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ASSESSMENT OF THE USE OF SPACE TECHNOLOGY IN THE MONITORING OF OIL SPILLS AND OCEAN POLLUTION - EXECUTIVE SUMMARY

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EXECUTIVE SUMMARY

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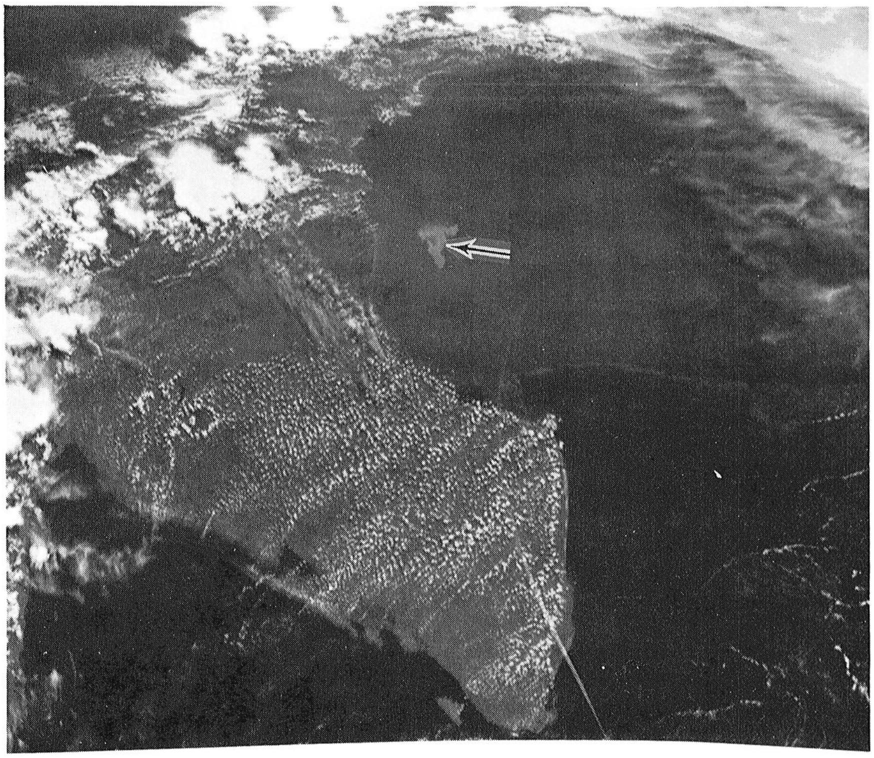

IXTOC I Oil Spill Viewed through TIROS Spacecraft (June, 1979)

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SECTION I

INTRODUCTION

The assessment performed in this study constitutes a portion of the NASA investigation directed by the U. S. House of Representatives and Senate concerning the potential of space technology in the monitoring of oceanic pollution. The directive is contained in the House-Senate Report on the 1978 NASA Authorization. Technical monitoring of the study was conducted by the Flight Electronics Division of the NASA Langley Research Center. The study was conducted by the General Electric Company, Space Division.

The aspects of oceanic pollution treated in the study were:

- Oil pollution due to accidental or deliberate activities in ocean vessels, or natural oil seeps originating from the ocean floor.
- Accidental or deliberate chemical pollution from industrial or municipal waste disposal.

The primary goal of this study was to determine the potential of remote sensing from satellites in the detection/monitoring of oil spills and ocean pollution due to waste disposal. In addition, the study examined the potential impact of other space-aided technologies such as communications and data handling.

The assessment objectives of the study address the following basic questions:

1. What are the measurement requirements for an oil spill and ocean pollution surveillance system and what are the end products required by the agencies who are assigned operational responsibilities?
2. What is the present state of knowledge of the detection of oil spill and ocean pollution and in what areas is further research needed to meet measurement requirements?
3. How adequate is present technology in meeting these measurement requirements?
4. What advances are required in present technology to meet these requirements?
5. What are the characteristics of a future satellite system which could meet the requirements?

A summary of overall conclusions on these basic questions is provided in Section II. Subsequent summary Sections (i. e. No. III-VII) will provide the proper context for these conclusions, although more detailed technical rationale is contained in the Technical Volume of the Final Report.

The technology aspects addressed in questions 2, 3, 4 above are discussed as follows:

- In Section IV, relative to meeting user measurement requirements.
- In Section VI, with respect to candidate elements for a future system.
- In Section VIII, summarizing recommended technology in support of oceanic pollution monitoring needs.

Section VII discusses salient characteristics and considerations for a potential future system that could support missions for oceanic pollution monitoring. The mission categorization presented in Section V provides a reference for the analyses related to candidate sensors and future systems.

Serving as the framework of the study were the requirements of the various governmental users of ocean pollution data, as discussed in Section III. Thus, a very important part of the study was the continuing dialog between key representatives of the various government user organizations, NASA and the GE Study Team. The potential contribution of space technology was analyzed within the context of a broad operational system which also employs aircraft observations and in situ measurements.

SECTION II

CONCLUSIONS ON KEY QUESTIONS

Summary answers to the five basic assessment questions, as stated in the Introduction, are as follows:

MEASUREMENT REQUIREMENTS (REF. QUESTION NO. 1)

Measurements to satisfy the user requirements fall into two categories: (1) those related to direct measurements on the pollutants and their distribution in the ocean, and (2) measurement of oceanographic and atmospheric parameters that constitute model inputs for predicting the trajectory (fate) of pollutants and their potential threat to sensitive shore areas. The measurements are listed below; the quantification of the requirement parameters are discussed in Section III.

OIL-SPILL CHARACTERISTICS

- Areal Distribution
- Thickness
- Classification

WASTE POLLUTANT CHARACTERISTICS

- Areal Distribution
- Concentration
- Classification

POLLUTANT TRAJECTORY MODELING

- Wind Speed
- Wind Direction
- Ocean Current Speed
- Ocean Current Direction
- Significant Wave Height
- Wave Length
- Wave Direction
- Air Temperature
- Surface Water Temperature
- Ice Cover Areal Extent
- Ice Thickness
- Weather Fronts
- Precipitation
- Suspended Sediment

Significant amount of interdependence exists between these two measurement categories, by virtue of the commonality of purpose on some of their parameters. For instance, measurements of wind parameters will be useful in the interpretation of pollutant image data. Similarly, current information on areal distribution of the pollution will be helpful in updating model predictions of pollutant trajectory.

Two measurement parameters that were found to have high impact relative to space-based monitoring are spatial resolution and sampling frequency. Specifically: imaging of oil spills and waste pollutants require relatively fine resolution, ranging from 10 to 30 meters; by contrast, pollutant-trajectory parameters generally require resolutions in the order of 10 kilometers. The frequencies of measurements over the 200 mile zone were: once and twice a day for oil spills and waste pollutant characteristics, and once to eight times per day for the pollutant-trajectory model parameters.

These coverage-related requirements were found to be sufficiently stringent to require special examination in the light of practical implementation approaches. It was determined that the coverage requirements were flexible, that is, the effectiveness of the space measurements related to spatial coverage do not decrease abruptly as we depart from the ideal or most stringent requirement (e.g. 10 meter resolution). This flexibility, concurred to by the representatives of the user community, enabled three important analyses in the study:

1. Establishment of effective (or reasonable) spatial resolution requirements, based on the percentage of significant pollution incidents able to be acquired. (Reference Figure III-3, Section III)
2. Determination of the area coverage that is possible by utilizing the orbits associated with existing or planned spacecraft such as NOSS (instead of idealized orbits for hypothetical, dedicated spacecraft).
3. Determination of the optimum role of aircraft sensors and spacecraft sensors is in meeting the coverage requirements.

The results of these analyses, from a requirements point-of-view, can be summarized as follows: (1) Spatial resolution goals of 60-100 meters from space were found to be reasonable, considering the high percentage of significant oil spills that will be detected in that range. (2) Coastal coverage of once a day in a large portion of the U. S. coast and more frequent coverage in selected portions of the coast are possible assuming the use of existing or planned spacecraft. This constitutes a great improvement over present and projected capabilities utilizing aircraft and would be of significant value to the users. (3) A "complementary" approach utilizing the best coverage capabilities of aircraft and spacecraft instruments would be optimun. This approach combines the synoptic coverage of all-weather space-borne sensors with the detailed, higher resolution coverage of airborne sensors over high density traffic shipping lanes and coastal areas constituting gaps in spacecraft coverage.

PRESENT STATE OF KNOWLEDGE IN DETECTION (REF. QUESTION NO. 2)

An important aspect of technology assessment is the level of knowledge of the scientific phenomenology relevant to pollutant detection, measurement and data interpretation. This degree of achievement can be divided into five basic steps, as shown below:

5. CAPABILITY TO PERFORM INFORMATION EXTRACTION
4. UNDERSTANDING OF OCEAN ENVIRONMENT VARIABLES
3. UNDERSTANDING OF ATMOSPHERIC & GEOMETRIC EFFECTS
2. EXPERIENCE IN ACTUAL DETECTION, THROUGH EXPERIMENTATION
1. BASIC KNOWLEDGE OF THE PHYSICS OF POLLUTION DETECTION

Overall Assessment of State of Knowledge

An initial baseline of knowledge exists on the characteristics of electromagnetic reflectance and emission for oil and waste pollutants versus water. This knowledge, based primarily on laboratory testing, has led to measuring techniques and concepts. A limited amount of aircraft and spacecraft-based testing has been performed to date, with more extensive, better controlled testing still to be conducted. The salient atmospheric effects are generally known from the results of aircraft experimentation and the application of models derived from other Earth Observation disciplines. Still missing are those knowledge steps related to a thorough understanding of the effects of ocean dynamics in pollution measurements, and the mathematical relationships and algorithms that would enable automated detection and identification of the pollutants, with high degree of confidence.

Following is a brief summary of the status of each of the aforementioned steps.

Step No. 1 - Basic Knowledge of the Physics of Pollution Detection

The concept of the detection technique is encompassed in this initial step. With respect to oil spills and waste pollutants, the fundamental physics of discriminating the pollutant from water using ultraviolet, visible and microwave detection, is understood.

The primary detection technique for oil spills from space employs the calming effect of the oil film on the ocean surface. In the visible spectrum, this wave suppression over the slick is manifested as an area of higher reflectance than that of the surrounding water, when viewed at the proper reflection angles. Thus, use is made of the fact that specular (or mirror) reflection is greater in oil than it is in water. The sole use of optical radiance contrast in the detection of oil from space requires additional development, due to the low signal to noise ratio under a variety of ocean and atmospheric conditions.

The radar return from the ocean surface, at incidence angles exceeding 10° -15°, is enhanced by wind-excited capillary waves. Suppression of the capillaries by the oil film decreases the radar return from the oil slick scene. This phenomenon has been demonstrated through aircraft-borne sensors over controlled oil spills, using real and synthetic aperture radar.

Ultraviolet radiation (from the sun or an artificial light source) will undergo higher reflection from an oil slick than from water, since oil is more highly reflective in this portion of the spectrum. Use of ultraviolet reflectance contrast in space observation is very limited due to the high degree UV atmospheric absorption.

The well-known phenomenon of fluorescence of oil can be used in oil-slick detection. In fluorescence, a fraction of the UV energy impinging on the oil is re-emitted at a longer wavelength. Since the fluorescence characteristics of oil are different than that of other substances and flourescence varies with type of oil, the technique has potential in classification as well as detection of oil. Recent research has also shown the potential of fluorescence in oil quantification.

The passive microwave emission properties of oil are understood, including the relationship between microwave signal strength and detection wavelength, effects of polarization, and the effect of surface roughness on emissivity. The microwave emission contrast between oil and water depends on the net effect of: (1) the increased emissivity of oil vs. water,

(2) the decrease in emissivity due to the calming effect of the oil film. The alternating variation in oil surface brightness temperature with increasing thickness has been used in the quantification of the volume of oil slicks.

Detection of waste pollutants is performed mainly through the use of optical techniques in the visible and IR portions of the spectrum. Radiance contrast between waste plumes and the unpolluted water permits the imaging of these substances during the difussion period. General spectral signatures based on radiance contrast vs. wave-length relationships have been developed for wastes such as sewage sludge, acids and dredge material.

Thermal infrared mapping of sewage outfall plumes is feasible, due to the convective rising of sewage waters, which are at higher temperatures than the receiving waters.

Waste detection techniques using aircraft-borne instruments is more advanced than those using space-based sensing, due to a more comprehensive aircraft testing program than that which is possible with available space sensors on currently operating spacecraft. Extrapolation of airborne sensing techniques to space sensing is treated in detail in the Technical Volume.

In summary, the present state of knowledge is approximately mid way in the achievement scale.

Step No. 2 — Experience in Actual Pollutants Detection, Gained Through Field Experimentation

Data has been gathered using aircraft, spacecraft and surface experimentation, in a wide spectrum ranging from the UV to microwave. Landsat-Multispectral Scanner data on oil slicks has been obtained in the visible spectrum, and the data has been enhanced using computer-aided techniques. Two limitations to this date are: (1) cloud cover, which has severely limited the amount of data over major spills such as the IXTOC oil well in the Bay of Compeche, (2) the lack of information on detailed local atmospheric and oceanographic data in the test site, (3) Sea-state conditions. Similar optical imagery of the IXTOC spill has been obtained using NIMBUS, TIROS, and GOES instruments. Aircraft tests over controlled oil spills have produced color photography by NASA, the US Coast Guard, Canadian Centre for Remote Sensing, and JBF Scientific.

In the microwave region, both active and passive techniques have been tested from aircraft, using controlled and natural oil spills.

The Environmental Research Institute of Michigan (ERIM) has gathered Synthetic Aperture Radar (SAR) over controlled oil spills. The data demonstrates the feasibility of oil spill detection and measurement of areal extent, using X-band SAR with HH polarization. Concerning space-based radar measurements, analysis of SEASAT data over known oil-slicks (Santa Barbara Channel) did not show a clear delineation of the seepage oil. The SEASAT L-band radar data is very rich in ocean features containing a large dynamic range; however, these features may be attributed to ocean surface dynamic phenomena caused by the wind and the coastal and subsurface topography in that region.

The Naval Research Laboratory has conducted USCG-sponsored experiments of multi-frequency passive microwave radiometry over controlled oil spills. Thickness measurement techniques were tested and found satisfactory in the region above 100 micrometers.

An extensive experimental program has been conducted on airborne measurements of waste plumes, particularly in the New York Bight and the Delaware Bay. Emphasis has been placed on optical sensors such as airborne multi-spectral scanners, however, fluorosensors and microwave radiometers have also been tested. Concurrently, with airborne observations, spacecraft data from LANDSAT-Multi-Spectral Scanner (MSS) and NIMBUS-Coastal Zone Color Scanner (CZCS) have been obtained over these sites. The MSS imagery, in particular, has resolved the plume boundaries. Pollutant concentrations and classification have been measured using aircraft sensor data, however, additional space experimentation is needed to extend these airborne techniques to space sensing.

In summary, experimental data, mainly from airborne sensors, has produced useful data in the initial development and verification of measurement techniques. Additional experimentation is needed, particularly using spacecraft sensors, with adequate surface truth data.

Steps No. 3 and 4 – Understanding of Atmospheric, Geometric and Ocean Effects and Environmental Variables

The effects of important environmental and spatial variables related to the atmosphere, ocean, air-water interface, sun angles, observation incidence angle are not sufficiently well understood to support the pollution measurements from space. Our understanding of the atmospheric absorption and scattering effects constitute an exception here, since knowledge has been gained through many years of data analysis in Earth Observation satellites. Data obtained by CCRS on radar cross section and contrast in scattered signal return from oil and water for various incidence angles is useful in determining preliminary design parameters for future active microwave sensors.

The baseline of data should include a sufficiently large sample representing the range of environmental conditions, in order to determine statistically significant correlations between observed parameters and the atmospheric/oceanographic environment. Specific examples of variables needed to be correlated with the pollution signal detected are:

1. Pollutant spatial distribution and rate of dispersion/diffusion
2. Wave height and directional wave spectra
3. Wind dynamics, including wind slicks (also known as "wind spills")
4. "Steady-state" wind speed and direction
5. Incidence angle of observation
6. Sun angle (for optical measurements only)
7. Three-dimensional ocean circulation
8. Sea-mist and foam content
9. Percentage of "white caps" on the ocean scene
10. Ocean water temperature, salinity and particulate content.

Step No. 5 — Capability to Perform Information Extraction on an Operational Basis

Considerable development is required in the areas of data interpretation and reduction techniques for extracting pollution information in the form and timeliness required by the user. Examples of steps in that direction are the "step-wise regression" techniques developed by R. Johnson to extract waste pollution concentration data in the presence of many variables such as pollutant material, sun angle and atmospheric conditions. Similarly, V. Klemas has developed useful classification techniques using "Eigenvector" analysis to eliminate ambiguities between waste pollution and other variables. Full development of models and appropriate algorithms for information extraction will depend to a great extent on the availability of field experimental data and a thorough understanding of the environmental effects, as discussed in Step Nos. 3 and 4.

ADEQUACY OF PRESENT TECHNOLOGY (REF. QUESTION NO. 3)

A general assessment of the adequacy of technology in terms of stage of maturity of sensing, support systems and information extraction is shown in the table and discussion below, relative to oil spills, waste pollution and inputs to pollution trajectory prediction models.

