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ADVANCED STUDY OF COASTAL ZONE OCEANOGRAPHIC REQUIREMENTS FOR ERTS E AND F

D. A. Adams, et al

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Prepared under Contract No NAS1 10281 by

OCEAN DATA SYSTEMS, INC
ROCKVILLE, MARYLAND

for

NATIONAL AERONAUTICS AND SPACE ADMINISTRATION
LANGLEY RESEARCH CENTER
HAMPTON, VIRGINIA

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Note:

Since the study commenced, Earth Resources Technology Satellites (ERTS) E&F have been redesignated Earth Observation Satellites (EOS) A&B. Both notations are used in the study.

ABSTRACT

The U. S. coastal zone, where 45 percent of the people live on 15 percent of the land, is the scene of a widening array of issues related to pollution, fisheries, hazards to shipping and coastlines, and coastal geography and cartography. Frequently the decisions of coastal resource managers relative to key issues are handicapped by lack of adequate marine environmental data in useful form. The study identifies the important coastal zone issues and marine-related data needed to aid in resolving them It also identifies which of the data might be acquired by satellite and the appropriate orbital and sensor characteristics for coastal missions. Recognizing the importance of high resolution and high frequency of coverage for these missions, the proposed spacecraft characteristics are: orbital inclination 72 degrees optimized for the coastal zone at an altitude of about 700 km with a high resolution multispectral imager, an IR imager, a low resolution multispectral imager, and visible near-IR spectrometer. Sensors should be pointable so that most coastal areas can be observed possibly on three out of four days.

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SUMMARY

The Advanced Study of Coastal Zone Oceanographic Requirements for ERTS E&F includes:

- an assessment of earlier studies of spacecraft applications in oceanography;
- identification of key coastal zone issues related to pollution, fisheries, hazards to shipping and coastlines, and coastal geography and cartography, and rationalization of their significance;
- delineation of coastal environmental data and related measurement specifications needed to aid the resolution of coastal problems.
- analysis of space engineering capabilities, including remote sensing, orbital mechanics, and configuration control, to acquire coastal oceanographic data; and
- proposals for optimum payloads and orbits for coastal zone missions.

The coastal zone has been defined variously for different purposes. Generally, it is considered the area within which biological and physical characteristics are influenced by the conjunction of land and water, particularly as they affect reproduction of marine life and waterfowl and industrial, commercial, and urban development. To broaden satellite data applications in coastal resource management, the coastal zone is defined for purposes of this study as lying between a line 50 miles from the base line for the territorial sea or the 200 meter isobath, whichever is farther from shore, and the inland boundaries of coastal counties. By considering only coastal regions of the United States, its territories, possessions, and the Trust Territory of the Pacific Islands, emphasis is given to domestic needs and priorities in coastal affairs, even though U. S. areas are only a small fraction of those world-wide.

The coastal zone is an important part of the marine environment; it is probably the most important part because it is where the people and problems are. Forty-five percent of the people live on 15 percent of the land; problems related to conflicting demands of land use and preservation are intensifying.

The issues considered to be most significant in coastal affairs within four national problem areas are identified in Section 1.0. For example, locating sources of discharge and

effecting enforcement are cited under pollution; improving scouting and catching operations and forecasting abundance are cited under fisheries; identifying hazards to navigation and assisting rescue operations are cited under hazards to shipping and coastlines; and identifying coastal land use patterns and monitoring and controlling shoreline processes are cited under coastal geography and cartography.

Each of these and other issues are considered from the viewpoint of unmet environmental data needs. To endeavor to quantify the importance of various kinds of environmental data to the resolution of coastal zone issues, judgments are made on the unimportance, importance, or criticality of various kinds of data to each issue and values are assigned accordingly within matrix cells. Six broad categories of environmental data are considered: physical properties of water, chemical properties of water, biological properties of water, geological and geophysical properties of the bottom, atmospheric properties, and land characteristics. Within these categories 49 data types are included in the analysis; of these, 23 are considered most relevant to the solution of coastal problems. These data are identified in Section 1.4.4.

Section 2.0 considers the 23 kinds of data from the viewpoint of measurement specifications required for application to specific issues. Judgments were made on ways in which the data might be used, either independently or correlated with other data, to attack the coastal issues, and values were assigned to specifications for spatial resolution, frequency of measurement, data response time, field of interest, etc., in 23 tables -- one for each data type.

This analysis indicates the great importance attached to high resolution and frequent coverage for satellite coastal missions.* For example, the ground resolution suggested for large area images, at least for selected applications, is 50-75 meters with 150 square kilometer field of view. Small area images will benefit from 10-20 meter resolution and 30 square kilometer field of view. Point or line samples should be limited to smaller areas. Coastline tracking, targeting, and intercept pointing, respectively, should be considered for these types of coverage. In general, the frequency of coverage should be daily for fishing and hazard issues, daily to weekly for pollution, and seasonal for geography and cartography.

Section 2.0 narrows the candidate spacecraft measurements from 23 data types to 13 types, applying these criteria: energy characteristics, spectral and spatial resolution and accuracy requirements, feasibility of remote measurement techniques, and alternate means of obtaining data. Spacecraft measurable data types and related sensor candidates are identified.

*Since these two needs may not always be compatible, three different types of coverage were considered: large area lower resolution images for contiguous coverage, small area high resolution images, and point or line measurements of sample data.

Section 3.0 discusses the technological readiness of remote sensing techniques for coastal zone missions, including, visible, near IR imagers, IR devices, spectrometers, passive microwave devices, radar scatterometers, and new sensors which may be adaptable in the future. Each of the sensors is discussed in terms of the current status of its development, its applicability to coastal zone measurements, and modifications that may be required. The concepts of a high resolution, multispectral imager, sensor pointing and tracking, and data sampling with a device such as an infrared comb radiometer may have particular relevancy for coastal zone applications.

Section 4.0 consideres alternatives for optimizing satellite orbital inclinations and altitudes for coastal zone missions. The conclusions reached are:

- only circular orbits should be considered
- altitudes should be in the range 550 to 1100 km
- orbital inclinations should be 98° (for sun synchronous orbits), 49°R, 72° or 64°R to optimize exposure for data applications to coastal geography and cartography, hazards to shipping and coastlines, and fisheries and pollution, respectively.
- an integral number of orbits per repeat cycle (14 or 15) should be employed to cover a limited number of areas daily. To provide broader area coverage on a two, three, or four day cycle, a fractional number of orbit repeat cycles (14.33, 14.5, 14.75) should be used.

Other conclusions regarding spacecraft engineering for coastal zone missions are:

- spacecraft weight will be in the range 680 to 1360 Kg with approximately 20% allocated for sensors.
- power requirements will be in the range 150 to 350 watts average load. Housekeeping (i.e., telemetry, communications, attitude control, thermal control, etc.), power requirements will approximate 5 to 10 watts for every 45 Kg of baseline spacecraft weight.
- on-board propulsion will be required to maintain orbital parameters for the mission duration.

-- unless new ground stations are added, on-board storage for sensor data will be necessary. Direct readout capability could reduce spacecraft requirements.

Finally, in Section 5.0 the criteria for selection of the payload configuration for each of the priority applications are identified and proposed sensor combinations and orbital data for each are noted in Table 5-2. For a single coastal mission including all four applications, we propose a spacecraft with orbital inclination of 72 degrees at an altitude of about 700 km carrying a high resolution multispectral imager, an IR imager, a low resolution multispectral imager, and a visible, near IR spectrometer.

Major recommendations of the study are:

1) A high resolution, pointable, multispectral (visible, near IR) imager should be developed with 10-20 m ground resolution and 30 km ground field of view.

2) A single imaging sensor should be developed which adequately provides four visible and near IR channels and one IR channel for large area (150 km) and 50-75 m resolution.

3) Spectral signature experiments should be conducted over the coastal zone to test their validity and to determine useful spectrometer bands.

4) Analysis and field experiments of microwave radiometry and radar scatterometry should be pursued to determine their feasibility for sea surface measurements.

5) Special orbits for providing frequent coverage of particular coastal areas (viz, the East Coast and southern Pacific Coast) should be used for at least some ERTS E&F missions, and the use of these orbits for non-coastal zone missions should be examined.

6) Consideration should be given to an attitude determination system that can relate the principal axis of one sensor to locations in an image from another sensor taken earlier within a two-three minute period.

ACKNOWLEDGMENT

We should like to acknowledge with appreciation the excellent cooperation and assistance provided during the study by Mr. Larry Brumfield and Dr. David Bowker, Technical Monitor and Alternate Technical Monitor for the study, respectively.

INTRODUCTION

This report presents the result of a joint effort by Ocean Data Systems, Inc. (ODSI), Rockville, Maryland and the RCA Astro-Electronics Division, Princeton, New Jersey on NASA Contract NAS1-10281, Advanced Study of Coastal Zone Oceanographic Requirements for ERTS E&F. ODSI participated as the prime contractor to give emphasis to determining the needs of the oceanographic community in the coastal zone, particularly in regard to pollution, fisheries, hazards to shipping and coastlines, and coastal geography and cartography. RCA's responsibilities as subcontractor were to:

- -- determine the feasibility of making the desired measurements by remote sensing from space;
- -- define sensor requirements and evaluate the sensor state-of-the-art for meeting these requirements;
- -- determine orbital and spacecraft requirements for making the desired measurements; and
- -- establish groupings of sensors to satisfy coastal zone mission requirements related to pollution, fisheries, hazards to shipping and coastlines, and coastal geography and cartography.

