on call.

CONCLUSIONS/RECOMMENDATIONS

The Navy has a defacto lead in national programs for science and applications of Satellite Remote Sensing Oceanography.

The strength of Navy and DOD operational requirements for Satellite Measurement of Oceanic Parameters has been a major factor in sustaining NASA and tri-agency program reviews by OMB, GAO, and Congressional Committees (SKYLAB, GEOS, SEASAT, NOSS).

A major new thrust area for NASA Applications Office Earth Observations program, and for NOAA is into satellite oceanography and applications.

Navy resources and priorities for new initiatives into the satellite oceanography area are limited.

Navy programs and projects requiring application of satellite oceanographic technology span a wide range of disciplinary areas: dynamic oceanography, coastal processes, polar regions, sensor technology, data processing and dissemination, systems research, acoustic systems RDT&E, etc...; and span a wide range of mission and funding sponsors: technology base (6.1, 6.2, 6.3), system development (6.6), and support for fleet operations and training. Because of limited resources, any single potential sponsor is reluctant to commit to programmatic support for fear that he will be assuming a disproportionate share of the cost burden. An attractive solution has been for the Navy to lay back and wait until NASA has solved all of the science and technology problems and provides measurements to meet Navy's requirements.

NASA satellite oceanography programs cannot be expected to meet Navy requirements without aggressive Navy participation. Neither NASA nor NOAA have the same specific functional requirements. This coupled with inadequate Navy funding, leads to the Navy being in a position of joining programs late, being inadequately prepared to handle the data, and the parameters measured generally do not meet specific Navy requirements. NASA program objectives result from compromises based on engineering constraints and from compromises between diverse requirements from a multiplicity of users. Navy reluctance to assert its proper leadership role results in duplication of effort, expenditure of high-cost national resources, and delays in realization of Navy objectives.

A major programmatic deficiency is that previous (NASA/NOAA) efforts have been devoted to sensor technology with inadequate plans, resources, and programs for data analyses. Navy programs must provide sufficient emphasis on analysis and applications algorithms, software programs, and models for operational utilization of the data, validation of requirements, and development of operational doctrine for fleet exploitation of derived data products.

In spite of the breadth of Navy programs, internal management and funding are derived from three basic sponsors: ONR (Code 400, NORDA, NRL), 6.1; NAVMAT (08T245), 6.2; OP952, 6.3.

A proper satellite oceanographic RDT&E plan must be completed which is structured in the format of a NDCP to provide management with program options and cost trade-offs. The cover memo to this document details the suggested approach.

The Navy must make a commitment to establish a sound program for utilization of satellite oceanic measurements in a prioritized sequence of projects to remove identified deficiencies in many application areas.

Prior to participation in interagency programs, the Navy must insist on signed memoranda of agreement defining Navy obligations and mutual responsibilities.

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