<table>
<tr><th></th><th>OIL SPILLS</th><th>WASTE POLLUTION</th><th>POLLUTION MODELS</th></tr>
<tr><td>Sensing Technology</td><td>Early Stage for Sensors & Techniques</td><td>Intermediate Stage for Sensors & Techniques</td><td>Advanced for Wind Speed/Direction, Wave Direction & Length</td></tr>
<tr><td>Support System Technology</td><td colspan="2">Technology Relative to Supporting Satellites & Subsystem is Adequate</td><td>Early Stage Relative to Data Handling System</td></tr>
<tr><td>Information Extraction Technology</td><td>Early Stage for Microwave</td><td colspan="2">Intermediate Stage</td></tr>
</table>

Concerning sensors and sensing methods: We are at an early stage of technology development in wide-swath synthetic aperture radars for oil spill detection. Optical sensors such as the Coastal Zone Color Scanner which has flown on Nimbus and Seasat characterize the "intermediate" stage of development leading to higher resolution and sensitivity instruments capable of waste pollution measurements. Fairly advanced technology exists in sensors for oceanographic and atmospheric inputs to pollution trajectory models, with the exception of ocean current oil thickness and sea-state parameters for wide spread frequent coverage.

With respect to support system technology: Although high resolution wide-swath sensing requires high electrical power and the handling of high data rates, the state-of-the-art supporting these needs is adequate. One of the main technology challenges of this mission will be the management of data from diverse sources, including its processing and correlation to suit the needs of several user organizations.

In the area of information extraction, the state-of-the-art in oil-spill detection is at an early stage relative to microwave data. This is due to the presence of ambiguities caused by other sea-surface dynamic phenomena such as wind-slicks, which appear as oil spills and thus tend to confuse the data.

A specific assessment of measurement technology relative to each of the user required measurements is included in Section IV, and is relevant to this discussion of technology adequacy.

ADVANCES REQUIRED IN PRESENT TECHNOLOGY (REF. QUESTION NO. 4)

Needs in Basic Science of Ocean Pollution Monitoring

- Understanding of the effects of the ocean environment on sensed radiance and emission of waste pollution and oil spills.
- Knowledge of the temporal variability of ocean and atmospheric phenomena pertinent to remote sensing of pollutants.
- Experimental data to support sensor and information extraction developments; obtained through extensive field testing using simultaneous measurements within a broad spectral band, with appropriate surface truth data.

Needs in Sensing Technology

- Development of wide-swath (e.g. 400 km), pointable Synthetic Aperture Radar for oil spill sensing within the 200 n. mi. coastal zone.

- Development of wide-swath Pointable Optical Linear Array (POLA) sensor for waste pollutant and plume measurements providing corroborative oil-spill imaging data.
- Technique for measuring oil slick thickness from space with 0.1 km resolution (e.g., improved resolution passive microwave radiometry).
- Technique for oil spill classification from space (e.g., laser fluorosensing from orbital altitudes)
- Technique for obtaining frequent measurements of ocean current velocity vectors and significant wave height, with 10 km resolution cell (e.g., SAR, scatterometry).

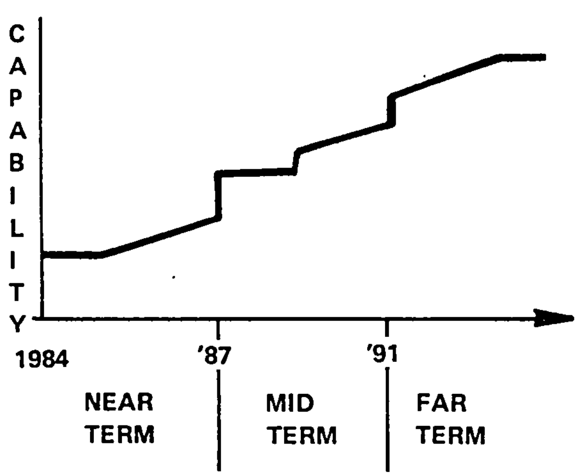
Needs in Support-System Technology

- End-to-end data processing techniques and systems to correlate data from many sources (e.g., satellites, aircraft, buoys) and present data to users in near real-time.
- Long-Life Traveling Wave Tubes (TWT) for SAR, Scatterometer and Altimeter
- High-voltage (8-11 kV) power supplies for TWT's.
- Multi-frequency feed for passive microwave radiometer.

CHARACTERISTICS OF A FUTURE SATELLITE SYSTEM (REF. QUESTION NO. 5)

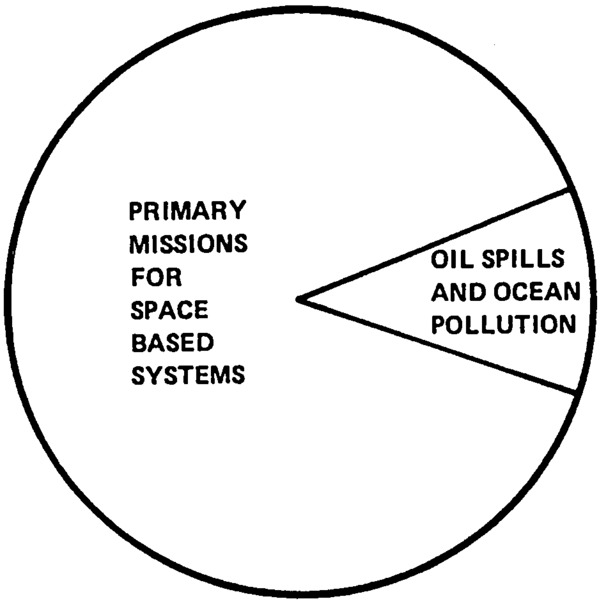
Assuming the advancement in the state-of-the-art through an adequate development program, a future system to monitor oil spills and ocean pollution would have the following general characteristics:

- EVOLUTIONARY



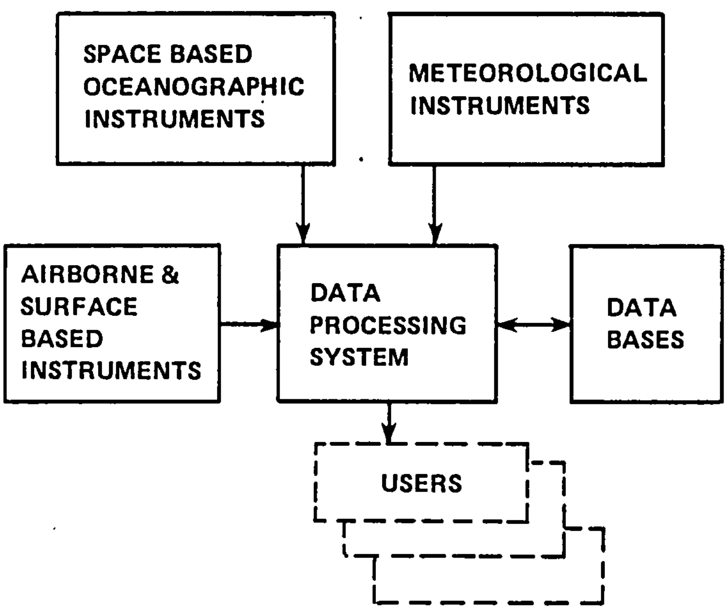
The level of capability of the system will increase gradually. During the mid-term period (1987-1991) full operational capability will be attained. Improvements will be realized in the far-term system (post 1991) by taking advantage of enhanced space sensing technology.

● A SHARED MISSION



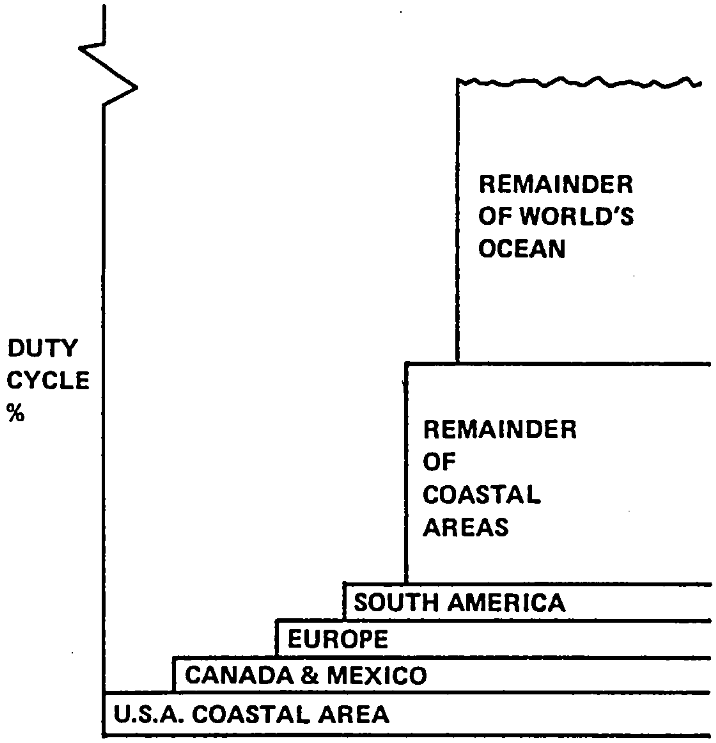
Satellites dedicated solely to this mission will not be necessary, since the sensors and space platforms of other systems such as the National Oceanic Satellite System and TIROS can be utilized. For instance, the Synthetic Aperture Radar used in this application will be the same instrument to be used in the Ice Processes and Climate Experiment (ICEX).

● COMPLEMENTARY APPROACH



The total system will depend upon the complementary role of various airborne, space-based and ground-based system elements. All these elements contribute data that must be processed and correlated in a centralized data processing facility. The data is presented to the users in near-real-time, within a delay period as specified for each measurement.

- <u>A NATIONAL SYSTEM WITH POTENTIAL GLOBAL CAPABILITIES</u>



There is a common interest among many coastal nations concerning ocean pollution control and monitoring. Moreover, the duty cycle of the satellite segment of the system is very small compared with its potential for global coverage of all coastal areas and/or the entire ocean areas. Consideration of global coverage is relegated to the far-term period in the 1990's.

SECTION III

USER REQUIREMENTS

STATEMENT OF THE OCEAN POLLUTION PROBLEM

Every few years the national attention turns to a spectacular pollution accident such as the oil spills in the Santa Barbara Channel in 1969, the Argo Merchant (1976), and more recently, the IXTOC well blowout in the Bay of Campeche (1979). While these large scale pollution events pose environmental problems, the larger problem in terms of detrimental effects upon the environment is due to the sustained rate of flow of oil and waste disposal pollutants into our coastal waters. This relentless contamination tends to inhibit the recovery from intrusions through natural processes, in important biological resources such as fisheries. Oil, for instance, affects marine ecosystems in many ways, mainly through: (1) toxicity acting directly on the marine organism, (2) physical coating of the organism, (3) loss of habitat, and (4) change in food supply.

The sources of oil pollution, on a worldwide basis, are shown in Figure III-1. Out of the total of 42 million barrels/year (1.8 billion gallons per year), about 27.5 million barrels per year are due to uncontrollable sources, non-point and fixed sources. The remainder, approximately 14.5 million barrels/year are due to transportation activities. Only 14% of the transportation segment are due to accidents such as groundings, strandings, and collisions. The remaining 86% are due to operational activities such as oil tanker tank washing, loading and docking activities, and bilge and bunker tank pumping.

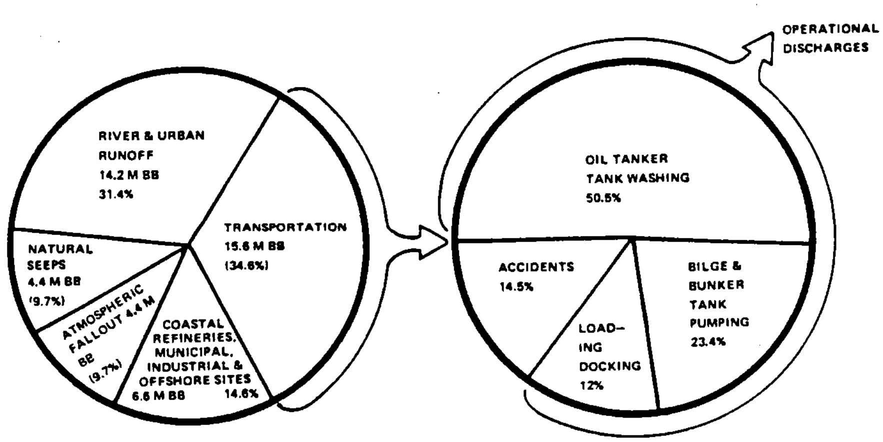


Figure III-I. Annual Input of Petroleum Hydrocarbons in the Oceans

Equally serious is the problem of industrial and municipal waste disposal. For instance, almost a decade ago, the Council on Environmental Quality, assessing the potential consequences of continued disposal practices, recommended to the President a comprehensive national policy on ocean dumping of wastes to end unregulated ocean dumping, and to prohibit ocean disposal of all materials harmful to the marine environment. The Marine Protection, Research and Sanctuaries Act of 1972 requires that the U.S. "...regulate the dumping of all types of materials into ocean waters and to prevent or strictly limit the dumping into ocean waters of any material which would adversely affect human health, welfare or amenities, or marine environment, ecological systems or economic potentialities."

The estimated quantity of pollutants from marine waste disposal in the U.S. is as follows:

Sewage Sludge:	4540 million kg/yr
Industrial Wastes:	1544 million kg/yr (Mid-Atlantic & Gulf of Mexico
Incineration of Organochlorides:	27 million kg/yr
Ocean Outfalls:	7.6 million cubic meters/day (> 2740 billion kg/yr)
Dredged Material:	31.5 million cubic meters/yr

Ocean outfalls, a major contributor and domestic and industrial wastes to the coastal environment, employ ducted discharges directly into the ocean. Some outfalls are sources of pollution due to inadequare treatment and ocean conditions leading to unsatisfactory dilution/dispersion of pollutants.

The general discussion above can be summarized by stating that there is a worldwide problem concerning the quantity and distribution of hydrocarbons and chemical and biological wastes into the coastal ocean environment. The objective of monitoring the ocean environment, from a pollution point of view, is threefold:

1. To detect illegal oil spills and waste dumps

2. To monitor the areal distribution and dispersion of pollutants

3. To permit a prediction of the trajectory of such pollutants based on ocean and meteorological conditions and projections.

Figure III-2 shows the various types of monitoring applicable to the pollution problem described above.

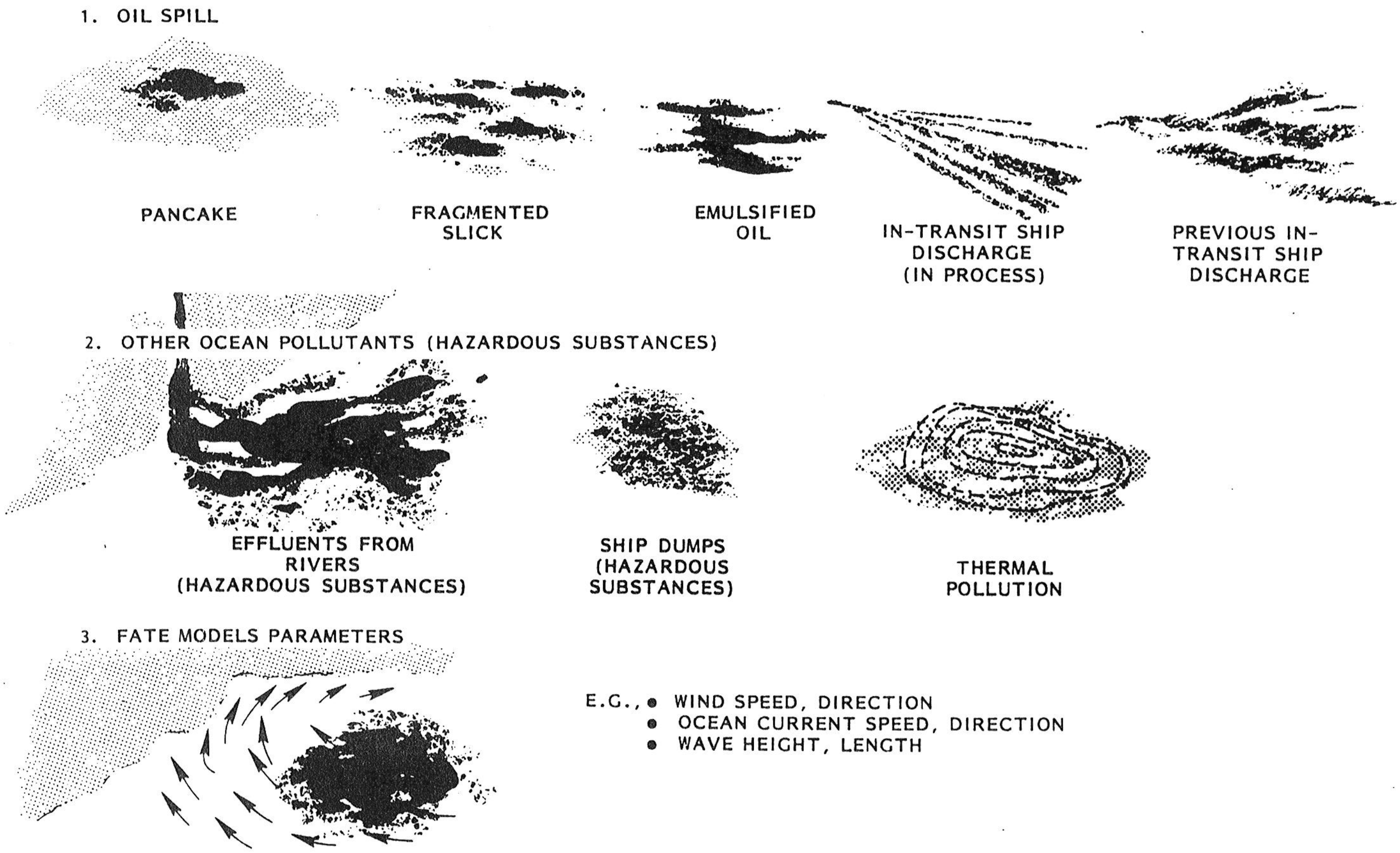


Figure III-2. Types of Oceanic Pollution Monitoring

The next section of this report deals with specific user requirements for pollution monitoring within the context of the pollution problem described above.