Broad objectives of the study were to:

- -- relate the experimental needs of the oceanographic community to national needs and priorities;
- -- define the breadth of experimentation in coastal zone oceanography which may require the use of a space platform; and
- -- assign experimental priorities which will aid NASA in the selection and grouping of experiments for ERTS E&F.

Over the course of the past five years, several studies have investigated spacecraft applications in oceanography. Their results are summarized in Appendix A. None of the studies, however, has focused on the coastal zone as a unique part of the marine environment; nor have they given emphasis to oceanographic needs for coastal resource management. The present study does both.

The study commenced on September 8, 1970. Once preliminary views were developed on the selection of the most urgent coastal zone issues and related unmet oceanographic data needs, an advisory meeting of Federal and State Government, industrial, and academic representatives was convened at Langley Research Center, October 14-15. Participants in the advisory meeting are identified in Appendex C. The meeting aided in formulating more specific views on coastal zone problems and oceanographic data needs. It was recognized at the meeting, however, that environmental data generally contribute only partially to coastal resource management decisions and that satellites represent but one means of marine environmental data acquisition. Views developed at the meeting served as a backdrop for deliberations of the study.

SECTION 1.0

SIGNIFICANT COASTAL ZONE PROBLEMS AND DATA NEEDS

1.1 What is the Coastal Zone?

The coastal zone has been defined variously for different purposes. It can be described generally as the area within which biological and physical characteristics are influenced by the conjunction of land and water, particularly as they affect reproduction of marine life and waterfowl, on the one hand, and industrial, commercial, and urban development, on the other. Because coastal areas are the locus of many of man's urgan settlements, the path of transportation for essential goods and materials, and convenient repository for industrial and municipal wastes, the ecology of the coastal zone is of great concern. The zone of specific ecological concern includes some inland reach, activity within which has a direct or indirect effect upon the coast.

The coastal states are strengthening their management of coastal affairs, including coastal land use and development. Authority is exercised in several ways, including issuance of state permits and by county and municipal governments through land use zoning and taxation. Offshore, both the Federal government and the States have responsibilities with respect to channels and harbors, fishing laws, and water and bottom rights.

Satellite observations designed to contribute to coastal resource management should not be restricted to the seaward side of the coastline. If ERTS E&F satellite sensors observe, record, and transmit imagery and measurements of relevant environmental features within a broadly defined coastal zone, additional benefits can be expected. The seaward extent of the coastal zone, by definition in this study, is a line 50 miles from the baseline for the territorial sea or the 200-meter isobath, whichever is farther from shore. The inland extent approximates the inland boundaries of the coastal counties.

In addition to the oceanic coastal zone, U. S. coasts of the Great Lakes are also considered in the study. The Great Lakes have only minor astronomical tides, are not saline, and their inflowing rivers are generally small. Nonetheless, because of their size, they exhibit patterns of circulation and wave development resembling those of the sea. Further, man's use of the lake front and the density of habitation along the shore are comparable to the most intensely developed areas of the sea coast. These pose problems of environmental control that are of national concern. The Great Lakes were included by the Congress for purposes of the Bureau of Sport

Fisheries and Wildlife estuarine inventory and included within advisory responsibilities of the National Council on Marine Resources and Engineering Development. For these reasons, they are included here.

By considering only coastal regions of the United States, its territories, possessions, and the Trust Territory of the Pacific Islands emphasis is placed on domestic needs and priorities in coastal affairs, even though U. S. areas are only a small fraction of those worldwide.

To delineate and describe the variety of biophysical environments which are represented, the coastal zone is subdivided into eleven regions, following the convention established in the "National Estuary Study". With the exception of the Great Lakes, these are also the regions identified in "The National Estuarine Pollution Study", from which source material is also drawn. Each of the eleven biophysical regions is described in Appendix B.

1.2 Why is the Coastal Zone Important?

The United States is in the midst of an urban revolution. In 1960, over 70 percent of our population lived in urban areas. The 1970 census is expected to show that this figure has increased to 75 percent. It is predicted that the country's urban population will reach 85 percent by the year 2000, and possibly 95 percent a century from now. This increase is accompanied by absolute increases in population of substantial proportions, perhaps as high as 50 percent in the next 30 years.

Urban centers are not evenly distributed over the country: most are located on or near the oceans, the Gulf of Mexico, and the Great Lakes. More than 75 percent of the population inhabits States bordering the coastline; 45 percent live in coastal counties, which represent only 15 percent of the land area of the country. Of the 45 percent of the population residing in coastal counties, 80 percent live in cities. The coastal zone is approximately twice as densely populated, and significantly more urbanized, than the rest of the country. Coastal counties have within their borders some 40 percent of all manufacturing plants in the United States, half of these being in the Middle Atlantic region alone.

There is no reason to expect trends of increasing use of coastal areas to change in the short term. The rate of development of coastal lands has been increasing much faster than the rate of growth of urban population. During the past 40 years, the land area in the United States covered by cities has expanded three times faster than the population. The total land area of urban settlements a century from now may be 20 to 30 times greater than that presently required.

Reasons for the phenomenon of coastal and urban growth are many. Dynamic urban growth itself is relatively recent. For a period of some 5,000 to 6,000 years, man's cities were essentially static. With only few and temporary exceptions, prior to the eighteenth century man lived in cities not exceeding 50,000 inhabitants. The cities were geographically confined to an area approximately a mile and a quarter on a side. This was true of Athens under Pericles; Florence during Michelangelo's life; and Rome, Paris, and London within the walls.

More recently, technological change has altered the character of urban life. First, industrial revolution, then the mechanization of transportation, and now the instruments of communication, by which men everywhere are motivated to levels of expectation which were formerly the province of only the wealthiest classes, have given impetus to change. The impact of preventive medicine, which has effectively doubled the average life span of the population of developed countries, has been equally profound.

Historically, urban development has been attracted to the water, to facilitate communication, transport and trade, and subsistence fishing. At the same time, labor intensive agricultural systems required a high proportion of the population to live in inland rural settlements. The balance is still changing. At present, some 10 percent of the population can feed the remaining 90 percent, and the country's economy is increasingly technologically and service-oriented. For manufacturing, the availability of water for industrial cooling and waste disposal constitutes an additional incentive for locating plants near large bodies of water. More recently, the construction of nuclear power (generating) plants, requiring more water for cooling than fossil fuel plants, contributes to the concentration of industry in coastal areas.

As industrial and agricultural production have shifted from labor-intensive to capital-intensive status, the growth of service industries has multiplied. Service industries tend to locate in or near urban centers. Hence, existing cities experience accelerated growth. Concomitantly, the use of coastal areas for recreation also expands. It has been estimated that over 80 million Americans annually use the seashore or lakefront for sports fishing, boating, swimming, surfing, and picnicking. With increasing personal income and leisure time, recreational use of the seashore is advancing more rapidly than coastal population.

Finally, the potential of coastal waters for aquaculture and mineral resource development may intensify future exploitation of the coastal zone. Offshore oil exploration and production are already advanced in many areas.

A dramatic, increasing, and apparently inexorable linkage exists between exploding urbanization and the coastal regions. If it has taken man 200 years to degrade significantly, say, 50 percent of the natural environment of the coastal zone of the United States, he is aimed toward finishing the job in substantially less time. It is necessary to underscore the importance of rational planning, conservation controls, and improved systems for surveillance, measurement, and reporting of coastal environmental conditions to aid in preserving the coasts even while they provide a home for increasing numbers of Americans.

1.3 Identifying Significant Coastal Zone Problems and Issues

Competitive uses of the coastal zone have fostered an expanding array and diversity of problems. Two major objectives of the study were to identify significant coastal zone issues within four national problem areas cited by the National Aeronautics and Space Administration, Langley Research Center, and to identify the environmental data required to aid their resolution.

The four national problem areas specified were: pollution, fisheries, hazards to shipping and coastlines, and coastal geography and cartography. Issues singled out for priority attention for each problem area are considered by us to be most relevant to the solution of coastal problems.

1.3.1 Pollution

In a world increasingly conscious of its surroundings, pollution is a visible, sometimes dangerous, sign of environmental decay. Ocean pollution from industrial sources is growing at the rate of 4.5 percent annually or three times faster than domestic population growth. The Department of Health, Education, and Welfare estimates that more than 50 million tons of solid wastes from all sources are deposited annually in the oceans The output of industrial waste is growing several times faster than the volume of sanitary sewage; current estimates of industrial effluents exceed 50 trillion gallons per year, much of which ultimately finds its way to the oceans.

The best index of the future potential for thermal pollution is the predicted increase in the generation of electricity. Electric power capacity is growing at an annual rate of 7.2 percent and is expected to double every ten years. More than 16,000 petroleum and gas wells have already been drilled off U. S. coasts and the number is increasing by more than 1,000 each year. An estimated 10,000 spills from all sources occur annually to pollute the navigable waters of the United States.

The word pollution, as used in the context of this study, is the degradation of the biophysical environment by man's activities; it not only includes discharge of sewage and industrial wastes, but also direct and indirect damage to the environment by physical, chemical, or biological modifications. Water pollution is only one form of deterioration. It is most acute in densely populated or industrialized areas, but its effects can often be traced to the most distant oceans. Increased knowledge of global environmental processes and awareness of man's impact on the environment have fostered specific national and international requirements for the detection and abatement of pollution.

The practice of ocean dumping of sewage sludges off our northeastern coast and the detrimental effect of such disposal underscore the need for oceanographic data related to surveillance and control. The data may be useful in resource management of fisheries and coastal mapping, as well as pollution monitoring. Regional monitoring of oil exploration, and marine transportation may require additional types of oceanographic data.

The ocean's ecological balance is threatened by man-generated pollution. One of the most abundant of man-made pollutants in the sea is DDT, originating from agricultural run-off. DDT does not degrade in water readily, hence two-thirds of the 1.5 million tons produced to date may still be in the oceans. DDT concentrates selectively through the food web and is found in all oceans and in most marine organisms, as well as in man. More than 400 new chemical substances are created each year and many find their way to the oceans.

The United States, as the most industrialized nation in the world, is believed to be responsible for approximately one-fifth of the world's coastal effluents. One effect is that shellfish in an estimated 1.2 million acres, 8 percent of the Nation's shellfish grounds, have been declared unsafe for human consumption.

Not all discharge into the coastal environment is detrimental. With proper controls, the heating of coastal waters can increase productivity of marine life many times and may enhance recreation potential. Purified sewage can be used as fertilizer in aquaculture projects; acid wastes can decrease turbidity. Coastal works can preserve marine habitats as well as enhance transportation, recreation, and commercial benefits; solid wastes can provide new marine habitats for aquatic life.

The major issues related to pollution are:

a. <u>Locate sources of discharge</u>

Sources of discharge may be classed as either "point sources" or "non-point sources". The former include municipal wastes, industrial effluents, and thermal discharges which originate from a single, stationary point. The latter include ship discharges of oil while underway and run-off from agricultural areas. Locating sources of discharge frequently depends now upon visual observation and mapping. Knowledge of water mass movements and current flow patterns is necessary to distinguish discharges in areas where multiple additions occur.

b. Determine types of discharge

Discharge classifications are associated with water use. The Environmental Protection Agency has classified water types by the use to which the water is put. Hence, more rigorous quality criteria are applied to water for recreation and esthetic uses than to water used for agriculture. Analytical tests are applied to classify the types of discharges and related water quality. The processes involved in deriving information on discharge type include taking water and sediment samples for determination of specific constituents and properties, including tests for temperature, pH, water color, turbidity, and odor. Laboratory analyses of water and sediment samples provide information on the chemical and biological characteristics of the water body and are used to describe additions to it. Coliform bacteria counts are standard indexes of water quality, as are dissolved oxygen measurements, bio-assays, and biochemical oxygen demand.

c. Determine the extent of pollution effects

Measurements of currents and water mass movement are essential in determining the spatial extent and magnitude of pollutant dispersion in estuarine and coastal waters. Dispersion and exchange rates are a function of both the advection and diffusion of a water body. Hence, resolution of this issue requires knowledge of three dimensional current movement, water density, water mass volume, concentration and density of pollutants, and local topography. Tidal data are useful in shallow areas and straits for assessing tidal currents. These factors can be combined with observations of water color, productivity, and sedimentation to derive information concerning coastal and estuarine circulation and flushing rates. Bioassays are frequently useful in determining the effects of concentrated pollutants. Dye tracing is a particularly effective means for mapping dispersion patterns, and predicting the movement of oscillating waste bodies in estuaries.

d. Determine assimilative capacity

At present, there is no universally accepted index of assimilative capacity; however, the application of the Streeter-Phelps streamflow equations provides a basis for discussion. The equations show that the ability of a water body to assimilate waste is a function of its mixing parameters, density, momentum, direction, temperature, saturation, productivity, biomass, and chemical constituents. Energy inputs such as wind, waves, and solar radiation can affect the above parameters. Fresh water inflow and salt water encroachment also should be considered. Properties of surficial bottom sediments and bioassays aid in understanding the ability of the bottom and water column to degrade some types of organic and inorganic pollutants.

e. Optimal siting of effluent-producing industries

Optimal siting of an effluent-producing source requires that the nature of the receiving body be known. Knowledge of water currents and bottom topography, as well as biological and chemical patterns, is essential to assure that overloading of a given area does not occur. Such knowledge must then be combined with various kinds of land use data to determine potential use conflicts. Consideration of local, State, and Federal government regulations, private propety rights, competitive uses such as recreation, industry, and municipal development is essential before the benefits and costs of siting or moving an effluent source can be determined.

f. Effect enforcement

A great many data types are useful in preparing and effecting enforcement action against polluters. The exact nature and concentration of the effluent which may be the subject of enforcement action must be known and its geographic extent and long and short-range effects must be identified. Graphic and image presentations are frequently useful in court cases, because the "sight" of pollution generally has substantial impact.

Critical data types in effecting enforcement actions are few. Essentially, they are limited to specific types of measurements required for water quality classifications related to pollution control in a particular area. Such data as pH, dissolved oxygen, temperature, bioassay, and withdrawal and discharge rates are generally included in the various water quality classification systems and usually are the only kinds that may be considered in enforcement actions. More recently, however, esthetic effects have been considered by the courts as grounds for legal action.

g. Assist rapid clean-up

The data needed to track and monitor pollutants and describe local marine conditions, particularly synoptic data, are most frequently used to assist rapid clean-up. In combatting oil spills, data describing mixing and dispersion processes are needed immediately by on-site managers. The rapid clean-up of spills also requires information relating to the nature and extent of the spilled material, national water quality standards, and the availability of manpower, equipment, and transportation.

1.3.2 Fisheries

The world's rapidly expanding population signals an urgent need for food from all sources. The living resources of the sea promise to contribute significantly to meeting the protein needs of 6 billion people by the year 2000. The United Nation's Food and Agriculture Organization estimates increases in yield from a well-managed fishery of from 3 to 5 million tons per year during the next 3 decades. Hence, seafood is at present one of the few major foods increasing faster than population growth.

The 850,000 square miles of continental shelf adjacent to U.S. coasts provide us with a large and productive fishing area. The United States also maintains the world's second largest fishing fleet, consisting of 76,000 powered vessels of which 12,000 are over 5 tons. Despite these resources, the relative position of the U. S. fishing industry has declined internationally, America currently ranks sixth in tonnage landed (from second place ten years ago), and fourth in value of fish landed. The Bureau of Commercial Fisheries has estimated that U. S. continental shelf areas could yield up to 20 million tons of fish yearly - about nine times present production; however, the United States catch has remained about level at 2.2 million tons annually for the last decade.

The discovery of new fishing areas in recent years has been uneven geographically. In the heavily fished waters of the Gulf of Mexico, few areas remain unexplored. Several unexplored areas off the Atlantic continental shelf have recently been identified as productive locations for lobsters and calico scallops. Several areas of the Northwest Pacific and Alaskan coasts have been only initially explored, and should command greater attention in the data collection process.

Table 1-1 outlines the value, location, and yield of high value species by region.

The preceding discussion suggests that the majority of problems, real and potential, in domestic fisheries lies within segments of the harvesting part of the industry and relates to actual fishing operations. The following issues have been selected as being most relevant:

TABLE 1-1

U. S. CATCH BY BIOPHYSICAL REGIONS AND ZONES OFFSHORE

Species	Value of Catch-1966 Millions $	Principal Region Where Caught	Tonnage (x1000) of catch by zone		
			Territorial Waters	Contiguous Zone	Other Areas
Shrimp	95.8	Gulf, SE	121	68	31
Salmon	67.1	NW	267	2	3
Tuna	44.6	Calif.	9	60	239
Oysters	26.1	Gulf, Ches.	60		
Lobsters	25.6	NE	27	3	
Menhaden	21.7	Gulf, Ches.	1104	36	
Clams	18.1	Mid-Atl., NE	30	23	
Flounders	16.3	NE, Pacific	50	88	5
King Crab	16.0	Alaska	38	6	
Haddock	14.1	NE	7	99	19
Blue Crab	10.8	Ches., S. Atl.	148		
Halibut	9.6	NW	17	31	4
Scallops	7.7	NE	1	10	
Dungeness Crab	7.3	Alaska	30		
Whiting		NE	42	62	
Ocean Perch		NE	10	10	4
Cod		NE	10	33	8

[1]Source: Bureau of Commercial Fisheries, 1968

a. Location of new fishing areas

Many, if not most, of the major fisheries in the 11 biophysical regions considered in this study have been identified. Nonetheless, "new" species and fishing grounds are sought and these may be extremely important to coastal economies where local competition for stocks is highest.

The shrimp fishery is an example of an operation partially dependent on the location of new and productive fishing areas. Although most of the general shrimping areas in the Gulf of Mexico and the Middle and South Atlantic are well known, new areas need to be located The discovery of new areas depends upon sampling the population which the fishing fleet desires to catch. Specifically in the case of shrimp, "try nets" are pulled as a routine operation before the setting of the main trawls. Such sampling practices in local, yet unfamiliar waters, frequently leads to the discovery of significant new or underutilized fishery resources.

A number of data types are also useful in the location of new fishing areas. While water temperature and plankton concentration are probably the two most important indirect indicators of possibly productive fishing areas, other supplementary data are useful. Fresh water inflow, salinity, dissolved organics, and water color are also good indicators of productivity, especially in estuarine areas; and these data may identify nearby harvesting areas. Pesticide data are useful in assessing damage to nursery stocks and the marketability of the surviving catchable species.

b. Improve scouting operations

Scouting for fishery stocks has mainly been combined with the actual fishing operation. In practice, fishermen search for stocks until some significant number are located, then harvest them. This practice has been inefficient, particularly in the case of scouting and fishing for pelagic species. Tuna fishermen, for example, have until recently left port with a gross knowledge of stock location, and cruised widely until fish were visually sighted. Transit and scouting operations are responsible for about 70 percent of overall fishery costs.