ROLE OF U.S. AGENCIES IN POLLUTION MONITORING

Requirements for oceanic pollution monitoring derive from: (1) federal legislation enacted to control the harmful effects of such pollution, and (2) the charters and responsibilities of the various government agencies. In order to discharge their responsibilities, these organizations require varying degrees of involvement in oceanic pollution monitoring, typically:

- U.S. DEPARTMENT OF TRANSPORTATION - U.S. COAST GUARD is the primary enforcement agency for laws relating to pollution by oil and hazardous substances. The Coast Guard maintains and operates a surveillance system for marine environment pollution. The main objectives of this system are:
  - Detection of harmful discharges of oil and hazardous substances
  - Assessment of area coverage and volume of pollutants
  - Prediction of the movement or trajectory of the pollutant discharges
  - Development of legal evidence for prosecution of violators of pollution laws
- U.S. DEPARTMENT OF INTERIOR - BUREAU OF LAND MANAGEMENT is responsible for Environmental Impact Statements to determine whether or not to lease off-shore facilities for applications such as oil extraction. An important part of the assessment is to determine the probable trajectory of the pollutant in the event of an accidental discharge. Furthermore, BLM determines the potential impact of such discharges upon biologically sensitive shore areas such as estuaries.
- U.S. DEPARTMENT OF INTERIOR - U.S. GEOLOGICAL SURVEY is responsible for the preparation of "Oil Spill Contingency Plans" in leased off-shore drill facilities. This involves the definition of safety procedures and facilities for drilling, production, and transportation of the oil, as well as ensuring the availability of clean-up equipment in the event of oil spills. USGS works with BLM in the performance of oil-spill risk analyses relative to sensitive shore resources.
- U.S. DEPARTMENT OF COMMERCE - NATIONAL OCIEANIC AND ATMOSPHERIC ADMINISTRATION (NOAA). NOAA provides important research and advisory support in the management, use and conservation of ocean resources, NOAA studies the impact of pollution on fisheries and other biological resources. In addition to providing satellite observations of the environment, NOAA develops measurement,

observational and analytical techniques and hardware for the measurement of ocean and atmospheric properties which are relevent to ocean pollution. NOAA has the leadership role in the planning under the National Ocean Pollution Research and Development and Monitoring Planning Act of 1978.

- ENVIRONMENTAL PROTECTION AGENCY has direct responsibility for monitoring pollution in inland waters, excluding the Great Lakes. EPA administers the "Clean Water Act" (as amended in 1977). This act makes provisions for:
  - The reduction and ultimate elimination of pollution discharges in navigable waters
  - International measures for the prevention of discharges by other countries
  - Conducting investigations concerning pollution of navigable waters
  - The establishment and maintenance of a water quality surveillance system for inland waters.
- U. S. STATE DEPARTMENT provides leadership in developing joint international contingency plans with neighboring countries such as Canada and Mexico. In cases like the Bay of Campeche spill, the State Department provides assistance in coordination when the spill transects international boundaries.
- DEPARTMENT OF DEFENSE (DOD) provides assistance in major pollution spills.
- DEPARTMENT OF HEALTH, EDUCATION AND WELFARE (HEW) is responsible for providing expert advice and assistance relative to the effect of actual or potential pollution incidents upon public health.

KNOWLEDGE AND MEASUREMENT REQUIREMENTS BY USERS

A survey of user needs in the oceanic pollution area was performed; based on this survey, a matrix was prepared, as shown in Table III-1. The vertical list in the matrix represents what the users need to know about the pollutant, polluter, or the environment surrounding actual or potential pollution incidents. The major users are listed across the top of the matrix. Each intersection marked with an "X" indicates that the particular item of knowledge is useful to the corresponding user.

The knowledge requirements served as a framework for the determination of measurement requirements to satisfy the users' needs. Analyses were performed to determine the

Table III-1. Knowledge Requirements by Users

KNOWLEDGE REQUIREMENTS	DOT USCG	DOC NOAA	DOC MAR AD	EPA	DOI USGS	DOI BLM	DOD NAVY	STATE DEPT.	HEW
1. DETECTION & LOCATION OF POLLUTANT	X	X		X			X	X	
2. QUANTITY & SPATIAL DISTRIBUTION	X	X	X	X	X	X	X	X	X
3. RATE OF DISCHARGE	X		X	X			X		
4. POLLUTANT CLASSIFICATION, COARSE	X		X		X	X	X	X	
5. POLLUTANT CLASSIFICATION, DETAILED	X	X		X					
6. SOURCE LOCATION	X		X	X			X	X	X
7. SOURCE IDENTIFICATION	X		X	X			X	X	
8. MOTION AND DISPERSION	X	X		X	X	X	X	X	
9. PREDICTED MOTION, SPREADING & SHORE IMPACT	X	X		X	X	X		X	
10. OPTIMUM POLLUTION ABATEMENT MEASURES	X	X		X	X				X
11. PREDICTION OF PROBABILITY OF DAMAGE TO ECOLOGY OR PROPERTY		X		X	X	X		X	X
12. ASSESSMENT OF DAMAGE	X	X	X	X	X	X		X	X
13. ECOLOGICAL INFORMATION		X		X					X

combination of measurements that would satisfy the knowledge requirements. This analysis was supplemented by a survey of selected technical personnel in the user organizations. Table III-2 is a summary of the performance parameters for those measurements. The list shows the most stringent requirements, i.e., those that would completely satisfy the monitoring needs of every user.

However, these "maximum" requirements were used as goals, and a more flexible approach to requirements was agreed upon during the Second Research Review. The approach focused on key requirements which drive the system cost and complexity, and determined through parametric analysis the degree of reduction in the accomplishment of the knowledge objectives, due to various levels of relaxation of the requirement. Two such analyses are salient in the

Table III-2. Summary of Measurement Requirements

PARAMETER	MISSION TYPE	RANGE OR SCOPE	PRECISION (±)	ACCURACY (±)	SPATIAL RESOLUTION OR GRID SIZE	FREQUENCY (EVERY N HRS)	DATA DELAY (HRS)
1. OIL SPILL AREAL DISTRIBUTION	SURV. & MONITOR	> 10m	5%	5%	10m	12	3
	MODELING	> 15m	10%	10%	15m	12	3
2. OIL SPILL COORDINATES	SURV. & MONITOR	US COASTAL AREA	0.5Km	1Km	N/A	12	6
	MODELING	US COASTAL AREA	-	250m	N/A	12	6
3. OIL SPILL THICKNESS	SURV. & MONITOR	0.1μm - 2mm	-	5%	10	12	6
	MODELING	0.1μm - 2mm	-	-	15	12	3
4. OIL CLASSIFICATION	SURV. & MONITOR	MAJOR TYPES	N/A	N/A	-	12	6
	MODELING	GROSS CLASSIFICATION	N/A	N/A	-	12	6
5. POLLUTANT DUMP SPATIAL DISTRIBUTION	SURV. & MONITOR	> 30m	-	-	30m	24	1/4 to 3
6. POLLUTANT DUMP COORDINATES	SURV. & MONITOR	US COASTAL ZONE	200m	200m	N/A	12 (FOR ACIDS)	3
7. WASTE POLLUTANT CLASSIFICATION	SURV. & MONITOR	ACID/INDUSTRIAL OR	GENERIC CLASS	GENERIC CLASS	> 30n	12 (FOR ACIDS)	3
8. WASTE POLLUTANT CONCENTRATION	SURV. & MONITOR	PPM TO MG/L	POLLUTANT DEPENDENT	POLLUTANT DEPENDENT	> 30n	12	3
9. POLLUTION SOURCE (E.G., VESSEL IDENTIFICATION)	SURV. & MONITOR	TANKERS, BARGES, RIVER EFFLUENT, NATURAL SOURCE	SUFFICIENT FOR LEGAL EVIDENCE		N/A	12	3
10. WIND SPEED	MODEL	0-50m/sec.	0.5m/sec	2m/sec	10Km	3	3
11. WIND DIRECTION	MODEL	0-360°	5°	10°	10Km	6	3
12. OCEAN CURRENT SPEED	MODEL	0-300cm/sec	5cm	5cm	10Km	6	3
13. OCEAN CURRENT DIRECTION	MODEL	0-360°	10°	10°	10Km	6	3
14. ICE COVER AREAL EXTENT	MODEL	0-100%	-	2%	10m	24	6
15. ICE THICKNESS	MODEL	0-50m	0.2m	0.5m	10m	24	6
16. SIG. WAVE HEIGHT	MODEL	0.3-25m	0.3m	0.3m	10Km	3	3
17. WAVE LENGTH	MODEL	0.3-1000m	10%	10%	10Km	3	3
18. WAVE DIRECTION	MODEL	0-360°	10%	10%	10Km	3	3
19. AIR TEMPERATURE	MODEL	-30° to 40°C	1°C	1.5°C	10Km	12	3
20. WATER TEMP. (SURFACE)	MODEL	-2° to 30°C	0.25°C	1°C	10Km	24	6
21. WEATHER FRONTS	MODEL	-	-	-	10Km	12	6
22. PRECIPITATION	MODEL	-	-	-	10Km	12	6
23. SUSPENDED SEDIMENT	MODEL				10Km	12	6

study: (1) target characterization analysis relative to spatial resolution requirements; and (2) orbital analysis to determine spatial and temporal coverage.

The results of the former (analysis 1 above) which are illustrated in Figures III-3 A/B indicate that a large percentage of the operational (intentional) and accidental discharges of oil reach a width of 70 to 100 meters in less than two hours from the spill incident. The implication of this finding is that a relaxation of the 10 to 15 meter resolution requirements for oil spill mapping will be in order; this possibility is explored in more detail in the System Options portion of this report.

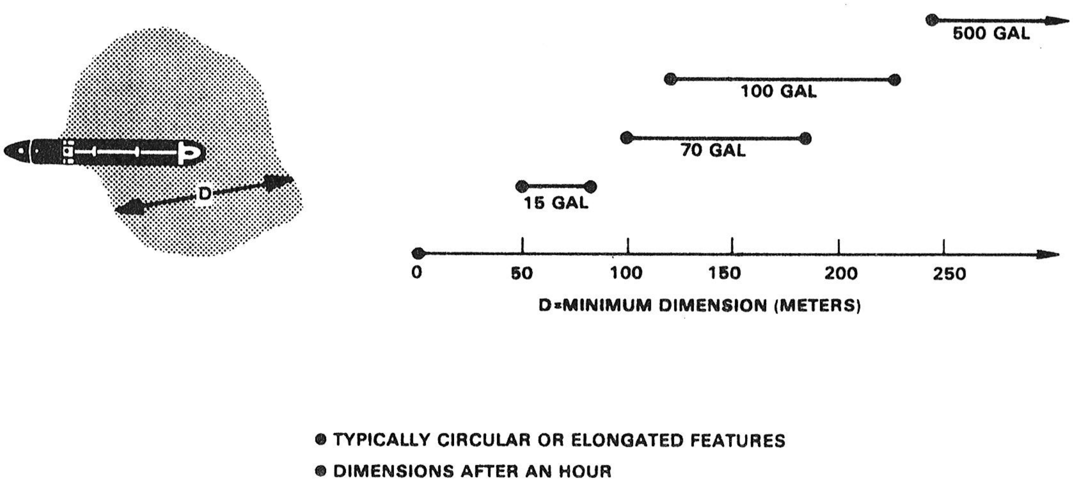


Figure III-3A. Spatial Characteristics of Accidental Oil Spills

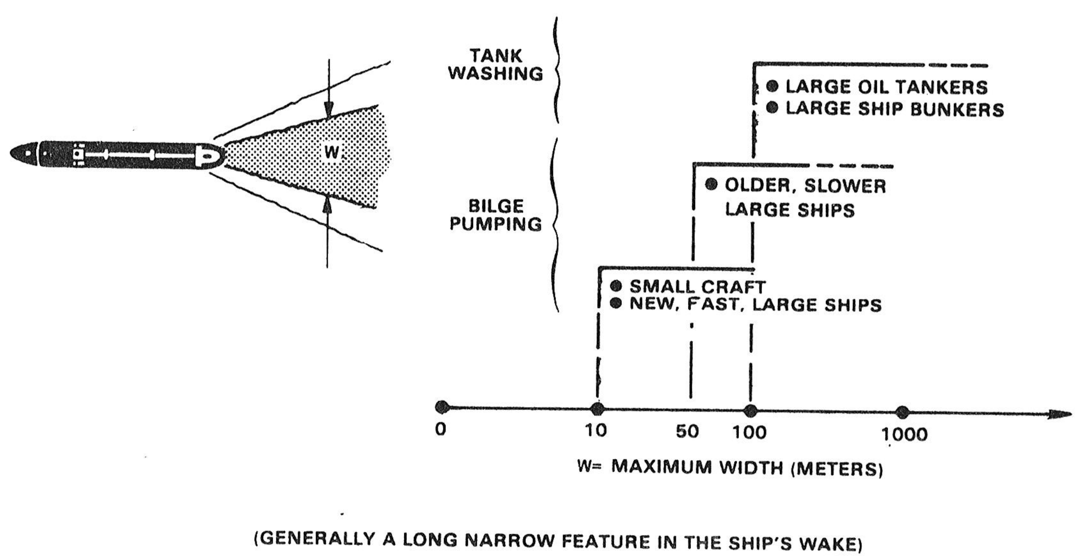


Figure III-3b. Spatial Characteristics of Intentional Oil Spills (Operational Discharge)

The second analysis mentioned above employed a computer program specially designed for this study, which permitted a precise computation of the monitoring coverage over the 200-mile economic coastal zone, with various orbits and swath-widths. The comprehensive results of this orbital analysis are documented in the Technical Volume of the final report.

GENERAL CONCLUSIONS ON USER REQUIREMENTS

1. The major categories of measurement requirements concern: Oil and waste pollutant location and spatial distribution (surface and sub-surface), pollutant classification, waste pollutant concentration, pollution source identification and inputs to pollutant trajectory models.

   The analysis recognized that requirements such as the determination of sub-surface pollutant spatial distribution are not directly measureable with remote sensing. The implementation approach (Ref. Section VII) acknowledges such limitations and reflects them in subsequent systems analyses.

2. Measurement requirements as stated are flexible within the limits of their capability to meet the user knowledge objectives.

3. The area of interest is the 200-mile coastal zone bounding the East and West Coast, Gulf of Mexico, Gulf of Alaska and Hawaiian Archipelago. This is consistent with the "Economic Zone" defined in the 1959 International Convention and recent Federal statutes.

SECTION IV

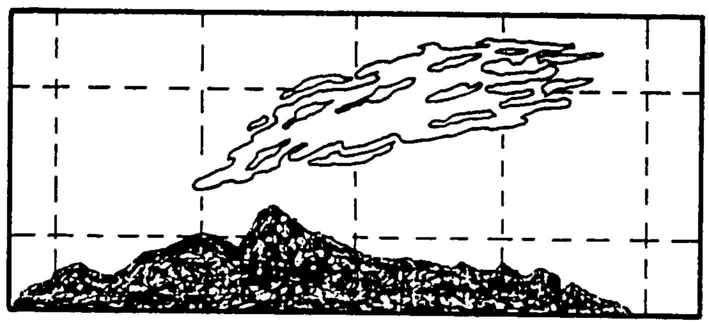
ASSESSMENT OF MEASUREMENT TECHNOLOGY FOR OIL SPILLS AND WASTES POLLUTION

An assessment of the current and projected space technology was made relative to meeting the user requirements as stated in Section III. This was performed in concert with the assessment objectives of the study (Reference Section I), namely:

- Present state of knowledge of the detection of oil spills and ocean pollution;
- Adequacy of present technology in meeting the measurement requirements;
- The required advances in technology to meet these requirements.

A summary of the results of this assessment for key measurement requirements is shown in Table IV-1, including the key system characteristics and implications. Following is a brief discussion of the technology aspects for each of these measurements.

<u>OIL SPILL DETECTION & MAPPING</u>



One of the primary surface effects exploited in the detection and mapping of oil spills is the suppression of wind-driven capillary waves due to the oil film. The contrast in radar reflectivity between the oil film and the surrounding water has been measured through aircraft tests conducted by the Canadian Centre for Remote Sensing (CCRS). Images of oil slicks have been obtained from airborne real-aperture radars by the U.S. Coast Guard (AOSS Oil Surveillance Detection Radar) and the Sweedish Coast Guard (SLAR System). Experimental tests by NASA and ERIM have shown the potential utility of synthetic aperture radar mounted on aircraft.