The use of aircraft in the location of tuna, menhaden, and anchovies represents a significant improvement in overall efficiency. Experienced pilots can locate schools of pelagic fish, identify them, and relay their position to the fishing vessels at a fraction of the cost required to find the stocks visually, using the fishing vessel as a scouting platform.

Knowledge of current direction and speed, other biological populations (e.g., food stocks or predators), water temperature, and regional bathymetry can enhance the scouting operation regardless of the method used.

c. Improve catching operations

Improvement of the catching operation in most fisheries is dependent upon market incentive, knowledge of new and improved equipment and methods, and the breaking of traditional fishing ties. Fishermen, especially those engaged in nearshore or coastal fisheries, have been reluctant to employ techniques other than those considered "tried and true."

The catching operation depends to a great degree upon the efficiency of scouting and location of significant stocks, but once the fisherman has his vessel in the proximity of a quantity of fish, he must put his equipment, knowledge, and skill to the test. Airborne direction of pelagic tuna and menhaden fishing has proved to be highly successful. Catching vessels are directed to or around the schools as the case requires, so that the vessels do not run over a school, increasing the possibility of the stocks scattering or sounding.

Two types of data may be critical in the catching operation: water temperature and bathymetry. Temperature is needed for judging the depth of set for traps, nets, and long-lines; bathymetry is required to prevent the fouling of fishing gear on the bottom and to aid the fisherman in setting gear for specific depths.

d. Forecast seasonal and long-term variation in abundance

For more than three decades, fisheries biologists have been attempting to determine the dynamics of fish populations. Fish, as well as land animals, have their own preferences for food and environment. Because of this, they tend to congregate in areas where their particular food is most plentiful and water temperature most agreeable. Most fish migrate during certain seasons of the year along comparatively well defined routes, stimulated by the urge to spawn, feed, or winter in a different location. Many species tend to feed and migrate as a group or school. A sound knowledge of migratory cycles, routes, and schooling behavior is necessary in forecasting the most favorable catch areas. Fishery charts, currently being developed on a world-wide scale, are largely based on this knowledge.

e. Provide a scientific basis for management of exploited fisheries

The first steps in developing a sound basis for regulation and management of exploited as well as unexploited fisheries is the identification of the various unique biological units (races or populations) in the fishery. For example, in Alaska, there are at least 2,000 salmon streams. Each unit requires a different set of conditions for survival and reproduction. Each competes for living and spawning areas and food supply. Research at the University of Washington indicates that a further distinction must be made between biological and management units. It defines the latter to include all salmon that enter "...a distinct fishing area during a specific period, which must be regulated as a unit." From the standpoint of efficiency, each management group should be as small and include as few spawning groups as possible.

The second step in developing management mechanisms for exploited fisheries is to assess economically the levels of effort and catch under commercial exploitation When catch data are combined with biological yield data, economic production functions can be derived to provide an index of optimum levels of exploitation.

The third step is provision of regulations and enforcement powers to insure the maintenance of a maximum sustained yield to society at a minimum cost to the fishermen. Data on population size are critical to the first step; the other steps require economic and social data which are not included in this study.

1.3.3 Hazards to Shipping and Coastlines

Despite the advanced state of the art of vessel navigation and coastal cartography, many ships and small boats are lost or damaged by grounding each year. While loss of life is being reduced in such incidents, private and public property losses continue to climb. The recent and widely publicized groundings of the TORREY CANYON and OCEAN EAGLE are illustrative of the environmental losses, principally public, incurred.

Coastal areas encompassing river and estuary entrances may have rapidly changing wind, wave, and tidal effects. Since these are areas frequently used for marine transportation to and from inland harbors, they should be regularly and accurately charted.

The loss of land and property to erosion, whether caused by hurricanes, winter storms, currents, or other forces, amounts annually to millions of dollars. Hurricanes sometimes result in loss of life also. The hurricane tracking and forecasting effort supported by a network of weather forecasting stations operated by U. S. agencies has played a major role in reducing loss of life, and to some degree, property, through accurate forecasting and data dissemination techniques. The major issues related to hazards to shipping and coastlines are:

a. Identify hazards to navigation

The identification of hazards to navigation is frequently data limited, owning to the infrequence of coastal hydrographic surveys and increasing use of coastal and estuarine waters for marine transportation and recreation. The bathymetry of the sea floor shifts under the influence of environmental forces, particularly in shallow water, and knowledge of such changes in coastal areas is important.

Sea ice has long been recognized as one of the more serious hazards to navigation in northern waters. Coast Guard ice patrolling and icebreaking have alleviated the most serious handicaps to marine navigation; nonetheless, sea and lake ice data are needed on a more complete scale for planning and operations in icy areas.

Meteorological data, including air temperature and pressure, wind speed and direction, and cloud type, are needed for predicting and monitoring hurricanes, tropical storms, and coastal squalls. Water current and hydrographic data are required to detect and monitor shoaling conditions along coastal inlets and in harbor waterways.

Meteorological data, including weather forecasts, are generally available through broadcasts and teletype. Dissemination of bathymetric and topographic data, as well as the location of wrecks and obstructions, requires the preparation, updating and distribution of charts and maps.

b. Provide climatological information

The availability of climatological information is critical to almost all uses of the coastal zone. Accurate forecasting requires the near-continuous monitoring of air and water temperatures, barometric pressure, and other meteorological data. A further requirement is that properties be reported synoptically from a number of sensors to a local center for analysis and aid in forecasting.

Climatological data are used to assess extreme coastal oceanographic conditions needed for final engineering design of coastal and offshore structures. Although hurricanes are noted for catastrophic effects, immense damage can be inflicted also by fast-moving coastal thundersqualls.

c. Monitor hazardous ocean phenomena

Among the most hazardous and destructive oceanic phenomena are hurricanes, thunderstorms, waterspouts, and icebergs. Surveillance of these phenomena in coastal areas and conditions conducive to their occurrence should be selectively expanded.

d. Assist rescue operations

Where lifesaving is involved in rescue operations, data contributing to search and rescue decisions should be of good quality.

Several types of data may be critical to rescue operations. Sea state observations, and information concerning water and air temperature, water currents, wind velocity, and other meteorological factors are required for timing, as well as effecting rescue operations. The data will aid in locating survivors and indicate survival time, which may affect rescue decisions, particularly the mode of rescue.

1.3.4 Coastal Geography and Cartography

The major issues are:

a. Complete and update coastal areas survey

Most of the coastline of the United States has been charted by one or more Federal agencies. However, the dynamic nature of coasts requires that cartographic presentations be updated at regular intervals and immediately after sudden change. In general, the continental shelf to the 200 meter isobath (and beyond) has been charted only for navigational purposes. Bathymetric, geological, and geophysical mapping of the continental shelf and slope have only begun.

Data describing current fields, tidal characteristics, bottom sediments, depth, hazards, etc., are needed for updating coastal area navigation charts. Critical area navigational charts require that regular updating be effected and that the information be distributed to users promptly.

Mineral exploration has been initiated in a few areas of the U. S. continental shelf, but the majority of the shelf has not been adequately explored or described. With the exception of exploration for pertoleum, some shelf areas have not been explored at all

Data that would contribute to description of the continental shelf include sediment type, distribution, permeability, and porosity, and sea bed and sub-bottom profiles.

b. Identify coastal land use patterns

One of the major tasks of the coastal zone manager is the identification of coastal land use patterns. This task appears to be deceptively simple, one of description. However, coastal land uses have followed no particular pattern, especially where development has occurred on a piecemeal basis.

In order for coastal managers to achieve a reasonable degree of success, rational prediction should be invoked in preparation for zoning and best-use designation of coastal zone properties, above and below the water.

One major responsibility of the coastal manager is to assure that the reasonable demands of people using coastal resources -- now and in the future -- be met. This requires that the managers plan to set aside areas for specific purposes, such as recreation (all types as direct service to the public interest) and heavy industry (to help alleviate future conflict between industrial and other developers in the private and public sectors).

Many data types required for coastal area planning are social, economic, and political, and are beyond the scope of this study.

Coastal managers require specific inventories of many types of resources and land and water use. Current and historical survey data are required for wise planning and best-use decisions. Coastal zone planners also require that usage data be assembled on a regional, as well as a local basis. High resolution presentations also are needed for detailed study and decisions. Updating for both should be effected at least annually.

c. <u>Assess mineral resources</u>

Continuing publicity given to a few underseas mining operations in various parts of the world is generating increased worldwide interest in coastal exploration. Recognition of the potential and possible importance of sea bed minerals in strengthening a national resource base has stimulated some States to encourage offshore exploration and development, by more clearly defining the laws and regulations regarding exploitation of underseas mineral resources within their jurisdiction.

Underseas mining remains in its infancy. The oceans present formidable problems to the discovery, delineation, and recovery of mineral resources, yet the minerals obtained from them must compete economically with landbased sources of supply. Recent experience has shown that development of the capacity necessary for sustained, profitable production of coastal seabottom minerals is extremely difficult, but possible.

The sequence of steps required to bring marine mineral deposits into production is essentially the same as for dryland minerals. First, a deposit must be located and explored to the extent necessary for a preliminary economic judgement. Secondly, if the judgement is favorable, the deposit must be characterized in sufficient detail to provide a basis for determining production technology requirements and to estimate as realistically as possible the profitability of its exploitation.

The problems normally confronting these initial steps are compounded in the marine environment by several factors, either relatively easy to control or non-existent on land. The sea presents unique problems in precisely assessing subsurface mineral deposits.

One essential requirement in the delineation of underseas minerals is accurate navigation. Deposits should be accurately defined; once established, identifying points must be readily relocatable. Significant advances have been made in the development of small portable positioning systems which provide reasonably high accuracy within short operating ranges, and therefore, are of particular interest to the marine mining industry. Systems also have been developed for placing buoys on the ocean floor. Rather than depending upon visual sighting, these ocean-floor buoys can be located by acoustic or electronic sensory systems.

The magnetometer is an exploration tool adapted for marine use. Because of the relative simplicity of its sensor arrangement, the proton magnetometer has been the instrument most widely used for geophysical surveys. Currently, the rubidium magnetometer is being adapted to the marine environment.

Although progress has been made in some problem areas confronting the exploration of seafloor mineral deposits, a major problem remains, namely, the accurate determination of mineral content and spatial distribution, without which a realistic preliminary economic judgement for recovery is not possible. Currently available sampling tools of the oceanographer, while useful for reconnaissance, are inadequate for obtaining the kind and quality of sample necessary for economic appraisal. This deficiency has been recognized, and improved sampling devices are in the design, fabrication and testing stages.

Besides offshore sand and gravel recovery, marine mining is in progress, for shells in San Francisco Bay and on the Texas coast, and for aragonite on the coast of Florida. These operations are in relatively shallow water, from 30 to 150 feet deep, close to shore, and in relatively sheltered areas.

d. Monitor and control shoreline processes

Seacoasts are dynamic features which respond in various ways to changing energy forces. The coastal zone includes the area in which bottom sediments and organisms are affected by tidal phenomena, longshore currents, periodic surges, and breaking waves. Additionally, the geographic location, climatic province, and substrate determine the nature of sedimentary processes and the density of organic populations.

Numerous coastal processes affect the dynamic equilibrium of coastlines. To monitor and control these processes, the following information is frequently needed: wave and tidal characteristics, current data, littoral transport and wave energy calculations, and accretion and erosion rates. The last are needed for engineering design and planning for changes that might follow the installation of beach protection and stabilization works.

1.4 Identifying Related Oceanographic Data Needs

1.4.1 Approach

A matrix approach was employed to facilitate analysis of the data needed to resolve the issues identified in the preceding sections. The matrix relates data types to key coastal zone issues. Values, reflecting conclusions of our analysis, are assigned within cells on a scale: 0 - unimportant, 1 - important, and 2 - critical. Column sums are indices of the relative value of each data type to the resolution of the specified national problems.

1.4.2 Definition of Data Types

Definition of the data descriptors used in the matrix presented in Section 1.4.3 are given below:

<u>Ice</u> - Occurrence, position of ice field limits, thickness, and concentration.

<u>Water Temperature</u> - Principally surface temperature, but can include temperature at any point in the water column.

<u>Water Density</u> - At any selected point.

<u>Currents</u> - Horizontal and vertical current direction and speed.

<u>Tides</u> - Height, period, volume.

<u>Waves</u> - Height, period, direction.

<u>Breakers and Surf</u> - Height, breaker depth, width of zone.

<u>Plankton (including fish eggs and larvae)</u> - Count, by species of plant and animal.

<u>Bacteria</u> - Fecal and total coliform counts; sphaerotilus - presence and mass.

Insects - Presence and number (by species).

Fish - Presence and number (by species).

Marine Mammals - Presence and number (by species).

Fouling Organisms - Presence and number (by species) mainly of barnacle-type growth and boring organisms.

Bioluminescence - Presence and distribution pattern.

Pigment Content - Presence and concentration of specified pigment.

Bioassays - A measure of biological response to pollution or other environmental alteration, obtained under controlled laboratory conditions or through observations in nature.

Color - Principally sea color.

Sediment Description - Identification of principal types of bottom sediments, e.g., gravel, shell, sand, clay; and the spatial arrangement of the principal sediment types.

Bathymetry - Depths below the sea surface.

Magnetic Field - Measurement of anomalies in the magnetic field of the earth.

Gravitational Field - Measurement of variations in acceleration due to gravity.

Permeability - Measure of the ability of fluids to move through the bottom sediments

Porosity - The relative volume of interstices in bottom materials.

Bottom O2 Uptake - Consumption of dissolved oxygen by bottom constituents.

Sediment pH - The hydrogen ion concentration of bottom materials.

Air Temperature - Ambient temperature at any specified point.

Barometric Pressure - The atmospheric pressure, principally at sea level.

Wind Speed - Measure of speed, principally of surface winds.

Wind Direction - Indication of the direction of surface wind flow.

Humidity - Relative humidity - the ratio of the amount of water vapor actually present in the air, principally at the surface, to the greatest amount possible at the same temperature.

Solar Radiation - Total incoming solar energy.

Tsunamis - Historical data - frequency, water level, location, damage.

Fresh Water Inflow - A measurement of total fresh water from land runoff, watersheds.

Sediment Settling Rate - Apparent rate of settling.

Salinity - Measure of total dissolved solids, principally salt concentrations.

Nutrients - Concentration of nurtient salts, principally of nitrogen and phosphate

Dissolved Gases - Concentration, mainly of oxygen and carbon dioxide.

Radioactive Tracers - Total counts of specific labeled compound.

Metals - Concentration of heavy metals, mainly mercury, lead, cadmium, silver, zinc, chromium.

pH - Measure of hydrogen ion concentration.

Particulates - Measure of suspended and floating solids.

Dissolved Organics - Measure of dissolved organic constituents, such as vitamins.

Pesticides & Herbicides - Principally concentration of DDT and its metabolities, Aldrin, Dieldrin, 2-4-D, 2-4-5T as indicators.

Petroleum - Floating, suspended, dissolved hydrocarbons.

Precipitation - Total rain, hail, mist, sleet, or snow fall.

Clouds - Identification of cloud cover, location, aerial expanse.

Topography - Elevations above the water surface.

Land Use - Identification of the principal type of land use.

Soils and Geology - Description of land above the water surface.

Vegetation - Description of terrestrial and aquatic growth.

1.4.3 Matrix Analysis

The analysis discussed in Section 1.4.1 is presented in Table 1-2, Importance of Data Types to Coastal Issues. Table 1-3 presents in summary and normalized form the values and column sums of Table 1-2.

TABLE 1-2

IMPORTANCE OF DATA TYPES TO COASTAL ISSUES

ISSUES*	Physical Properties of Water: Ice	Water Temp	Currents	Tides	Waves	Breakers & Surf	Tsunamis	Fresh Water inflow	Water Density	Chemical Properties of Water: Salinity	Nutrients	Dissolved Gases	Radio Tracers	Metals	pH	Dissolved Organics	Pesticides & Herb	Petroleum
POLLUTION																		
Locate Sources of Discharge	1	1	2	1	0	0	0	1	1	2	1	1	1	1	1	0	0	2
Determine Types of Discharge	0	2	0	0	0	0	0	0	1	2	2	2	2	2	2	2	2	1
Determine Extent of Pollution Effects	0	0	2	1	0	0	0	1	2	1	0	0	0	1	1	0	0	1
Determine Assimilative Capacity	0	2	2	2	0	0	0	2	2	1	1	1	1	1	1	0	0	2
Optimal Siting for Industry	0	2	2	2	1	0	2	0	2	2	1	1	1	1	1	1	1	2
Effect Enforcement	0	1	0	0	0	0	0	0	0	1	1	1	1	1	1	1	1	2
Assist Rapid Clean-up	0	2	2	2	2	2	0	2	1	1	0	0	0	1	1	0	0	2
FISHERIES																		
Locate New Fishing Areas	0	2	1	1	0	0	0	1	2	2	2	2	0	2	2	2	2	0
Improve Scouting Operations	0	0	2	1	0	0	0	1	0	0	2	1	0	0	0	2	0	0
Improve Catching Operations	0	2	1	1	1	0	0	1	1	0	0	0	0	0	0	0	0	1
Forecast Abundance	0	1	2	0	0	0	0	1	1	1	2	1	0	0	0	1	1	1
Improve Management	0	2	2	0	0	0	0	2	0	2	1	1	0	0	1	0	1	0
HAZARDS TO SHIPPING & COASTLINES																		
Identify Hazards to Navigation	2	1	2	2	1	1	1	0	0	0	0	0	1	0	0	0	0	2
Provide Climatology	1	2	1	0	1	1	0	0	1	0	0	0	0	0	0	0	0	0
Monitor Ocean Phenomena	2	2	2	1	2	1	2	0	1	1	0	0	1	0	0	0	0	0
Assist Rescue Operations	1	2	2	1	2	2	0	0	0	0	0	0	0	0	0	0	0	1
COASTAL GEOGRAPHY & CARTOGRAPHY																		
Assess Mineral Resources	0	1	1	1	0	1	0	0	0	1	1	0	1	2	1	0	0	2
Improve Coastal Surveys	1	1	1	1	0	0	0	1	0	1	1	0	1	1	0	0	0	1
Identify Land Use	0	1	1	1	0	0	1	1	0	1	1	0	1	1	1	1	1	1
Monitor Shoreline Processes	1	1	2	2	1	2	1	1	1	0	0	1	1	0	0	0	0	0