Still unresolved is the problem that other ocean dynamic features such as wind-slicks cause a similar suppression of the capillaries and thus create ambiguities in discriminating true oil spills from other ocean surface phenomena. Examples of these ambiguities have been

Table IV-1. Space Technology Capability Summary

Measurement Type	(A) Key User Requirements	(B) State of Knowledge Of Detection	(C) Sensing Technology Assessment	(D) Needed Technology Advances	(E) Key System Characteristics/ Capabilities	(F) Overall Assessment
1. Oil spill areal distribution	• 10-15 m resolution, • Two measurements/ day to 200 m. mi.	• Effect of oil on microwave backscatter is understood; • Need knowledge of ocean dynamics (1) to resolve ambiguities (2) identify optical signatures	Basic radar & optical sensors/techniques available; Need to tailor to pollution mission	• Wide-swath, high resolution, pointable radar (SAR) and optical imager • Info extraction to resolve ambiguities	• 10-15 m resolution is not cost effective 60-100 m adequate to detect most spills	• Space sensing requires research in information extraction • High temporal frequency requires complementary use of spacecraft & aircraft
2. Oil spill thickness required for quantification	• 0.1 μm-2mm thickness range • 10-15 m resolution	Physics of thickness measurements in microwave are known	Passive microwave radiometer techniques available for gross resolutions & thickness above 1mm.	• Large microwave antennas • Optical technique development for thin DK films (e.g., laser fluorescence	• Large space platforms for antennas & laser optics	• Oil thickness measurement not feasible from space in foreseeable future • Can measure from aircraft
3. Oil spill classification	• Oil type - Crude - Refined - Characteristics	Oil fluorescence phenomenon is well understood	Laser fluorosensor technology is in experimental stage	• Advanced laser fluorosensors for space	• Large space platforms • Atmospheric attenuation and distance would necessitate large optics from space	• Oil classification not feasible from space in foreseeable future • Can measure from aircraft
4. Waste pollutant spatial distribution	> 30 meter resolution	Optical radiance contrast relationships are developed, need expansion for space observations	Optical sensor technology available for gross resolution (e.g., 1 Km).	Need wide swath, high resolution sensor development	• Handling of high data rates	• Can measure from space; need additional development
5. Waste pollutant concentration (Dilution)	> 30 meter resolution; Detection of small traces of hazardous substances	Statistical data handling techniques have been successful in measuring concentrations	Optical sensor are available for gross resolution	Need experimental data under various atmospheric & surface conditions, from space sensors	• High sensor detectivity • Multi-channel instrument	• Promising techniques; require additional space-based data
6. Waste pollutant classification	• Differentiate: - Acids - Sludge - Bio-digested waste	Difference in reflectance spectral characteristics is known	Advanced optical sensor (POLA) would be suitable for gross classification	• Multispectral linear arrays • Wide-swath	High data rates	Gross classification possible with multi-spectral linear array
7. Wind speed and direction	• 10 Km resolution cells • Speed measurements every 3 hours	Relationships between speed/direction & normalized radar cross-section is known	Scatterometer has demonstrated capability	• Elimination of wind-direction ambiguity • Filling of central gap area in swath	Satellite must accommodate multiple antennas	Can measure with scatterometer
8. Ocean current speed and direction	• 10 Km grid • Measurements every 6 hours	• Sea topography vs. currents is understood • IR mapping of boundaries is a mature science	• Microwave & laser altimetry sufficiently accurate, but • Cannot provide 10 Km, once/6 Hr. coverage	• Multi-beam altimetry at very high incidence angles	• Altimeter can only measure at points along orbit track: 10 Km grid is difficult to attain	• Not feasible would require a fleet of satellites to provide coverage • Can measure from aircraft
9. Wave height (H 1/3)	• 10 Km grid • Measurements every 3 Hrs.	• Correlation between altimeter pulse rise-time and wave height is known	• Altimeter sensor technology is mature	• Techniques for combining altimetry data with sea-state model outputs • Explore new techniques using SAR/ scatterometer	• Altimeter can only measure at points along orbit track: 10 Km grid is difficult to attain	• Not feasible would require a fleet of satellites to provide coverage • Can measure from aircraft
10. Wave direction and length	• Measurements every 3 Hrs. • Wave length range: 0.3 meter to 1 Km	• SAR image data interpretation techniques are available	• Basic radar technology is at hand; need to tailor to pollution mission • Spatial resolution is the lower limit of measurement capability	• Need different techniques for low-range of wave-lengths	• Many satellites needed for once/3 Hrs coverage • High data rates, high power, for fine resolution	• SAR can only measure waves above SAR resolution limit

observed in SEASAT-SAR imagery over the Santa Barbara channel, where natural oil seepage forms oil slicks of resolvable dimensions. These ambiguities can also be observed in SAR imagery from aircraft, particularly when a high ratio of the area of the surrounding water to the oil slick is present. It is our assessment that research testing relative to this phenomenon can determine whether: (a) differences in the signal-level, dynamic characteristics, or geometric pattern between oil spills and oil slicks can permit adequate discrimination, or (b) the characteristics and random occurrence of these surface phenomena are such that an adequate frequency of false alarms is not feasible.

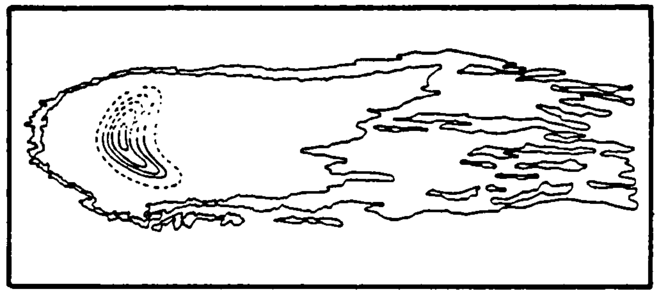
Important elements of that research are: (1) gaining better understanding of the ocean dynamic features; (2) performance of tests using controlled spills or taking advantage of known spills, under various wind and sea-state conditions. Testing is required both from aircraft and space platforms, to determine the effect of altitude/synopticity on the detectivity of oil slicks.

Detection and mapping of oil slicks using optical sensors has the obvious disadvantage of being obscured by cloud cover. It has, however, the potential of being used operationally to corroborate microwave data when the cloud conditions will permit such measurements. Three techniques that show promise in this are are (1) measurement of temperature differences as sensed in the thermal infrared spectrum; (2) detecting the difference in reflectance in portions of the visible spectrum; (3) detecting the difference in visible specular reflectivity due, again, to the suppression of the capillaries by oil films. The latter technique has the same ambiguity limitations as that using the radar. Recent imagery of the recent Bay of Campeche spill using LANDSAT and Tiros-N imagery has demonstrated the utility of optical techniques in monitoring the progress of large known spills and thus providing a synoptic map of the entire oil spill.

Useful advancements in projected technology for oil spills and ocean pollution monitoring include the development of wide-swath pointable sensors. Operational analyses showed that a 400 Km. swath capable of being placed anywhere within a 600 Km access swath would greatly enhance the capability of covering the 200 n. mi. coastal zone.

OIL SPILL QUANTITY

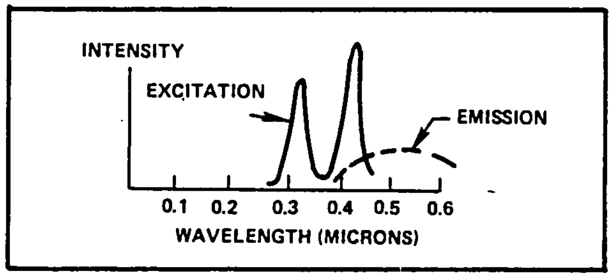
Two techniques for measuring oil thickness: passive microwave radiometry and laser fluorescence are complementary since the former is useful in thick oil films (above approximately 0.1 mm) and the latter is useful in thin films.



Using passive microwave radiometry, the region of the oil slick exhibits a higher brightness temperature than the surrounding water; this increase is dependent on oil thickness. NRL has developed a multi-frequency technique to eliminate ambiguities in the brightness versus thickness function. The state-of-the-art in passive microwave radiometers - at least for the next decade - will not permit the types of resolution required for this measurement, due to the multi-hundred-meter antennas required to attain 15 or over 30 meter resolution. The technique is suitable, however, for measurement from aircraft. Future projections for multi-mission space platforms may permit the incorporation of large radiometer antennas for this and other applications.

A laser fluorosensor can measure oil thickness by detecting the difference in amplitude of the emitted fluorescence signal corresponding with the difference in oil film thicknesses. Due to the attenuation effects of the atmosphere in the UV fluorescence region and the relatively long range from an orbiting satellite, the optics required for this application are very large. As in the case of oil thickness measurements with microwave radiometers, the application may be feasible only when large space platforms are in operation. Both techniques are considered vital to successful quantification of oil spills from aircraft based sensors and require continued development.

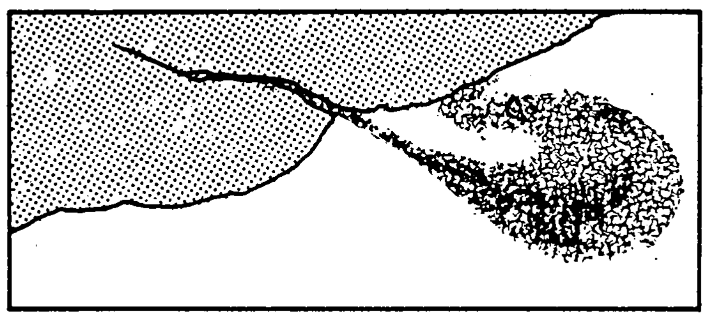
OIL SPILL CLASSIFICATION



Laser fluorescence has been successfully tested from low altitudes to discriminate oil from water and to classify among various oil types. Specifically, tests have been conducted to measure fluorescence characteristics at different wavelengths. For instance, by measuring the ratio of fluorescent emissions at 0.433 and 0.533 micrometers, gross classification of oils has been accomplished. However, further research is needed here, including field testing under various environmental conditions.

The same limitations in optics size discussed for the oil thickness measurement applies here. Therefore this technique is suitable for aircraft-based sensing, until large space platforms become operational.

WASTE POLLUTANT DETECTION & MAPPING



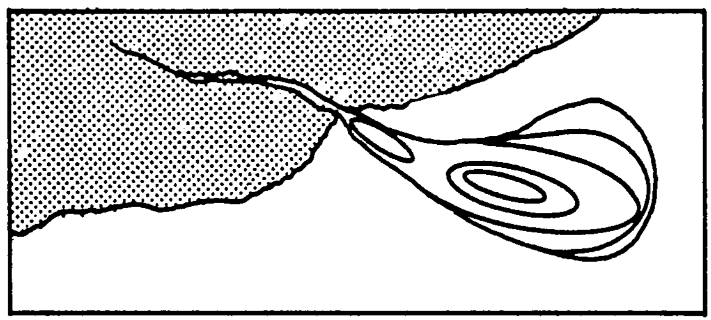
Reflectance contrast between waste pollutants and the surrounding water has been used as a means of detecting waste plumes. The contrast varies with pollutant material, concentration, observation sun-angle, and atmospheric effects. Ambiguities arise during the interpretation of spectral radiance data, since differentiation between waste pollution and the effect of clouds or sediment is sometimes difficult. Techniques to eliminate these ambiguities have been developed. They employ various spectral bands to produce distincitive statistical plots of radiance vs. wavelength which are indicative of waste plumes.

Infrared sensing technology, highly advanced for the measurement of sea-surface temperatures, can be employed for the detection of sewage plumes from sources such as ocean outfalls.

These sources, which are common in many coastal municipalities in the West Coast produce a persistent surface temperature rise due to convection, in those regions where sewage difussion takes place. Temperature mapping in the atmospheric spectral window of 8-12.6 micrometers is suitable for this application.

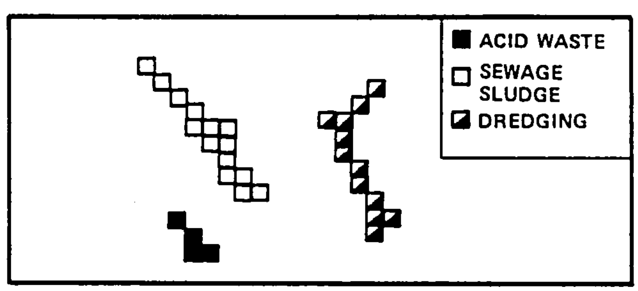
Coverage of the 200 n. mi. coastal zone with high resolution and sensitivity requires development of a wide-swath multispectral sensor. Use of push-broom multi-spectral linear arrays would provide the required capability for this application.

WASTE POLLUTANT CONCENTRATION



The state-of-the-art for this measurement is characterized by multi-spectral sensing in the visible spectrum, coupled with Multiple Regression Analysis (MRA) for data interpretation. In MRA, the spectral band having the highest correlation with concentration is determined. Statistical analysis (i.e. step-wise regression analysis is applied, using other significant channels, to determine the relationship that will produce the highest accuracy of concentration measurement. NASA-Langley has employed this technique successfully, relative to airborne data obtained in development testing. Data from space platforms is required to adapt the technique for space monitoring applications.

WASTE POLLUTANT CLASSIFICATION



The spectral radiance of polluted water varies with the type of pollutant. Atmospheric effects can mask the identifying signatures of the various pollutants such as acid waste, sewage sludge and bio-digested wastes. Information extraction techniques have been developed by NASA Langley to minimize the effects of variables such as atmospherics and sun angle. In-scene background elimination is accomplished by finding the ratios of waste plume radiances to unpolluted water radiance, at various wavelengths in the visible spectrum. The characteristic relationship between these ratios and wavelength are indicative of the type of pollutant. As in the case of pollutant concentration measurements, the multi-spectral data acquisition and information extraction techniques require further development using space data, to adapt them to space observation.

WIND SPEED AND DIRECTION

Wind speed and direction measurements have been successfully demonstrated from low earth-orbit satellites such as SEASAT. The scatterometer emits pulses at a uniform rate, and the electromagnetic waves are scattered and reflected from the illuminated portion of the ocean surface. A small portion of the scattered signal is detected by the scatterometer receiver, and permits the computation of the Normalized Radar Cross-Section (NRCS). The technique employed to determine wind direction is based on the fact that the NCRS is greatest when observing the scene in the up-wind direction, and lowest in the cross-wind direction. Two measurements per resolution element at different headings are usually sufficient to determine wind direction.

Scatterometers flown to-date have had wind direction ambiguities (aliases), which sometimes can be resolved through the use of historical wind data. Development of a scatterometer that eliminates these ambiguities will be on important advancement for this application. The use of more than four antenna beams at different headings has been proposed as a solution to this problem, and will be verified in future space systems.

All scatterometers built to-date produce measurements within a swath containing a gap region centered about nadir. Methods of filling that gap need to be developed for this application.

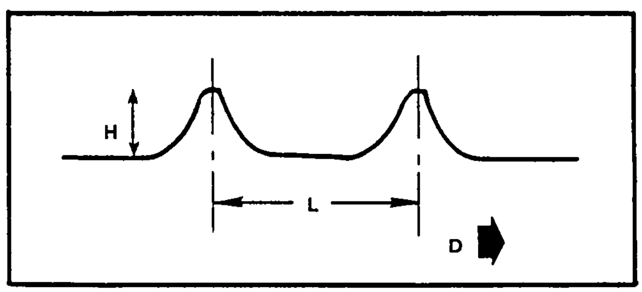
OCEAN CURRENT SPEED AND DIRECTION

Mapping of ocean current boundaries has been accomplished successfully from space, particularly with respect to large currents such as the Gulf Stream, where a significant thermal and color differential is produced by the stream. However, the requirement for this application is quantitative: to map the speed and direction of the currents in this coastal zone with a resolution of 10 km. To date the only technique that is applicable to this need is the inference of current through mapping of the sea-surface contour. This method is based on the physical rise in the sea surface when crossing an ocean current in the Gulf Stream this averages about one meter). The state-of-the-art of microwave or laser space altimeters is sufficiently advanced to permit the measurement of sea-surface topography with the required precision. The determination of the precise ephemerides necessary to provide the altimeter reference is also within the state-of-the-art.

The requirement for a 10 km grid every six hours presents a problem since state-of-the-art altimeters can perform measurements only at nadir, at discrete points along the orbit track. A satellite at low earth orbit, or instance, could provide daily readings every 2800 km across the equator. Therefore, increasing the number of satellites is not a practical solution. New techniques for ocean current measurements from satellites need to be developed; these need not be limited to altimetry, and should emphasize those methods that produce ocean current measurements across a wide swath.

WAVE HEIGHT

Wave height has been successfully measured through the use of altimetry. Precise measurements of the rise time for the return radar pulse is interpreted in terms of significant wave height. The same limitations in grid-size resolution discussed for current speed/direction measurement apply here.



A potential area of technological development for this application is the use of synthetic aperture radar data and/or scatterometer data in conjunction with new information extraction techniques. NASA Wallops has a promising concept for a multiple beam altimeter which produces altimetry data within a narrow swath (~ 50 km). The expansion of similar concepts to produce swaths in the order of 400 km should be explored.

Another possible solution is to combine sparse altimeter data with wave height models. Sophisitcated models such as the Fleet Numerical Weather Model (FNWM) produces directional wave-spectra with 300 km grid. Developments are underway that would permit predictions within smaller grids. The enhancement of these models with spacecraft data such as altimetry (for wave height calibration) and scatterometry (for wind speed input to the model) needs to be explored.

WAVE DIRECTION AND LENGTH

Radar images of the ocean surface reveal the wave patterns and from these we can measure wave-length and infer direction.

The requirement for measurements every three hours would necessitate multiple satellites even with a wide-swath pointable SAR.

A similar solution to that discussed above concerning wave height is possible here. It consists of combining SAR data with ocean wave model predictions, to produce the required frequency of wave direction and length measurement.

Another limitation of SAR data for this application is the fact that the SAR image would only show waves that are equal to or longer than the SAR resolution. Thus, using a 30 meter resolution SAR, the wave-length region from 0.3 meter to 30 meters would not be measurable. New technological developments are needed in this area. For instance, a scanned (pencil-beam) SAR could measure ocean wave-lengths across discrete lines instead of mapping the entire area, thus permitting high resolution with modest data reates and radar power.

ANCILLARY MEASUREMENTS FOR MODEL INPUTS

The remainder of the measurement requirements deal with parameters that are of secondary importance in the fate and impact models. Means for obtaining all these measurements are indicated below:

- Water and air temperatures, - routinely measured through meteorological satellites and weather fronts
- Precipitation - measured through dual frequency passive microwave radiometer (37 & 21 GHz)
- Suspended sediment - measured through multi-spectral colorimetry.
- ICE coverage - measured with Synthetic Aperture Radar

SECTION V

OCEAN POLLUTION MISSIONS

A formal structure of the ocean pollution measurement missions and goals was developed through (1) personal contacts with system operators, users, designers, researchers, etc., (2) a thorough review of documentation -- technical, legislative, and programmatic, and (3) first-hand experience as a member of the remote sensing applications community. The objectives of this analysis were: (1) to gain a better understanding of the temporal and spatial requirement for performing the measurements and handling the data; (2) identifying the various elements comprising the system, and their roles. Table V-I defines the major missions and submissions.

Table V-1. Major Missions and Submissions

SURVEILLANCE & MONITORING	FUNCTIONS INCLUDED
1. DETECTION	1. SURVEILLANCE & DETECTION OR UN-REPORTED OIL SPILLS OR WASTE DUMPS, WHETHER ACCIDENTAL OR DELIBERATE
2. MAPPING & TRACKING	2. IMAGING OF THE AREAL EXTENT & BOUNDARIES OF THE POLLUTION; DETERMINING THE LOCATION; TRACKING THE CHANGE IN AREA, SHAPE & LOCATION VS. TIME.
3. QUANTIFICATION	3. MEASURING THE OIL VOLUME THROUGH AREAL EXTENT & THICKNESS MAPPING; INFERRING WASTE POLLUTANT QUANTITY BY AREAL EXTENT & SURFACE CONCENTRATION.
4. POLLUTANT CLASSIFICATION	4. TYPE OF OIL: CRUDE CLASS, REFINED OIL CLASS, AGED VS. NEW SPILL; TYPE OF WASTE: ACID CLASS, SLUDGE, BIO-DIGESTED WASTE.
5. POLLUTER IDENTIFICATION	5. DESIGNATION & LOCATION OF SHIP, OFF-SHORE FACILITY OR COASTAL POINT SOURCE.
6. SYNOPTIC VS. COASTAL POLLUTION MONITORING & BUILDING OF DATA BASE	6. ASSESSMENT OF AMOUNT DISTRIBUTION & TYPE OF VARIOUS POLLUTANTS WITHIN THE U.S. 200 N. MI. COASTAL ZONE, DURING LONG TIME INTERVALS

Table V-1. Major Missions and Submissions (Cont'd)

SURVEILLANCE & MONITORING	FUNCTIONS INCLUDED
7. SYNOPTIC GLOBAL POLLUTION MONITORING & BUILDING OF DATA BASE (IMPLEMENTATION OF THIS MISSION IS NOT ADDRESSED IN THE STUDY)	7. SAME AS (6) ABOVE FOR ALL OCEAN AREAS, AS A MEASURE OF GLOBAL POLLUTION.
MODELING	
8. FATE MODELING	8. PREDICTION OF OIL OR WASTE POLLUTION TRAJECTORY AND SPREADING CHARACTERISTICS; APPLIES TO ACTUAL SPILLS/DUMPS THREATENING COASTAL AREAS, OR POTENTIAL POLLUTION (E.G. FROM AN EXISTING & PROPOSED OFF-SHORE OIL WELL)
9. IMPACT/RISK MODELING	9. ASSESSING THE POTENTIAL DETRIMENTAL EFFECTS TO SENSITIVE COASTAL BIOLOGICAL OR RECREATIONAL RESOURCES; DETERMINING THE PROBABILITY OF OCCURRENCE BASED ON OCEAN & METEOROLOGICAL STATISTICAL DATA.
10. SYNOPTIC OCEANOGRAPHIC/ METEOROLOGICAL/ECOLOGICAL MONITORING & BUILDING OF DATA BASE	10. BUILD-UP OF A DATA BASE OF MET./ ECOLOGICAL STATISTICS USEFUL IN FATE AND IMPACT MODELING

Each sub-mission covers certain discrete performance objectives in support of one or more users. The sub-missions are mutually exclusive of each other to preclude overlap but may be supportive of each other. For example, Mapping and Tracking has the two-dimensional (areal) extent of the pollutant as a principal output, whereas Quantification adds the third dimension -- thickness -- in further characterizing the pollutant in terms of quantity.

MISSION SCENARIOS

Analyses were performed to determine role of space-based monitoring within the broader perspective of mission activities by the responsible agencies, as defined in ten sub-missions shown above. The logic employed in the analysis requires an initial assessment of the pollution that is detected (in submission no. 1) or reported, to decide whether or not to respond and to decide the nature of that response. If the decision is to act upon the information obtained, the resulting activity falls into two non-excusive categories: (a) measurement of parameter to characterize the pollutant or polluter, covered by submissions no. 2, 3, 4, and 5; (b) projection of the pollution trajectory (fate) or impact on sensitive coastal resources, performed through computer models (submissions 8 and 9) utilizing inputs from real-time response measurements and several continuously updated data bases (submissions no. 6, 7, and 10).

This mission definition and response logic led to the postulation of three discrete scenarios:

- SCENARIO I - Pollution surveillance and monitoring (encompasses sub-mission no. 1)
- SCENARIO II - Pollution and polluter measurements (encompasses sub-mission no. 2 through 5)
- SCENARIO III - Fate and impact projection (encompasses sub-missions no. 6 through 10)

Figure V-1 identifies the types of outputs of the analysis of missions and scenarios, based on an examination of the measurement requirements to support the missions within each scenario. These outputs provided the framework for the definition of candidate sensors, platforms and data handling systems, as discussed in the next section.

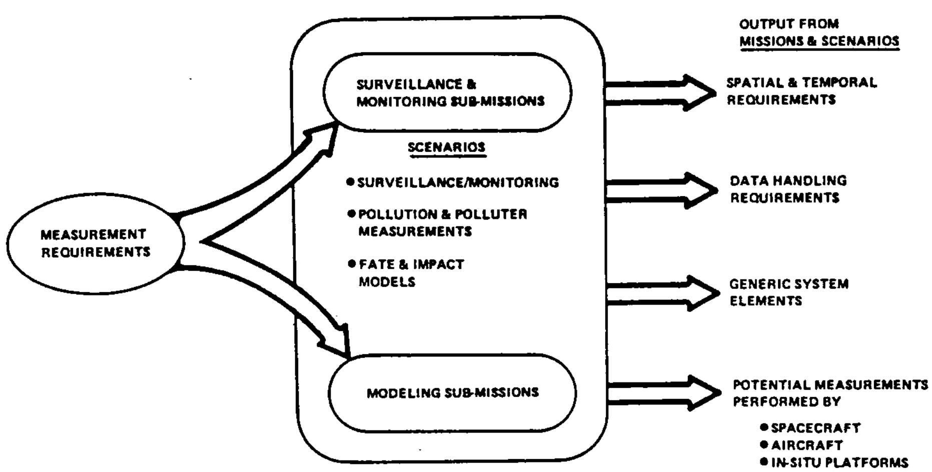


Figure V-1. Measurement Requirements, Missions and Scenarios

SECTION VI
CANDIDATE SENSORS, PLATFORMS, AND DATA PROCESSING SYSTEMS

SENSORS

A set of over 60 sensors and sensing techniques were analyzed against the measurement requirements defined in Section III. The objective of this analysis was to determine the suitability of these instruments or modified versions thereof, as space sensors in meeting the measurement requirements. The categories covered by this survey included:

- Existing space sensors in experimental or operational spacecraft, or available for potential use in future missions.
- Space sensors currently in the developmental stage.
- Aircraft sensors or sensing techniques which potentially could be modified and adapted to remote sensing from space.

The methodology for the assessment of candidates and selection of the recommended sensors is depicted in Figure VI-1.

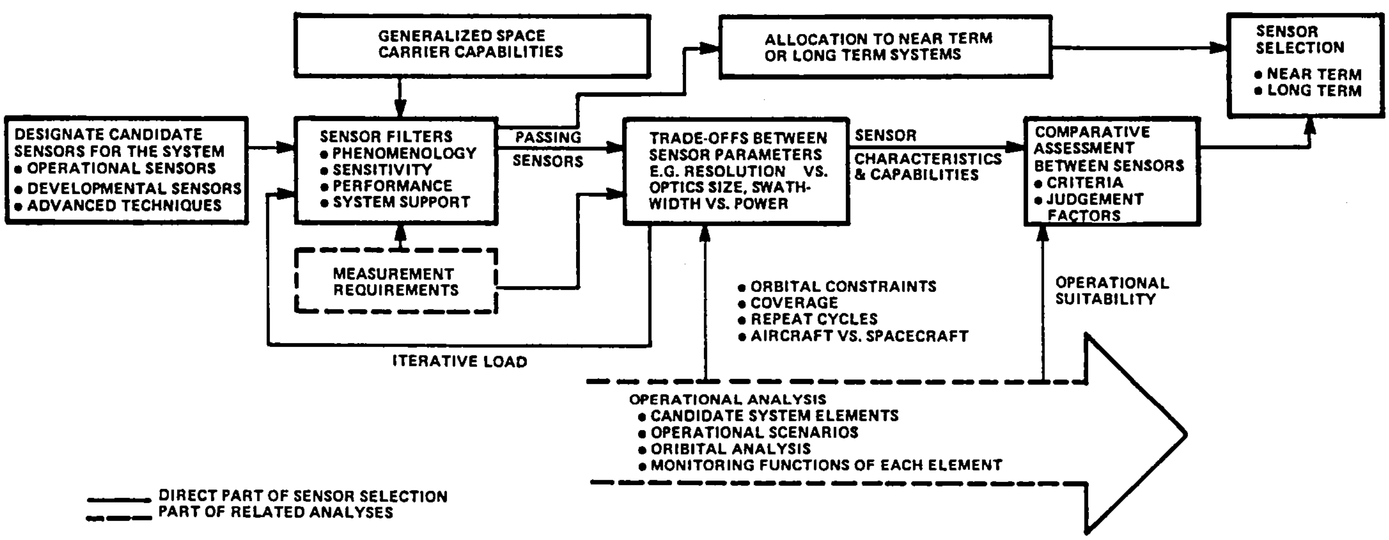


Figure VI-1. Methodology for Sensor Selection

Basically, the process surveyed the state of the art to determine those sensors and techniques that are viable within the various time frames in the study. Each sensor was put through a set of "filters" which determined its suitability relative to the following criteria:

Filter (A) Development and Operational Status Is the relationship (signature) between the observable and the required measurement sufficiently understood or developed? Is there sufficient operational experience with the measurement technique?

↓

Filter (B) Detectivity/Sensitivity Can adequate signal-to-noise ratios be attained? Is there sufficient sensitivity, considering the range and atmospheric effects from orbital attitudes?

↓

Filter (C) Sensor - Performance Suitability Can the sensor meet the user requirements and corresponding measurement specifications for oil spill and ocean pollution monitoring? Primary parameters are accuracy, resolution, coverage, and range?

↓

Filter (D) Compatibility with Spacecraft Are the required size, weight, power and other support requirements of the sensor compatible with near-term spacecraft platforms?

Those instruments which passed the filters were subjected to parametric trade-offs to determine the desired performance and physical characteristics, or to establish parametric relationships (e.g. between resolution and power requirements in radar imagers) that would be useful in subsequent trade-offs between monitoring system options. Finally, in cases where several alternative sensors could perform the required measurement, a comparative assessment was made to determine the sensor that best fit the requirements of the mission.

The methodology made provisions for the selection of sensors, within the context of concurrent operational analyses of candidate spacecraft, operational scenarios, and orbital constraints. This feature of the analysis provided assurance that the sensor selections fit within the larger framework of realistic operational constraints.

The candidate sensors that were selected for each of the measurement requirements are shown on Figure VI-2.

MEASUREMENT	SENSORS FOR 1984-87 SYSTEM	SENSORS FOR 1988-91 SYSTEM	SENSORS FOR 1992-2000 SYSTEM
MARINE WASTE DUMP AREAL DISTRIBUTION CONCENTRATION AND CLASSIFICATION (5, 7, 8)*	• POINTABLE OPTICAL LINEAR ARRAY • COASTAL ZONE COLOR SCANNER/AVHRR • THEMATIC MAPPER	• POINTABLE OPTICAL LINEAR ARRAY • COLORIMETER (ADVANCED CZCS) • MULTI-SPECTRAL LINEAR ARRAY (OERS)	• HIGH RESOLUTION OPTICAL/IR GEO-SYNCHRONOUS SENSOR
MARINE WASTE DUMP COORDINATES (6)	• GLOBAL POSITIONING SYSTEM	• GLOBAL POSITIONING SYSTEM • PRECISION ATTITUDE DETERMINATION SYSTEM	• GLOBAL SERVICES SYSTEM FOR POSITION-ING AND POINTING
POLLUTION SOURCE (9)	• SYNTHETIC APERTURE RADAR • POINTABLE OPTICAL LINEAR ARRAY (TO AID HIGH RESOLUTION OBSER-VATIONS BY AIRBORNE INSTRUMENTS)	• SAME AS PREVIOUS TIME FRAME	• HIGH RESOLUTION SAR • SYNTHETIC APERTURE PASSIVE MICRO-WAVE RADIOMETER
WIND DIRECTION (11)	• MICROWAVE SCATTEROMETER • PASSIVE M-WAVE RADIOMETER	• MICROWAVE SCATTEROMETER • PASSIVE M-WAVE RADIOMETER	• MICROWAVE SCATTEROMETER • WIND LIDAR • PASSIVE M-WAVE RADIOMETER
WIND SPEED (10)	• MICROWAVE SCATTEROMETER	• MICROWAVE SCATTEROMETER	• MICROWAVE SCATTEROMETER • WIND LIDAR
OCEAN CURRENT SPEED & DIRECTION (12, 13)	• MICROWAVE ALTIMETER • COASTAL ZONE COLOR SCANNER	• MICROWAVE ALTIMETER • COLORIMETER	• WIDE-SWATH ALTIMETER • ADVANCED OCEAN CURRENT SENSOR
ICE COVER AREAL EXTENT (14)	• SYNTHETIC APERTURE RADAR • PASSIVE M-WAVE RADIOMETER	• SYNTHETIC APERTURE RADAR • PASSIVE M-WAVE RADIOMETER	• SYNTHETIC APERTURE RADAR • SYNTHETIC APERTURE PASSIVE M-WAVE RADIOMETER
ICE THICKNESS (15)	• NO SUITABLE SENSOR AVAILABLE	--	--
SIGNIFICANT WAVE HEIGHT (16)	• MICROWAVE ALTIMETER	• MICROWAVE ALTIMETER	• WIDE-SWATH ALTIMETER • SWEPT FREQUENCY M-WAVE RADIOMETER
WAVE LENGTH (17)	• SYNTHETIC APERTURE RADAR	• SYNTHETIC APERTURE RADAR	• SYNTHETIC APERTURE RADAR
WAVE DIRECTION (18)	• SYNTHETIC APERTURE RADAR	• SYNTHETIC APERTURE RADAR	• SYNTHETIC APERTURE RADAR
AIR TEMP (NEAR SURFACE) (19)	• VERT. TEMP. PROFILE RADIOMETER	• VERT. TEMP. PROFILE RADIOMETER	• ADVANCED VTPR
WATER TEMPERATURE (20)	• PASSIVE M-WAVE RADIOMETER	• PASSIVE M-WAVE RADIOMETER	• HIGH RESOLUTION PASSIVE M-WAVE RADIOMETER
WEATHER FRONTS (21)			
PRECIPITATION (22)	• PASSIVE M-WAVE RADIOMETER	• PASSIVE M-WAVE RADIOMETER	• HIGH RESOLUTION PASSIVE M-WAVE RADIOMETER
SUSPENDED SEDIMENT (23)	• COASTAL ZONE COLOR SCANNER/ADV. VERY HIGH RESOLUTION RADIOMETER	• COLORIMETER (ADVANCED CZCS)	• COLORIMETER (ADVANCED CZCS)
OIL SPILL DETECTION & AREAL DISTRIBUTION (1)	• SYNTHETIC APERTURE RADAR RADAR • THEMATIC MAPPER	• SYNTHETIC APERTURE RADAR • POINTABLE OPTICAL LINEAR ARRAY • MULTISPECTRAL LINEAR ARRAY	• GEOSYNCHRONOUS SAR • ADVANCED MULTI-SPECTRAL LINEAR ARRAY • HIGH RESOLUTION PASSIVE M-WAVE RAD
OIL SPILL COORDINATES (2)	• SAME AS #1, AIDED BY GPS	• SAME AS ABOVE, AIDED BY GPS & PRECISION SENSOR POINTING SYSTEM	• GEOSYNCHRONOUS SAR AIDED BY GLOBAL SERVICES SYSTEM POS & POINTING
OIL SPILL THICKNESS (3)	• PASSIVE MICROWAVE RADIOMETER (LARGE SPILLS ONLY)	• PASSIVE MICROWAVE RADIOMETER (LARGE SPILLS ONLY)	• LASER STIMULATED FLUORESCENCE (RAMAN SCATTEROMETER)
OIL CLASSIFICATION (4)	• NO AVAILABLE SENSOR	• NO AVAILABLE SENSOR (WILL USE AIRBORNE LASER FLUOROSENSOR	• HIGH RESOLUTION PASSIVE M-WAVE RAD. • LASER STIMULATED FLUOROSENSOR

*NUMBERS IN PARENTHESES REFER TO PARAMETER NUMBERS IN MEASUREMENT REQUIREMENT (REF. TABLE III-2)

Figure VI-2. Selected Space Sensors vs. Time Frame

The sensors are further correlated with each of the three time-frames. These selections are further refined during the analysis of system options in Section VII. Following is a brief description of each of the key space sensors selected.