ISSUES*	Biological Properties of Water: Plankton	Bacteria	Insects	Fish	Marine Mammals	Fouling Organisms	Bioluminescence	Pigment Content	Bioassays	Color	Geological & Geophysical Properties of Bottom: Sediments	Bathymetry	Magnetics	Gravity	Permeability	Porosity	Bottom O_2 Uptake	Particulates	Sediment Settling Rate	Sediment pH
POLLUTION																				
Locate Sources of Discharge	1	1	1	1	0	1	0	1	1	2	1	1	0	0	1	1	0	1	0	1
Determine Types of Discharge	2	2	1	1	0	1	0	1	2	2	0	1	0	0	1	1	2	2	0	1
Determine Extent of Pollution Effects	1	1	1	1	1	1	1	1	2	2	1	1	0	0	1	1	1	1	1	1
Determine Assimilative Capacity	1	1	1	0	0	0	0	0	1	0	1	1	0	0	2	2	2	1	0	1
Optimal Siting for Industry	1	1	1	1	1	1	0	0	2	1	1	2	0	0	2	1	1	1	2	1
Effect Enforcement	1	1	1	1	0	1	0	1	2	1	1	1	0	0	1	1	1	1	0	1
Assist Rapid Clean-up	1	1	0	0	0	0	0	0	1	0	1	1	0	0	1	1	1	1	0	1
FISHERIES																				
Locate New Fishing Areas	2	2	1	2	2	0	2	2	2	2	1	2	0	0	0	0	1	1	0	1
Improve Scouting Operations	2	0	0	2	2	0	1	1	1	2	0	2	0	0	0	0	0	1	0	0
Improve Catching Operations	1	0	0	1	0	0	0	0	0	0	0	2	0	0	0	0	0	0	0	0
Forecast Abundance	2	0	0	2	2	0	0	0	1	0	1	0	0	0	0	0	1	0	1	1
Improve Management	2	1	0	2	1	1	0	1	2	1	1	2	0	0	0	0	0	0	1	0
HAZARDS TO SHIPPING & COASTLINES																				
Identify Hazards to Navigation	0	0	0	0	0	1	0	0	0	1	2	2	1	1	0	0	0	1	1	0
Provide Climatology	0	0	0	0	0	0	0	0	0	0	0	0	1	1	0	0	0	0	0	0
Monitor Ocean Phenomena	0	0	0	0	0	0	0	0	0	1	0	1	0	0	0	0	0	0	0	0
Assist Rescue Operations	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0
COASTAL GEOGRAPHY & CARTOGRAPHY																				
Assess Mineral Resources	0	0	0	0	0	0	0	0	0	1	2	2	1	1	1	1	1	1	1	1
Improve Coastal Surveys	1	0	0	1	0	0	0	0	0	1	2	2	1	1	1	1	0	1	1	0
Identify Land Use	1	0	0	1	1	1	0	0	1	1	1	2	0	0	0	0	0	1	1	0
Monitor Shoreline Processes	0	0	0	0	0	1	0	0	0	1	2	2	0	0	1	1	0	1	1	0

ISSUES*	Atmosphere: Air Temperature	Baro Pressure	Winds	Humidity	Solar Radiation	Precipitation	Clouds	Land Characteristics: Topography	Land Use	Soils and Geology	Vegetation
POLLUTION											
Locate Sources of Discharge	1	0	1	1	0	1	1	0	0	0	1
Determine Types of Discharge	0	0	0	0	0	0	0	0	0	0	1
Determine Extent of Pollution Effects	1	1	1	1	0	1	0	0	1	0	1
Determine Assimilative Capacity	1	1	1	1	1	1	0	0	0	1	1
Optimal Siting for Industry	1	1	0	0	0	1	0	1	2	1	1
Effect Enforcement	1	1	0	1	1	1	0	0	0	0	0
Assist Rapid Clean-up	0	0	1	0	0	1	0	1	1	2	1
FISHERIES											
Locate New Fishing Areas	1	0	0	0	2	0	0	1	0	0	1
Improve Scouting Operations	0	0	1	0	0	1	2	0	0	0	[illegible]
Improve Catching Operations	0	0	1	0	0	1	0	0	0	0	1
Forecast Abundance	1	1	1	0	1	1	0	0	1	0	1
Improve Management	0	0	0	0	0	0	0	0	1	0	1
HAZARDS TO SHIPPING & COASTLINES											
Identify Hazards to Navigation	1	1	2	0	0	1	1	2	0	0	1
Provide Climatology	2	2	2	2	2	2	2	1	0	0	0
Monitor Ocean Phenomena	2	2	2	2	2	2	2	0	0	0	0
Assist Rescue Operations	1	0	2	0	0	1	1	1	0	0	0
COASTAL GEOGRAPHY & CARTOGRAPHY											
Assess Mineral Resources	0	0	0	0	0	0	0	2	2	2	1
Improve Coastal Surveys	0	0	0	0	0	0	0	1	1	1	1
Identify Land Use	1	0	1	0	1	1	1	1	2	1	1
Monitor Shoreline Processes	1	0	1	0	0	0	0	2	1	2	2

*See text for complete titles

TABLE 1-3

SUMMARY MATRIX

Convention:

a. Matrix Sum Table 1-2
b. Normalized Sum

PROBLEM AREAS		Physical Properties of Water									Chemical Properties of Water								
		Ice	Water Temperature	Currents	Tides	Waves	Breakers & Surf	Tsunamis	Fresh Water Inflow	Water Density	Salinity	Nutrients	Dissolved Gases	Radioactive Tracer	Metals	pH	Dissolved Organics	Pesticides & Herb.	Petroleum
Pollution	a.	1	10	10	8	3	2	2	6	9	10	6	6	6	8	8	4	4	12
	b.	0.1	1.4	1.4	1.1	0.4	0.3	0.3	0.9	1.3	1.4	0.9	0.9	0.9	1.1	1.1	0.6	0.6	1.7
Fisheries	a.	0	7	8	3	1	0	0	6	4	5	7	5	0	2	3	5	4	2
	b.	0	1.4	1.6	0.6	0.2	0	0	1.2	0.8	1.0	1.4	1.0	0	0.4	0.6	1.0	0.8	0.4
Hazards to Shipping & Coastlines	a.	6	7	7	4	6	5	3	0	2	1	0	0	2	0	0	0	0	3
	b.	1.5	1.8	1.8	1.0	1.5	1.2	0.8	0	0.5	0.2	0	0	0.5	0	0	0	0	0.8
Coastal Geography & Cartography	a.	2	4	5	5	1	3	2	3	1	3	3	1	4	4	2	1	1	4
	b.	0.5	1.0	1.2	1.2	0.2	0.8	0.5	0.8	0.2	0.8	0.8	0.2	1.0	1.0	0.5	0.2	0.2	1.0
Column Sum Normalized Values*		2.14	5.58	6.03	3.99	2.38	2.29	1.54	2.81	2.84	3.43	3.01	2.11	2.36	2.54	2 24	1.82	1.62	3.87

*Values rounded to nearest tenth except for sum.

TABLE 1-3 (Cont'd)

MATRIX SUMMARY

Convention

a. Matrix Sum Table 1-2
b. Normalized Sum

Biological Properties of Water

PROBLEM AREAS		Plankton	Bacteria	Insects	Fish	Marine Mammals	Fouling Organisms	Bioluminescence	Pigment Content	Bioassays	Color
Pollution	a.	8	8	6	5	2	5	1	4	11	8
	b.	1.1	1.1	0 9	0.7	0 3	0.7	0.1	1.6	1 6	1.6
Fisheries	a.	9	3	1	9	7	1	3	4	6	5
	b.	1.8	0.6	0.2	1.8	1.4	0.2	0.6	0 8	1.2	1.0
Hazards to Shipping & Coastlines	a.	0	0	0	0	0	1	0	0	0	2
	b.	0	0	0	0	0	0.2	0	0	0	0.5
Coastal Geography & Cartography	a.	2	0	0	2	1	2	0	0	1	4
	b.	0.5	0	0	0.5	0 2	0.5	0	0	0.2	1 0
Column Sum Normalized Values*		3.44	1.74	1.06	3.02	1.94	1.67	0.74	1.37	3.02	3.64

Geological & Geophysical Properties of Bottom

PROBLEM AREAS		Sediments	Bathymetry	Magnetics	Gravity	Permeability	Porosity	Bottom O_2 Uptake	Particulates	Sediment Set. Rate	Sediment pH
Pollution	a.	6	8	0	0	9	8	8	8	3	7
	b.	0 1	1.1	0	0	1 3	1 1	1.1	1.1	0.4	1.0
Fisheries	a.	3	8	0	0	0	0	2	2	2	2.0
	b.	0.6	1 6	0	0	0	0	0.4	0.4	0.4	0 4
Hazards to Shipping & Coastlines	a.	2	4	2	2	0	0	0	1	1	0
	b.	0.5	1.0	0.5	0.5	0	0	0	0 2	0.2	0
Coastal Geography & Cartography	a.	7	8	2	2	3	3	1	4	4	1
	b.	1.8	2.0	0.5	0.5	0.8	0.8	0.2	4.0	1.0	0.2
Column Sum Normalized Values*		3.71	5.74	1 00	1 0	2.04	1 89	1.79	2.79	2.08	1.65

*Values rounded to nearest tenth except for sum.