Synthetic Aperture Radar (SAR).

The SAR was selected as the primary sensor for oil spill detection and areal extent monitoring from space due to its day-night, all-weather capability. While both passive and active microwave sensors were considered for this measurement, the spatial resolution requirement eliminated the use of passive microwave sensor. Other measurements that were found feasible for the SAR were ocean wave-length and ice coverage areal extent. The SAR performance parameters required for ocean pollution measurement were defined as:

- 30-100 meter resolution
- 390 km swath width, pointable
- 600 km access ground range
- Operability under adverse weather conditions

A block diagram of a synthetic aperture radar is illustrated in Figure VI-3. The transmitter generates high power pulsed signals which are radiated by a broadside oriented antenna, reflected by a scene target, and phase coherently detected. The pulse repetition frequency is sufficiently high so that the radar platform traverses a distance less than one-half the antenna diameter between pulses.

To meet the wide swath requirement, the antenna aperture must have either of two shapes while fulfilling a minimum area constraint imposed by ambiguity limits. In one configuration, a fan beam can be radiated from a long rectangular aperture with the wide beam pattern in the elevation plane to illuminate the swath. In the other configuration, a pencil beam is radiated and the beam is scanned to cover the swath as illustrated in Figure VI-4.

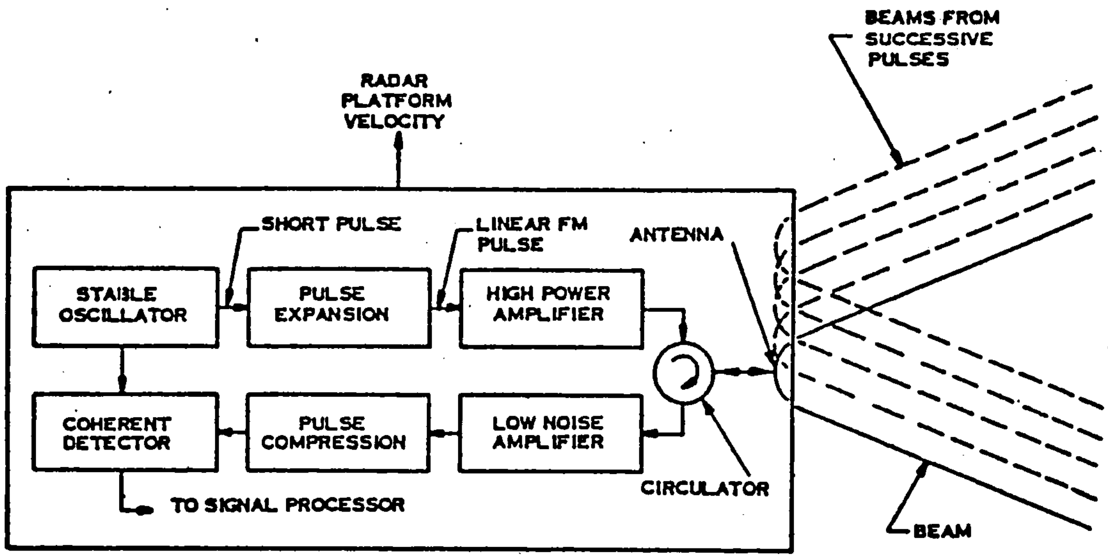


Figure VI-3. SAR Block Diagram

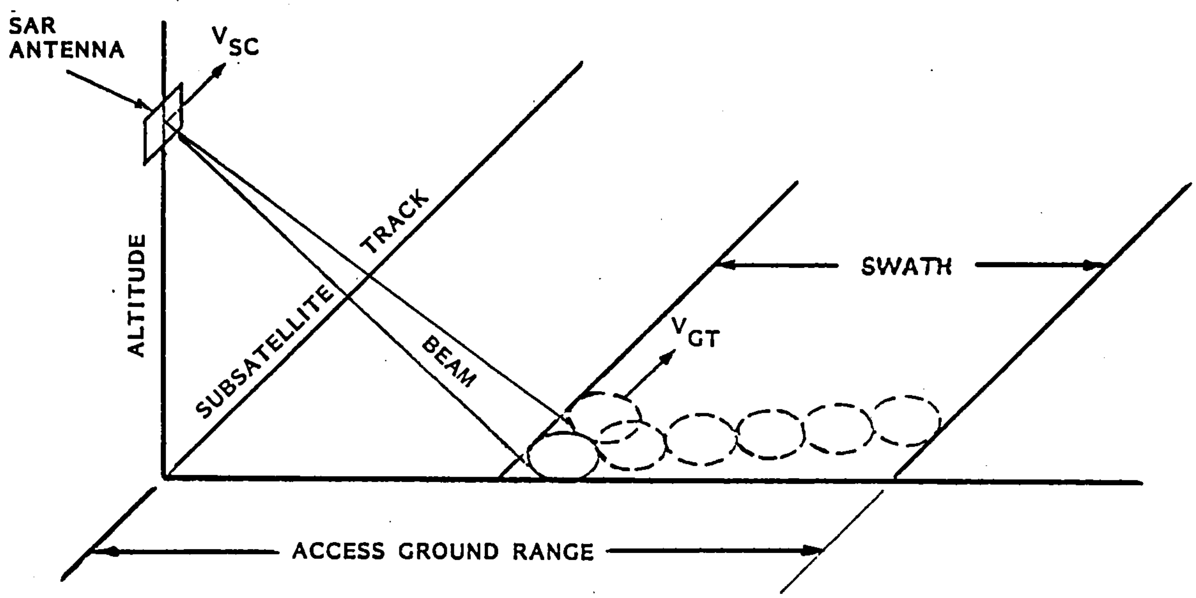


Figure VI-4. Scanned Beam SAR

For the present application, the fan beam approach would require a very long antenna and the antenna flatness tolerance of a small fraction of the radar wavelength will be difficult to meet aside from spacecraft structural problems. The scanned pencil beam approach appears to be considerably more suitable for satellite applications such as this one because the antenna aperture is more nearly square. The scanning may be accomplished by a phased array or by scanning multiple feeds illuminating a reflector. The X-band was selected, operating at a frequency of 9375 MHz, due to the more promising experimental results obtained from aircraft observations of oil slicks as compared with those using other microwave frequencies.

In signal processing, an image is generated of the scene illuminated with the antenna beam in each scan position. The aggregate of the images are combined to produce one image of the entire swath as shown in Figure VI-5.

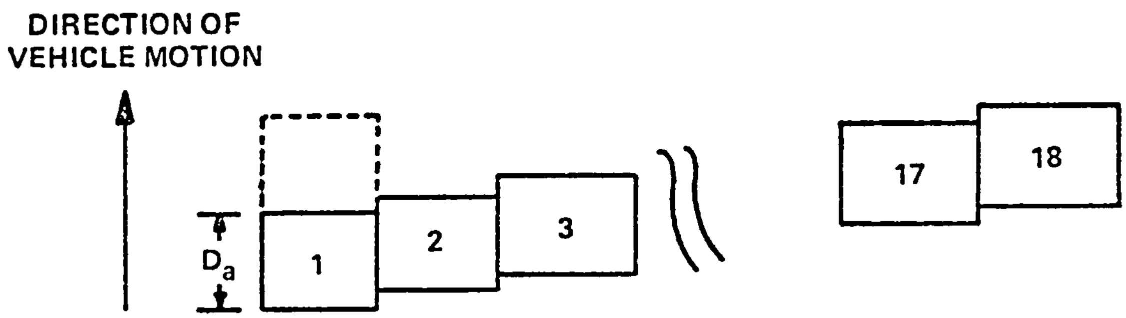


Figure VI-5. Relative Patch Locations for SAR

Dedicated Optical Sensor

The dedicated optical sensor for operation on a satellite platform consists of a Pointable Optical Linear Array (POLA). Pushbroom linear arrays in the visible and thermal infrared spectral region are envisioned in this concept.

The POLA sensor performs the functions of pollutant detection, areal mapping, classification, and quantification. The observables in the visible spectrum are water-pollutant reflectivity differences and pollutant spectral signature. The latter is provided by provision of several narrow spectral channels in the region 0.4 μm to 0.7 μm. The observable in the 8-12.5 μm infrared is temperature. The POLA sensor also may serve to reduce the false alarm rate associated with oil slick detection by the microwave radars, for example, as caused by ship wakes and wind spills.

The POLA sensor operates in the pushbroom mode, i.e., the cross-track array field-of-view is scanned in the along-track direction by the satellite motion. The arrays are pointable in the cross-track direction by optics gimbals to allow selection of particular areas of observation. This capability minimizes the required array size for continuous coastal zone coverage. The salient sensor parameters are:

Optics Diameter: 21 cm

Access Field of View: $\pm 35^{\circ}$ about Nadir

Swath Width: 390 km

Resolution: 30 m (visible), 100 m (IR)

Spectral Coverage: Visible: 0.43 - 0.45 μm, 0.55 - 0.60 μm, 0.65 - 0.7 μm
IR: 8.0 - 12.5 μm

Noise Equivalent Incremental Reflectivity (NE. Δp): 0.16% (visible spectrum)

Noise Equivalent Incremental Temperature (NE. ΔT): 0.02 $^{\circ}$K (IR spectrum)

Number of Detectors per Spectral Channel: 1.25×10^4 (Visible)
3.75×10^3 (IR)

Array Length: 22.5 cm

Microwave Scatterometer

The scatterometer was selected for the measurements of ocean surface wind speed and wind direction. The engineering parameter measured by the microwave scatterometer is sigma nought (σ_o) or more commonly, the radar backscatter coefficient. In this application, this parameter is measured for 10 kilometer contiguous cells, across a 1300 km swath with a 200 km gap on either side of the satellite subtrack at a satellite altitude of 900 km. These measurements are made so that there are two mutually orthogonal measurements in each resolution cell.

In addition to wind speed and direction, the scatterometer provides valuable inputs to the ice cover extent algorithms. Another potential use is in the reduction of ambiguities for the SAR measurements of oil spill areal extent.

The Microwave Scatterometer operates at 14.6 GHz and is essentially a long pulse doppler radar operating in a beam-width-limited mode. It transmits 100 watts pulses, of 4.8 millisecond duration, that illuminate the six fan beam antenna pattern in sequential steps. The signal processor uses the doppler shift of the return pulses to separate the signal into equal length cells within the illuminated patterns. Figure VI-6 shows the functional blocks within the scatterometer.

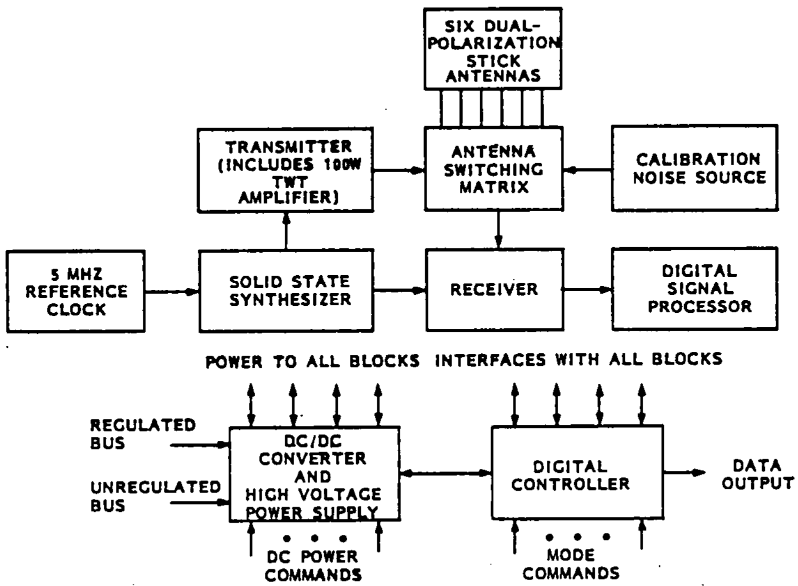


Figure VI-6. Scatterometer Functional Block Diagram

Microwave Radiometer

The engineering parameters measured by the Microwave Radiometer are the radiometric brightnesses of the observed scenes at an earth incidence angle of 50° as a function of frequency and polarization. These parameters are measured continuously at the highest frequencies and over sampled at the lower frequencies across a 1690 km swath at a 900 km satellite altitude.

From this matrix of measurements for each cell, many geophysical parameters can be determined. The primary geophysical parameters that can be determined by the Microwave Radiometer for use in the oil spill Fate Model are ocean surface windspeed, ice cover extent (low resolution), ocean surface temperature and precipitation.

The Microwave Radiometer consists of a scanning 3.6 - 4.0 m antenna followed by low noise, wideband receivers operating at 4.3 GHz, 10.65 GHz, 18.7 GHz, 21.3 GHz and 36.5 GHz. There are separate receivers for each frequency and each polarization. The dual channel processors operate as total power radiometers with cold sky and hot load calibrations before and after each data scan. Figure VI-7 shows the functional blocks within the radiometer.

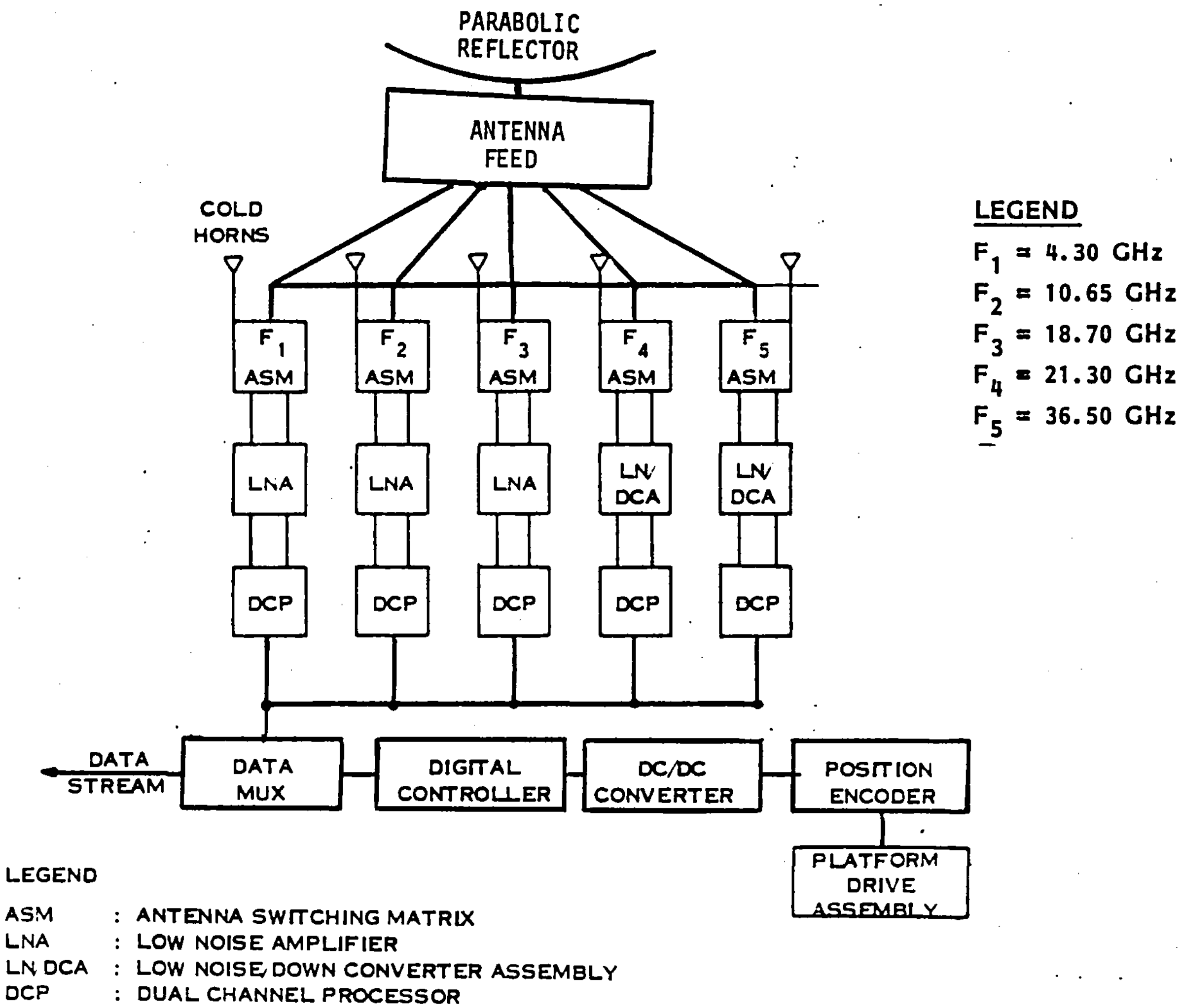


Figure VI-7. Microwave Radiometer Block Diagram

Microwave Altimeter

The engineering parameters measured by the Microwave Altimeter are round-trip-pulse time and return-pulse shape. These parameters are measured at the satellite subtrack across a 13.5 km swath when the satellite is at an altitude of 600-900 km. These measurements are combined to provide one second averages for the parameters measured. The primary parameters determined by the altimeter are spacecraft altitude and ocean significant wave height (h 1/3). Additional parameters that can be determined are ocean surface windspeed and ice thickness (as inferred by altitude measurements).

The Microwave Altimeter selected for this application operates at 13.5 GHz and is essentially a short-pulse, chirpped radar operating in a pulse-width-limited mode. It transmits 2 kilowatt pulses, of 3.2 microsecond duration and 320 MHz chirp, that illuminate a circular IFOV at spacecraft nadir. The signal processor uses digital filter techniques to provide 60 samples, separated by 3.125 nanoseconds, of each return pulse in order to determine the return pulse shape. Figure VI-8 shows the functional blocks within the altimeter.