TABLE 1-3 (Cont'd)

SUMMARY MATRIX

Convention:

a. Matrix Sum Table 1-2
b. Normalized Sum

PROBLEM AREAS		Atmosphere							Land Characteristics			
		Air Temperature	Baro. Pressure	Winds	Humidity	Solar Radiation	Precipitation	Clouds	Topography	Land Use	Soils & Geology	Vegetation
Pollution	a.	5	4	4	4	2	6	1	2	4	4	6
	b.	0.8	0.6	0.6	0.6	0.3	0.9	0.1	0.3	0.6	0.6	0.9
Fisheries	a.	2	1	3	0	3	3	2	1	2	0	4
	b.	0.4	0.2	0.6	0	0.6	0.6	0.4	0.2	0.4	0	0.8
Hazards to Shipping & Coastlines	a.	6	5	8	4	4	6	6	4	0	0	1
	b.	1 5	1.2	2.0	1.0	1.0	1.5	1.5	1.0	0	0	0.2
Coastal Geography & Cartography	a.	2	0	2	0	1	1	1	6	6	6	5
	b.	5	0	0.5	0	0.2	0.2	0.2	1.5	1.5	1.5	1.2
Column Sum Normalized Values*		3.12	2.02	3.67	1.57	2.14	3.21	2.29	2.99	2.47	2.07	3.16

*Values rounded to nearest tenth except for sum.

1.4.4 Summary of Matrix Analysis

Based on the foregoing analyses, data types most relevant to each of the four national problem areas are (from Table 1-3):

Pollution

Petroleum*
Bioassays*

Water Temperature*
Currents*
Salinity*

Water Density*
Permeability*

pH*
Tides*
Metals
Plankton*
Color*
Bathymetry*
Particulates*
Porosity (bottom)*
Bottom O_2 Uptake*
Bacteria*

Sediment pH

Fisheries

Fish*
Plankton*

Currents*
Bathymetry*

Water Temperature*
Nutrients*
Mammals*

Fresh Water Inflow
Bioassays*

Salinity*
Dissolved Gases*
Dissolved Organics*
Color*

Hazards to Shipping & Coastlines

Winds*

Water Temperature*
Currents*

Ice*
Waves*
Air Temperature*
Precipitation*
Clouds*

Barometric Pressure*
Breakers & Surf*

Tides*
Bathymetry*
Humidity*
Solar Radiation*
Topography*

Coastal Geography & Catrography

Bathymetry
Sediments*

Topography
Land Use*
Soils & Geology*

Currents*
Tides*
Vegetation

Water Temperature
Sediment Settling Rate
Radioactive Tracer Concentration
Particulates
Color
Metals
Petroleum

*Indicates data types critical to one or more issues in a national problem area.

] Indicates data types receiving approximately equal rating in the matrix analysis.

In addition, the following data types were found to be critical to at least one issue:

Nutrients
Bioluminescence
Pigment Content

Considering all four national problem areas, the following list identifies the data types considered most relevant to the solution of coastal zone problems, in order of value from Table 1-3.

Currents*
Bathymetry*
Water Temperature*
Tides*
Petroleum*
Sediments*
Winds
Color*
Plankton*
Salinity*
Precipitation
Vegetation
Air Temperature
Fish
Bioassays*
Nutrients*
Topography*
Water Density*
Fresh Water Inflow*
Particulates
Metals*
Land Use*
Waves*

*Indicates the data are critical to the solution of issues in more than one national problem area.

SECTION 2.0

MEASUREMENT REQUIREMENTS

2.1 Measurement Specifications

For priority data types identified in Section 1.4.4, consideration has been given to data applications, including specific ways in which the data might be used, either independently or correlated with other data, to attack the critical coastal zone issues. In this way judgments were made on selected measurement specifications such as spatial resolution, frequency of measurement, data response time, and field of view. This analysis is presented in Tables 2-1 through 2-23*.

2.2 Spacecraft Measurement Candidates

Measurement requirements for each of the data types shown in Tables 2-1 to 2-23 were compared to the measurement capabilities of both current remote sensors and those ancicipated by the 1975 period. Factors considered, among others, were the emission characteristics of the phenomena to be measured and the measurement accuracies required in terms of delineating both the spatial and spectral properties of the phenomena being measured. From this analysis it was possible to determine which data types were likely to be measurable from spacecraft altitudes (also those not likely to be measurable) and the type of sensors that would be necessary to perform the measurements. Data types were identified as non-measurable either on the basis that they could not be measured from spacecraft altitudes or that other methods were more suitable.

This section of the report describes the basis for selection of the data types to be measured and relates each type to one or more corresponding methods of measurement. Specific types of sensors which are capable of making similar types of measurements are indicated and specific operating parameters for these sensors as defined for the coastal zone are discussed.

2.2.1 Basis for Selection

There are many factors that need to be considered in order to determine whether or not a particular measurement can be made from space altitudes and whether or not a suitable sensor exists to make the measurement. Those of primary importance include the determination of the energy characteristics of the phenomena to be measured and the determination of spectral intervals which will permit optimum viewing. Also of major importance are the spatial and spectral resolution requirements and accuracies. Others, of perhaps lesser importance, include the geographical extent of the areas of interest,

*Sea ice substituted for air temperature in Tables.

TABLE 2-1

MEASUREMENT SPECIFICATIONS - CURRENTS

NEED	ISSUE	SPATIAL RESOLUTION	FREQUENCY OF MEASUREMENT	DATA RESPONSE TIME	SIZE OF FIELD OF INTEREST
Pollution	Locating Sources of Discharge	10m-100m	1/day	1 wk	0.1-10km
	Determining Types of Discharge	-	-	-	-
	Determining Extent of Pollutant Effect	10-100m	1/day	1 wk	0.1-10km
	Determining Assimilative Capacity	10-100m	1/day	1 wk	0.1-10km
	Optimal Siting of Effluent Producing Ind.	10-100m	1/day	1 mo	0.1-10km
	Effect Enforcement Action	-	-	-	-
	Assist Rapid Cleanup of Accidents*	10-100m	1/hr	inst	0.1-10km
Fisheries	Location of New Fishing Areas	100-1000m	1/wk	1 day	1.0-100km
	Improve Scouting Operations	100-1000m	1/day	1 day	1-100km
	Improve Catching Operations	100-1000m	1/day	1 day	1-100km
	Forecast Seasonal & Long Term Variations	100-1000m	1/wk	1 mo	1-100km
	Provide Scientific Basis For Mgmt.	-	-	-	-
Hazards to Shipping & Coastlines	Identify Hazards to Navigation	100-1000m	1/day	1 day	1-100km
	Provide Climatological Information	1-10km	1/day	1 day	1-100km
	Monitor Hazardous Ocean Phenomena	1-10km	1/day-1/hr	1 day	1-100km
	Assist Rescue Operations	100-1000m	1/hr	inst	1-100km
Coastal Geography & Cartography	Assess Mineral Resources	100-1000m	1/mo	1 mo	1-100km
	Complete and Update Coastal Surveys	100-1000m	1/day	1 wk	1-100km
	Identify Coastal Land Use Patterns	100-1000m	1/wk	1 mo	1-100km
	Monitor & Control Shoreline Processes	10-100m	1/wk	1 wk	.1-10km
	- Not relevant to the issue. *Data needs most acute here. Short reporting time				

TABLE 2-2

MEASUREMENT SPECIFICATIONS - BATHYMETRY

NEED	ISSUE	SPATIAL RESOLUTION	FREQUENCY OF MEASUREMENT	DATA RESPONSE TIME	SIZE OF FIELD OF INTEREST
Pollution	Locating Sources of Discharge	10-100m	1/wk	1 day	0.1-10km
	Determining Types of Discharge	100-1000m	1/mo	1 wk	1-100km
	Determining Extent of Pollutant Effect	1-10km	1/mo	1 wk	1-100km
	Determining Assimilative Capacity	100-1000m	1/wk	1 wk	1-100km
	Optimal Siting of Effluent Producing Ind	100-1000m	1/wk	1 mo	1-100km
	Effect Enforcement Action	100-1000m	1/wk	1 wk	1-100km
	Assist Rapid Cleanup of Accidents	100-1000m	1/wk	1 day	1-100km
		100-1000m	1/wk	1 day	1-100km
Fisheries	Location of New Fishing Areas	1-10km	1/mo	1 mo	1-100km
	Improve Scouting Operations	1-10km	1/mo	1 mo	1-100km
	Improve Catching Operations	1-10km	1/mo	1 mo	1-100km
	Forecast Seasonal & Long Term Variations	-	-	-	-
	Provide Scientific Basis For Mgmt.	-	-	-	-
Hazards to Shipping & Coastlines	Identify Hazards to Navigation	100-1000m	1/wk	1 day	1-100km
	Provide Climatological Information	1-10km	1/wk	1 day	1-100km
	Monitor Hazardous Ocean Phenomena	1-10km	1/wk	1 day	1-100km
	Assist Rescue Operations	100-1000m	1/wk	1 day	1-100km
Coastal Geography & Cartography	Assess Mineral Resources	10-100m	1/mo	1 mo	0.1-10km
	Complete and Update Coastal Surveys	100m-1000m	1/mo	1 mo	1-100km
	Identify Coastal Land Use Patterns	10-100m	1/mo	1 mo	0.1-10km
	Monitor & Control Shoreline Processes	10-100m	1/wk	1 wk	0.1-10km