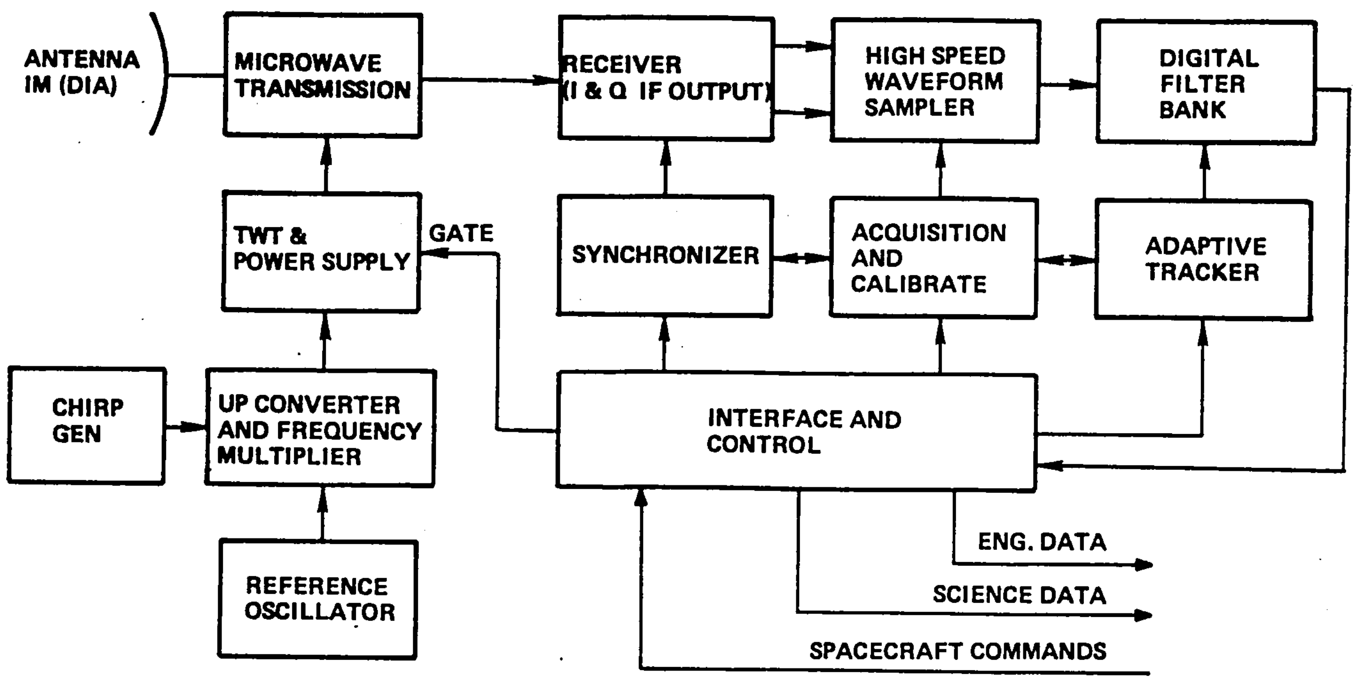


Figure VI-8. Altimeter Block Diagram

PLATFORMS

Selection of the platforms for the System was subordinated to the selected sensors. For instance, given the requirement for a specific remote sensor, the current and planned spacecraft or surveillance aircraft were surveyed to determine if any of those carried the exact sensor or modifiable version of that instrument. In cases such as the Pointable Optical Linear

Array, where the sensor was not available, two alternatives were followed:

1. The performance of similar flight instruments (e.g. Coastal Zone Color Scanner) on board other platforms such as Nimbus, was reviewed to ascertain whether its measurement could be acceptable with tolerable performance degradation, or,

2. Review of the stage of definition of future platforms (e.g. potential spacecraft for the ICEX mission) to determine if the addition of the required sensor (e.g. POLA) would be possible.

The analysis recognized the very dynamic nature of the planning for various satellites such as the National Oceanic Satellite System, Operational Earth Resources Satellite and the carrier for the Ice Processes and Climate Experiment (ICEX) mission. Nevertheless, preliminary definitions of specific platforms such as those mentioned above were used in the model system for the study, in order to permit broader and more realistic consideration of the variables and trades involved in the system definition process.

Figure VI-9 is a matrix showing the platforms that would carry the selected instruments, correlated with major missions and sub-missions. A brief definition of the major platforms is included below.

Airborne Oil Surveillance System (AOSS II)

The U.S. Coast Guard operates an oil surveillance system on board a C-130 aircraft. AOSS surveillance patrols are routinely scheduled; also, a large portion of the AOSS flight time is in support of monitoring missions for reported spills. Flight time capability of the aircraft is in excess of 12 hours. The payload complement of the AOSS II includes the following:

- Oil Surveillance Detection Radar (ODSR-94)
- Line Scanner covering the frequencies 8-13 microns (channels 1 & 2) and 0.32-0.3 micron
- Passive Microwave Imager (37 GHz) equipped with TV monitor & video recorder
- Aerial Reconnaissance Camera in the visible and near IR.

			SPACECRAFT												AIRCRAFT										IN SITU					
			ICEX					NOSS					OERS		MET SATS	ARI			AARI						USCG	BUOYS		SHIPS		COASTAL	
	SUB-MISSIONS		SCAT	ALT	SAR	PMR	POLA	SCAT	ALT	SMMR	C/A	CLR	TM	MLA	VARIOUS	SLAR	UV/IR	TV	SAR	UV/IR	TV	PMR	ALT	LSF	VISUAL	MB	DB	M/O	ODSS	CCR	MS
SURVEILLANCE & MODELING	DETECTION	N			X								X			X	X	X							X						
		M			X		X							X					X		X	X			X						
	MAPPING & TRACKING	N			X	X				X	X		X			X	X	X							X		X				
		M			X	X	X			X		X		X					X		X	X			X	X	X				
	QUANTIFICATION	N									(X)		(X)				(X)								X						
		M					(X)					(X)		(X)						(X)	X	X			X						
	POLLUTANT CLASSIFICATION	N									(X)		(X)																		
		M					(X)					(X)		(X)										X							
	POLLUTER IDENTIFICATION	N																X							X				(X)		
		M																			X				X				(X)		
	SYNOPTIC U.S. COASTAL POLLUTION MON'G. & DATA BASE BUILD	N			X	X				X	X		X			X	X	X							X				(X)		
		M			X	X	X			X		X		X					X		X	X			X	X			(X)		
	SYNOPTIC GLOBAL POLLUTION MON'G. & DATA BASE BUILD	N			X	X				X	X		X																		
		M			X	X	X			X		X	X	X																	
	FATE MODELING	N	X	X	X	X		X	X	X	X		X		X	X	X	X								X	X	X			X
		M	X	X	X	X	X	X	X	X		X		X	X				X	X	X	X	X			X	X	X		X	X
MODELING	IMPACT/RISK MODELING	N	X	X	X	X		X	X	X	X		X		X	X	X	X								X	X	X			X
		M	X	X	X	X	X	X	X	X		X		X	X				X	X	X	X	X			X	X	X		X	X
	SYNOPTIC O/M/E MONITORING AND DATA BASE BUILD	N	X	X	X	X		X	X	X	X	X'	X		X	X	X	X								X	X	X			X
		M	X	X	X	X	X	X	X	X			X		X				X	X	X	X	X			X	X	X		X	X

N - NEAR TERM (1984-87)
M - MID-TERM (1988-91)

X = FOR OIL AND OTHER OCEAN POLLUTANTS
(X) = FOR POLLUTANTS OTHER THAN OIL ONLY

AARI - ADVANCED AIRBORNE REMOTE INSTRUMENTATION
ALT - ALTIMETER
ARI - AIRBORNE REMOTE INSTRUMENTATION
C/A - COASTAL ZONE COLOR SCANNER/ADV VERY HIGH RESOLUTION RADIOMETER (CZCS/AVHRR)
CCR - COASTAL CURRENT RADAR
CLR - COLORIMETER
DB - DRIFTING BUOYS
LSF - LASER STIMULATED FLUOROSENSOR
MB - MOORED BUOYS
METSATS - METEOROLOGICAL SATELLITES
MLA - MULTISPECTRAL LINEAR ARRAY
M/O - METEOROLOGICAL & OCEANOGRAPHIC SENSING SYSTEMS
MS - METEOROLOGICAL STATIONS
NOSS - NATIONAL OCEANIC SATELLITE SYSTEM
ODSS - OCEAN DUMPING SURVEILLANCE SYSTEM
OERS - OPERATIONAL EARTH RESOURCES SYSTEM
PMR - PASSIVE MICROWAVE RADIOMETER
POLA - POINTABLE OPTICAL LINEAR ARRAY
SAR - SYNTHETIC APERTURE RADAR
SCAT - SCATTEROMETER
SLAR - SIDE-LOOKING AIRBORNE RADAR
SMMR - SCANNING MULTICHANNEL MICROWAVE RADIOMETER
TM - THEMATIC MAPPER
USCG - U.S. COAST GUARD
UV/IR - ULTRAVIOLET/INFRARED LINE SCANNER

Figure VI-9. Platforms and Sensors (Employment Concept)

ARI (Aireye) Remote Sensing System

The U. S. Coast Guard is developing an airborne, real-time, all-weather, day/night remote sensing system that will detect oil pollutants and identify violating vessels. The system, designated "Aireye," will be installed on six of the 41 new Falcon 20G jet aircraft (military designation HU-25A) purchased by the Coast Guard to replace the aging HU-16E Grumman Albatross as its medium range surveillance aircraft. The sensor system will include a side looking airborne radar, two-channel infrared/ultraviolet line scanner, aerial reconnaissance camera, airborne data annotation system, and a control, display and record console. To identify polluting vessels at night, an active gated television (AGTV) also is being developed for inclusion in the Aireye system. The AGTV will use a one-watt, pulsed, lead vapor laser illuminator and will be capable of recording vessel names at night from a slant range of 700 meters. In addition to an active and passive mode, the AGTV will be capable of both computer and manual target acquisition and tracking. Each of the sensors will produce annotated, hard copy imagery suitable for prosecution of polluting vessels.

National Oceanic Satellite System (NOSS)

The satellite for this system will be a Multimission Modular Spacecraft (MMS) utilizing an MMS standard bus and modules. The payload will contain an array of instruments for the measurement of the following ocean parameters:

- Wind speed and direction
- Sea surface temperature
- Significant wave height; wave amplitude, length components, and direction
- Ice cover and geophysical characteristics
- Water-mass definition of chlorophyll and turbidity
- Horizontal water surface current speed and direction.

The baseline payload considered for this study, taken from the March 1979 NOSS definition, included the Scatterometer, Radar Altimeter, Scanning Multi-Channel Microwave Radiometer, Coastal Zone Color Scanner, Advanced Very High Resolution Radiometer, Surface Data Acquisition System, and Global Positioning System Receiver/Processor.

The specific orbit for NOSS will be defined in the Phase B studies but is considered as a 600 to 900 km altitude near-polar (85-110°) orbit. The vehicle will be launched by the STS Shuttle from the Western Test Range.

Platform for the Ice Processes and Climate Experiment Mission (ICEX)

The ICEX mission was an important element in the study, since it was identified as the only one requiring the use of a Synthetic Aperture Radar in the near time-frame. The baseline approach for the study was to share this SAR, since the latitudes of interest in the ocean pollution mission were complementary to those in ICEX. Planning in the study was based on the ICESAT satellite concept which required a low orbit and was to measure ice processes and climate parameters. The baseline sensors assumed for this platform were the Synthetic Aperture Radar, Scatterometer, Altimeter, and Passive Microwave Radiometer. The current stage of definition of the platform or combination of platforms that will perform the ICEX mission does not permit a definitive plan relative to the sharing of the platform(s). The key here will be the sharing of the SAR with this mission, and the potential addition of the optical sensor (POLA) on the same platform.

Operational Earth Resources Satellite (OERS)

This satellite will be a Multimission Modular Spacecraft utilizing a MMS standard bus and modules. Its primary mission will be to perform earth resources surveys over land masses, including operational missions in Agriculture, Geology, Hydrology and Land Usage. The baseline instruments will be a Thematic Mapper (multi-spectral scanning radiometer) and a High Resolution Pointable Imager. The swath width of the pointable imager is too narrow for the ocean pollution surveillance mission, and cannot satisfy the requirements of the POLA sensor.

DATA SYSTEM

The primary system element related to data handling is the Mission Data Processing System (MDPS).

The MDPS is a centralized facility for processing, correlating, and analyzing ocean pollution data from various sources such as aircraft, satellites, ships and buoys. Data from the cooperative data sources will be transmitted to the MDPS in real-time or near real-time. Computation will be effected through an array of processors as depicted in Figure VI-10.

Outputs from the MDPS are used in several ways: (1) the latest processed data is placed in temporary storage; (2) data is abstracted for archival storage; (3) displayed for interpretation and evaluation in an interactive operative mode; (4) transmitted to the local command posts. Figure VIII-11 shows the main components of the MDPS and their interfaces

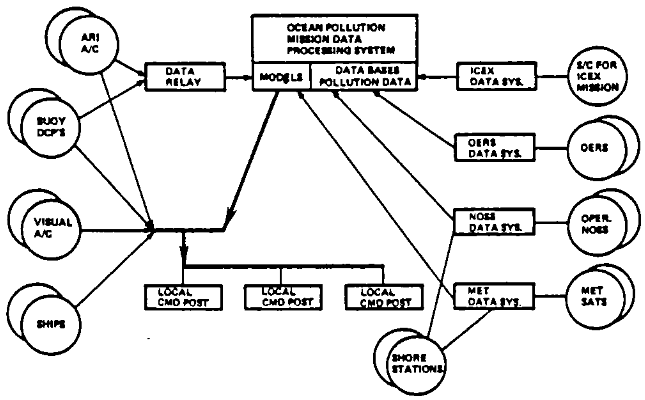


Figure VI-10. MDPS Concept

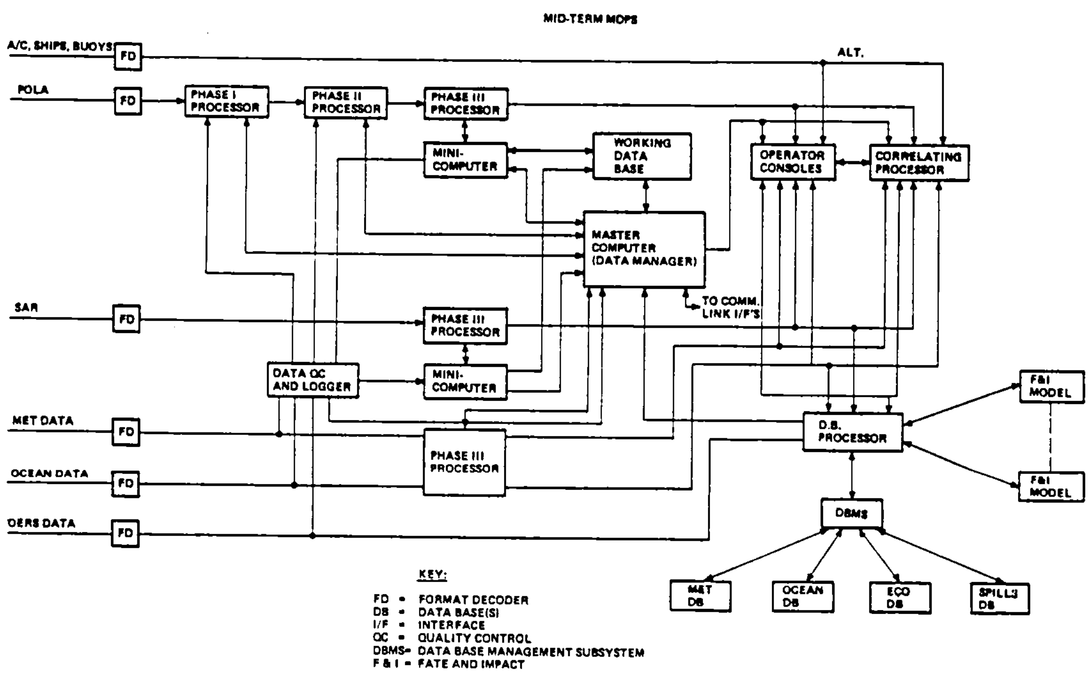


Figure VI-11. MDPS Components & Interfaces

TECHNOLOGY/ENGINEERING DEVELOPMENT REQUIREMENTS RELATIVE TO SYSTEM ELEMENTS

Pointable Imaging Sensors

The orbital analysis using swath width as a variable showed the requirement for pointable imagers, namely the SAR and Pointable Optical Linear Array (POLAR), in order to adequately cover the 200 nm coastal zone. In the case of the SAR, a significant decrease in data rate can be realize by permitting the 390 km swath to be positioned anywhere within a 600 km access swath. A pointable optical sensor and a POLA will also reduce the data rate, which is a significant driver in the data processing system cost.

Long-Life TWT's

The operational system for pollution monitoring depends on the development of high reliability long-life TWT's for the SAR, Scatterometer, and Alternater operating at intermediate power levels. Since the mission requires relatively low duty cycles, it may be desirable to turn tube heater power off in the off-cycle, however, the effects of thermal cycling in the heater should be investigated.

Multi-Frequency Radiometer Feed

The passive microwave radimeter for this application requires a multi-frequency feed for frequencies ranging from 4.25 GHz to 37 GHz. Potential structural and frequency interference problems associated with this design will require continued development effort.

High Voltage Supplies for TWT's

Voltage levels from 8 kV to 11 kV will be used to drive the SAR and Passive Microwave Radiometers. Long-life reliable voltage supplies for these applications will require development and demonstration.

Data Processing

In the area of sensor data processing, the most critical development for this application will be the correlation of scanned-beam SAR "patches" into a mosaic of the image. Important parameters here will be signal frequency, pulse-timing and phase stability.

The signal processor for the Scatterometer requires a 25:1 improvement in frequency capability to increase the resolution from 50 x 50 km (Seasat state-of-the-art) to 10 x 10 km for this application.

Concerning the Mission Data Processing System (MDPS), the Correlation Processor development will be critical. This processor must perform real-time and near-real-time radiometric and geometric corrections, and permit the display of over-layed images from various sensors.

Information Extraction

Extensive field experimentation is required to gain a better understanding of ocean surface phenomena that is relevant in extracting oceal pollution information from the sensed signal. The required data includes the radar cross-section under various ocean dynamics, wind conditions and precipitation. Experiments should determine signal return under various incidence angles. Testing should include signal measurements from controlled oil spills of variable thickness and weathering/aging.

The development of sensing techniques for the determination of oil thickness, oil type, disposed waste classification, and disposed waste concentration is required for implementation of a near-term-system.

SECTION VII
SYSTEM CONSIDERATIONS

The variety of generic and specific system elements which have been described in Section VI may be combined in many possible system options, each providing a practicular level of support of the user requirements and mission needs. Based on qualitative and quantitative trade-off analyses, insight into the users' applications of various system elements, the relative maturity of critical technologies, and other programmatic considerations; several discrete system mixed options were defined and are highlighted in Table VII-1. The six options selected and detailed in this Section range from a maximum support option (I) through a no cost option (VI), which employs the capabilities of the various currently-active, planned, and proposed systems through the next decade. Options I through III employ various levels of enhanced spacecraft remote sensing techniques, whereas option IV utilizes primarily aircraft for pollution detection. Option V was included to provide a minimum cost approach to make the most of planned and proposed remote sensing systems by augmenting the communications and data presentation elements. The approximate relative cost and effectiveness of each option are estimated in this section.

HIGH RESOLUTION MULTIPLE SPACE IMAGING

Option I features advanced technology sensors at all three levels - in space, in the air, and on the surface. The pointable high resolution synthetic aperture radar and optical multispectral linear array will provide primary and corroborative imaging data on ocean pollutants over a large percentage of the 200 nautical mile coastal zone on a daily basis. Oil spilled into the marine environment - whether by accident or intentionally - will be resolvable by these sensors under certain weather and/or viewing conditions.

The synoptic spacecraft detection and monitoring capabilities will assist the aircraft and surface platforms by defining the high probability spill areas (for frequent close-in surveillance) and by providing the initial detection of suspected pollution in progress to which the aircraft and/or nearby ships may respond, making close-in measurements of the pollutant and potential polluter. State-of-the-art sensors - such as synthetic aperture radar,

Table VII-1. Highlights of System Mix Option

	Hi.-Res. Mult. Space Imaging	Med.-Res. Mult. Space Imaging	Med.-Res. Single Space Imaging	Predominantly Aircraft Imaging	Minimum Cost Improved Data Usage	No Modifications
Major Element	Option I	Option II	Option III	Option IV	Option V	Option VI
Platform/Sensors						
• Space	NOSS • Scatterometer • P.M-wave rad. • Altimeter ICER • SAR • POLA } 30 meters resolution	Same as I except SAR/POLA resolution reduced to 100 meters	Same as I except SAR resolution reduced to 100 meters, and elimination of POLA	Same as VI	Same as VI	No significant use of space sensing, except METSAT data base support
• Air	USCG-ARI Advanced ARI • SAR • Laser Fluor. • PMR • Radar Altimeter			Increased ARI-Fleet (80-100 Aircraft)	Same as VI	USCG-ARI Advanced ARI
• Surface	Buoys Ships Coastal Stations			Same as VI	Same as VI	Buoys Ships Coastal Stations
Data System	Centralized data processing facility (MDPS)	Adjusted for 100 meters resolution	Adjusted for 100 meter res. and no POLA	Limited capability centralized facility	Add to VI: • OSC User Terminal • Info. extraction relationships	No major oceanic pollution data processing
COMM Link	TDRS DOMSATS	Reduced Bandwidth from I	Reduced Bandwidth from II	Improved user terminals, leased lines	Phone lines from ground stations	

laser fluorosensing, and passive microwave imaging - will enhance the aircraft's ability to identify and quantify the pollutant.

In addition to making maximum use of existing data systems - including NOSS, NESS, and NWS - a dedicated data processing system will be developed and implemented. It will be the full capability version described in Section VI incorporating special processing for the space SAR and POLA, and high speed "smart" correlation processing from the various platforms and sensors in order to minimize the false alarm rate.

MEDIUM RESOLUTION MULTIPLE SPACE IMAGING

Option II differs from Option I primarily in the resolution level of the spacecraft pollution detection sensors - now 100m as opposed to 30m. This resolution change will degrade the space detection capabilities against the intentional operational discharges of small ships and newer and/or fast non-tankers. This class of oil pollution may be frequent but is comparatively low in overall volume. The pollution response and model input capabilities of this option are virtually unchanged from Option I.

Another significant modification due to the change in resolution is in the data communication and processing systems. Reduced space sensor data rates in turn reduce the wide band communication link requirements and permit down-sizing of certain components in the data processing system.

As in Option I, the development of information extraction algorithms for processing these data will be a major challenge throughout the program timeline through the near-term.

MEDIUM RESOLUTION SINGLE SPACE IMAGING SENSOR

Option III will retain the Option II capabilities of the primary space detection sensor (SAR) but not include the corroborating optical sensor (POLA). Synoptic space detection and monitoring of marine oil pollution, both day and night under a wide range of weather conditions, will still be a feature of this option.

Further communications data link savings will be effected by the deletion of the high rate POLA sensor and major cost savings within the data processing system will be possible because of the removal of the POLA processor.

Full aircraft and surface detection and response capabilities will remain in this option, as well as multi-level data acquisition providing inputs for the fate and impact models.

PREDOMINANTLY AIRCRAFT IMAGING

Option IV represents a major change in approach to the wide area pollution surveillance and monitoring mission - the employment of a much larger fleet of aircraft in lieu of dedicated space imaging sensors. The estimated fleet size for all weather, full coverage of the U. S. coastal zone with aircraft is a strong function of the resolution and type of imaging radar employed. Approximate numbers of aircraft required to provide daily flights over the U. S. coastal zone range from on the order of 100 for real aperture radar systems down to approximately 30 for synthetic aperture systems. Balanced against the improved response capabilities for rapid close-in pollution and polluter measurements attendant to such a large aircraft fleet are 1) the greatly increased operating and maintenance costs of a large aircraft fleet and 2) the loss of the synoptic coastal zone view provided by dedicated spacecraft sensors.

Data communications and processing systems will be different from the previous options and must support a greatly increased number of data acquisition platforms, each with much lower data rates than the comparable space sensors. It is envisioned that a centralized data processing system (MDPS) would be required in both the near and mid terms but would have a limited capability in the near term compared to Options I through III. While providing model users with the same archival and processing capabilities as in the earlier Options, the use of onboard processing for SLAR imagery will eliminate that portion of the MDPS. In the mid term, it is possible that the processing of SAR imagery from the aircraft will be handled in the MDPS in a centralized fashion (utilizing data relay via wide-band leased phone lines) rather than having onboard SAR processing for each aircraft.

MINIMUM COST/IMPROVED DATA USAGE

Option V is a minimum cost approach to make the best use of existing ocean pollution data sources as soon as possible. Data sources would include the current and planned Coast Guard aircraft sensing systems and all space sensors with demonstrated or potential applicability. Notable in the latter category are the high resolution optical and microwave sensors proposed for the Operational Earth Resources System and the ICEX system, both planned for the mid 1980's. Furthermore, the meteorological and oceanographic space sensing capabilities of the various METSATS and proposed NOSS spacecraft would be included. The MOPS approach is to make program arrangements to share usage of the appropriate space sensors without impacting performance of the primary missions.

The outstanding feature of this option is the acquisition, distribution, and presentation of data from already existing sources. To meet the low cost goal, phone lines (in some cases leased lines) would augment the already-built communications links of the parent systems, providing low rate data to multiple user terminals within the MOPS network. These terminals could be graphic plotters, for example, and would be in the numerous Coast Guard OSC (On Scene Coordinator) offices and in Washington (National Response Center). Thus, at minimum expense, available data for pollution response activities would be rapidly provided to the primary user in the field, with some flexibility in presentation of the data and mobility in placement of the data terminal.

NO MISSION-SPECIFIC MODIFICATIONS

Option VI is the no cost future baseline. Surveillance and monitoring capabilities will be provided as presently planned by Coast Guard remote sensing aircraft and certain planned and proposed spacecraft. The frequency and breadth of coverage will be significantly less than with any of Options I through IV.

The lack of synoptic detection capabilities that has provided problems in surveying the current Gulf of Mexico oil well blow-out would continue under this option.

Furthermore, the disaggregated data sources (meteorological, oceanographic, and ecological) available for use in fate and impact models would not benefit from the common archiving and distribution provided under the several proposed MOPS data processing systems.

RELATIVE COST AND EFFECTIVENESS OF SYSTEM OPTIONS

Having defined several discrete system mix and capability options and developed a set of structured scenarios within which different elements of each option play their parts, semi-quantitative scoring of the options was performed.

In addressing the effectiveness of each option, a number of performance criteria were considered. Two slightly different approaches were settled upon:

- Parametric support, estimating degree of satisfaction of performance parameters such as spatial resolution and frequency of data acquisition.
- Mission support, estimating each option's performance in the context of the scenarios previously defined.

Using a scale of 1 to 10 --ranging from almost no satisfaction of the criterion to full satisfaction of the criterion-- a subjective score for each option vis-a-vis each of the criteria was established. Figure VII-1 presents these scores, together with the two effectiveness totals (Parametric and Mission Support) which have been normalized by subtracting out the no system/no cost (Option VI) score.

Similarly, a relative cost score for each option was estimated. The cost estimating process addressed only major costs incremental to the Option VI (no cost) baseline. Moreover, emphasis was placed on the relative rather than absolute level of these costs across options. The elements costed were an option-specific set selected from the following list:

- Added platforms
- Platform modifications
- Added sensors
- Sensor modifications
- Major operations and maintenance
- Data processing hardware and software
- Communications links
- Hardware and software R&D

CRITERIA		I	II	III	IV	V	VI
SPATIAL RESOLUTION	PARAMETRIC SUPPORT	9	7	7	7	7	7
TEMPORAL RESOLUTION		8	8	6	9	2	1
AREAL COVERAGE		8	8	6	9	3	1
TIMELINESS (INFO TO USER)		8	8	8	9	4	1
EFFECTIVENESS SCORES	*	23	21	17	24	6	0
	**	24	20	15	25	5	0
SCENARIO I: OIL	MISSION SUPPORT	9	8	7	9	4	3
SCENARIO I: OTO***		6	5	3	5	2	1
SCENARIO II: OIL		8	7	6	9	5	4
SCENARIO II: OTO***		7	6	5	8	4	3
SCENARIO III		8	8	8	8	4	3

	I	II	III	IV	V	VI
RELATIVE COST • INCREMENTAL TO OPTION VI • NORMALIZED TO OPTION I	1.0	.5	.3	8.0	.01	--

* SUM OF CRITERIA SCORES MINUS OPTION VI SUM
** SUM OF SCENARIO SCORES MINUS OPTION VI SUM
***OTO: POLLUTANTS OTHER THAN OIL

Figure VII-1. Relative Scores of System Options

The resulting relative cost scores are displayed in Figure VII-1 as the estimated costs over and above the baseline (Option VI) normalized by the "full-up" space/air system (Option I) cost.

DISCUSSION OF SYSTEM OPTION SCORES

The scores resulting from this analysis are only relative and approximate, since many of the elements that are treated are conceptual and project many years into the future. On the basis of the scoring, the following general conclusions may be reached:

- The scores for "parametric support" and "mission support" have good correlation within each option.

- The medium resolution multiple sensor option (II) is attractive, since it is only slightly less effective than Option I, which is the full-capability system, while it is significantly less costly than Option I.

- Option IV, which utilizes relatively narrow swaths observed from a large fleet of aircraft, is the most effective but also most costly.

- At the other end of the capability scale, Option V yields relatively low effectiveness for much lower costs than the high capability systems (Options I through IV). By design, it yields slightly improved support from existing and planned systems at a modest cost.

SECTION VIII

OVERALL CONCLUSIONS AND RECOMMENDATIONS

A fundamental question in the study concerns what space technology is able to accomplish for the user community today, and what it could accomplish in the near-term future. The following paragraphs address this question by providing an overview of salient capabilities and limitations, while placing these limitations within the proper perspective.

Sensors on-board earth resources and meteorological satellites today have proven that imagery of major pollution events such as that of the IXTOC oil-well is able to provide a synoptic view of large areas containing complex distribution of the pollutant. The limitations today stem from two sources: The optical instruments are useful only under nearly cloud-free conditions, and the data reduction and communication facilities are not geared for the rapid turn-around cycle required by the agencies responsible for day-to-day surveillance and response-monitoring.

Concerning the future, say the mid-1980's, specific capabilities on satellite systems such as NOSS will be directly applicable to the ocean pollution missions. These capabilities include the measurement of important oceanographic parameters such as wind speed and direction that constitute inputs to pollution (e.g. oil spill) trajectory prediction models. Other space-related capabilities that are useful here are space-relay communication links for high data, and precision position determination systems such as GPS. The primary limitation concerning the utility of future sensors in detecting and mapping ocean pollution is technological in nature: Information extraction technology in the area of oil spill and waste pollution detection and classification is in a very early stage of development. Environmental factors, both ocean and atmosphere-related need to be understood, to permit the elimination of ambiguities in interpretation of the pollution data.

In order to place this technological uncertainty within the proper prospective, a parallel may be drawn between this application and a more familiar application, namely agricultural crop identification. Previous concepts of crop identification "signatures" were modeled on the basis of known spectral-radiometric relationships that laboratory tests had shown were characteristic of various crop species.

After analyzing a large amount of orbital data versus ground truth data, the uncertainties became evident; these were due to environmental variables and plant physiological characteristics at various stages of development. As a result of extensive laboratory and field research, the importance of other factors such as crop stage of maturity were recognized. Time emerged as a vital discriminatory parameter: Reflective and emissive characteristics at various stages during the crip season, correlated with the known "growth calendar" of many varieties of plants became integral elements of the crop signature relationship.

In a similar manner, the ocean pollution application requires a baseline of information not only on the effects of environmental variables on the detected signal, but also the nature of the environmental phenomena itself. Following the analogy even further, detailed information concerning ocean dynamic phenomena may also make it possible to use time variability as a discriminating factor (although at a greatly reduced scale). For instance, change detection between successive radar looks during a wind-slick may make it possible to discriminate between that transient event and the more constant signal pattern due to the oil slick.

This analogy has been introduced merely to place the technology needs of the ocean pollution mission in the proper context, relative to normally evolving information extraction developments.

Specific recommendations for technological and engineering developments relative to ocean pollution monitoring are as follows:

R&D TO DEVELOP INFORMATION EXTRACTION TECHNIQUES

A baseline of experimental data is needed on space observations and aircraft sensing of waste pollutants and oil spills under a wide variety of environmental conditions. In addition, ocean dynamic phenomena should be studied to aid in the development of information extraction techniques and elimination of pollutant detection and classification ambiguities. The extensive field experimentation should include adequate surface truth data, to permit conclusive data reduction and interpretation.

DEVELOPMENT OF INSTRUMENTS FOR BROAD SPATIAL/TEMPORAL COVERAGE

Parametric design studies are recommended on the types of space instruments for oil and waste pollution monitoring that are suitable for frequent coverage of the 200 n. mi. coastal zone. The two prime instruments identified in this study are the wide-swath pointable SAR and the Pointable Optical Linear Array. Results of these parametric analyses are needed for the potential incorporation of this mission in the future development of these multi-application instruments.

OIL QUANTIFICATION METHODS

New or improved techniques should be developed for sensing oil slick thickness, a measurement that is necessary in the quantification of oil spills. Multi-frequency passive microwave radiometry techniques for high resolution (e.g. 0.1 to 0.2 Km.) mapping of thickness distribution from space should be explored.

NEW TECHNIQUES FOR FATE-MODEL INPUT DATA

A substitute for nadir-altimetry should be found, for measuring significant wave height and ocean current speed and direction. A potential area of research here is the development of automated data processing techniques using signal returns from sensors such as synthetic aperture and laser radars.

DATA HANDLING AND COMMUNICATION SYSTEM APPROACHES

The requirements of the oil spills and ocean pollution mission are typical of many emerging applications where data must be collected from many diverse sources, processed in real-time or near real time, and formatted to meet the user's needs. Consideration of the pollution mission needs is recommended for inclusion in future R&D efforts relative to end-to-end data processing and communication techniques and systems.

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16. Abstract

The United States Congress in the NASA Authorization Act of 1978, directed NASA to investigate the potential of satellite systems and space technology to detect and monitor oil spills and ocean waste disposal in the U.S. waters. As a result, a program of spacecraft studies, was initiated along with field measurements and laboratory investigations to provide the scientific information to perform the assessment. The space system study, which is documented in this report is directed toward all weather remote sensing and surveillance where the space system would provide information to regulatory agencies for closer investigation with aircraft and ships. This volume is the Technical Volume.

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