- Not relevant to the issue

TABLE 2-3

MEASUREMENT SPECIFICATIONS - WATER TEMPERATURE

ISSUE	SPATIAL RESOLUTION	FREQUENCY OF MEASUREMENT	DATA RESPONSE TIME	ACCURACY RANGE/SENS'VTY	SIZE OF FIELD OF INTEREST
Pollution					
Locating Sources of Discharge	10-100m	1/wk	1 day	0-50°C ±0.1°C	0 1-10km
Determining Types of Discharge	10-100m	1/mo	1 wk	0-50°C ±0 1°C	0 1-10km
Determining Extent of Pollutant Effect	-	-	-	-	-
Determining Assimilative Capacity	10-100m	1/wk	1 wk	0-50°C ±0 1°C	0 1-10km
Optimal Siting of Effluent Producing Ind	10-100m	1/wk	1 wk	0-50°C ±0 1°C	0 1-10km
Effect Enforcement Action	10-100m	1/hr-cont	1 day	0-50°C ±0.1°C	0 1-10km
Assist Rapid Cleanup of Accidents	10-100m	1/hr	1 hr	0-50°C ±0 1°C	0 1-10km
Fisheries					
Location of New Fishing Areas	100-1000m	1/wk	1 day	0-40°C ±1 0°C	1 0-100km
Improve Scouting Operations	100-1000m	1/hr	inst	0-40°C ±1 0°C	1.0-100km
Improve Catching Operations	100-1000m	1/hr	inst	0-40°C ±1 0°C	1 0-100km
Forecast Seasonal & Long Term Variations	100-1000m	1/wl	1 mo	0-40°C ±1 0°C	1 0-100km
Provide Scientific Basis For Mgmt.	100-1000m	1/wk	1 wk	0-40°C ±1.0°C	1 0-100km
Hazards to Shipping & Coastlines					
Identify Hazards to Navigation	10-100m	1/day	1 wk	-10-50°C ±1.0°C	0 1-10km
Provide Climatological Information	100-1000m	1/hr	inst	-10-40°C ±1 0°C	1-100km
Monitor Hazardous Ocean Phenomena	100-1000m	1/hr	inst	-10-40°C ±1 0°C	1-100km
Assist Rescue Operations	100-1000m	1/hr	inst	-10-40°C ±1 0°C	1-100km
Coastal Geography & Cartography					
Assess Mineral Resources	100-1000m	1/wk	1 mo	0-50°C ±0 1°C	1-100km
Complete and Update Coastal Surveys	1-10km	1/day	1 mo	0-40°C ±1.0°C	1-100km
Identify Coastal Land Use Patterns	1-10km	1/wk	1 wk	-10-40°C ±1 0°C	1-100km
Monitor & Control Shoreline Processes	1-10km	1/day	1 wk	-10-40°C ±1.0°C	1-100km

\- Not relevant to the issue

TABLE 2-4

MEASUREMENT SPECIFICATIONS - TIDES

NEED	ISSUE	SPATIAL RESOLUTION	FREQUENCY OF MEASUREMENT	DATA RESPONSE TIME	SIZE OF FIELD OF INTEREST
Pollution	Locating Sources of Discharge	100-100m	1/hr	1 day	1.0-100km
	Determining Types of Discharge	-	-	-	-
	Determining Extent of Pollutant Effect	1-10km	1/hr	1 day	1-100km
	Determining Assimilative Capacity	1-10km	1/hr	1 mo	1-100km
	Optimal Siting of Effluent Producing Ind.	100-1000m	1/hr	1 day	1-100km
	Effect Enforcement Action	-	-	-	-
	Assist Rapid Cleanup of Accidents	100-1000m	1/hr	inst	1-100km
Fisheries	Location of New Fishing Areas	100-1000m	1/hr	1 wk	1-100km
	Improve Scouting Operations	100-1000m	1/hr	cont-1 hr	1-100km
	Improve Catching Operations	100-1000m	1/hr	cont-1 hr	1-100km
	Forecast Seasonal & Long Term Variations	-	-	-	-
	Provide Scientific Basis For Mgmt.	-	-	-	-
Hazards to Shipping & Coastlines	Identify Hazards to Navigation	100-1000m	1/day	1 day	1-100km
	Provide Climatological Information	-	-	-	-
	Monitor Hazardous Ocean Phenomena	100-1000m	1/day-1/hr	1 day	1-100km
	Assist Rescue Operations	10-100m	1/hr	inst	0.1-10km
Coastal Geography & Cartography	Assess Mineral Resources	100-1000m	1/day	1 wk	1-100km
	Complete and Update Coastal Surveys	100-1000m	1/day	1 mo	1-100km
	Identify Coastal Land Use Patterns	100-1000m	1/hr	1 mo	1-100km
	Monitor & Control Shoreline Processes	100-1000m	1/day	1 wk	1-100km

- Not relevant to the issue.

TABLE 2-5

MEASUREMENT SPECIFICATIONS - PETROLEUM

NEED	ISSUE	SPATIAL RESOLUTION	FREQUENCY OF MEASUREMENT	DATA RESPONSE TIME	SIZE OF FIELD OF INTEREST
Pollution	Locating Sources of Discharge	10-100m	1/hr-cont	inst	0.1-10km
	Determining Types of Discharge	10-100m	1/hr	1 wk	0 1-10km
	Determining Extent of Pollutant Effect	100m	1/hr-1/day	1 hr	1-10km
	Determining Assimilative Capacity	100m	1/hr-cont	1 wk	1-10km
	Optimal Siting of Effluent Producing Ind.	100m	cont	1 mo	1-10km
	Effect Enforcement Action	10m	1/hr-cont	cont-1 wk	0 01-10km
	Assist Rapid Cleanup of Accidents	100m	cont	cont-inst	1-10km
Fisheries	Location of New Fishing Areas	-	-	-	-
	Improve Scouting Operations	-	-	-	-
	Improve Catching Operations	10-100m	1/day	1 day	0 1-10km
	Forecast Seasonal & Long Term Variations	1 0-100km	1/day	1 day-1 mo	1-100km
	Provide Scientific Basis For Mgmt.	-	-	-	-
Hazards to Shipping & Coastlines	Identify Hazards to Navigation	10-1000m	cont	inst	0.1-100km
	Provide Climatological Information	-	-	-	-
	Monitor Hazardous Ocean Phenomena	-	-	-	-
	Assist Rescue Operations	-	-	-	-
Coastal Geography & Cartography	Assess Mineral Resources	1-100km	1/mo	1-6 mo	to 100km
	Complete and Update Coastal Surveys	-	-	-	-
	Identify Coastal Land Use Patterns	0 1-100km	1/day	1day-6 mo	0.1-100km
	Monitor & Control Shoreline Processes	-	-	-	-
	- Not relevant to the issue				

TABLE 2-6

MEASUREMENT SPECIFICATIONS - SEDIMENTS

NEED	ISSUE	SPATIAL RESOLUTION	FREQUENCY OF MEASUREMENT	DATA RESPONSE TIME	SIZE OF FIELD OF INTEREST
Pollution	Locating Sources of Discharge	10-100m	1/mo	1 wk	0.1-10km
	Determining Types of Discharge	-	-	-	-
	Determining Extent of Pollutant Effect	0 1-10km	1/mo	1 wk	0.1-100km
	Determining Assimilative Capacity	0 1-10km	1/mo	1 mo	0.1-100km
	Optimal Siting of Effluent Producing Ind.	100m-1km	1/mo	1-6 mo	1-10km
	Effect Enforcement Action	10-100m	1/mo	1 wk	0 1-10km
	Assist Rapid Cleanup of Accidents	10-100m	1/hr	inst	0.1-10km
Fisheries	Location of New Fishing Areas	0 1-10km	1/wk	24 hrs	0.1-100km
	Improve Scouting Operations	-	-	-	-
	Improve Catching Operations	-	-	-	-
	Forecast Seasonal & Long Term Variations	0 1-10km	1/wk	1 wk-1 mo	0.1-100km
	Provide Scientific Basis For Mgmt.	0 1-10km	1/wk	1 mo	0.1-100km
Hazards to Shipping & Coastlines	Identify Hazards to Navigation	10-100m	1/day	<24 hrs	0.1-10km
	Provide Climatological Information	-	-	-	-
	Monitor Hazardous Ocean Phenomena	-	-	-	-
	Assist Rescue Operations	-	-	-	-
Coastal Geography & Cartography	Assess Mineral Resources	0 1-10km	1/mo	1 mo	0.1-100km
	Complete and Update Coastal Surveys	1 0-1000m	1/wk	1 mo	0 1-100km
	Identify Coastal Land Use Patterns	0 1-100km	1/mo	1 mo	0.1-100km
	Monitor & Control Shoreline Processes	1-100m	1/mo	1 mo	0.1-10km

- Not relevant to the issue

TABLE 2-7

MEASUREMENT SPECIFICATIONS - WINDS

NEED	ISSUE	SPATIAL RESOLUTION	FREQUENCY OF MEASUREMENT	DATA RESPONSE TIME	SIZE OF FIELD OF INTEREST
Pollution	Locating Sources of Discharge	10km	1/hr	1 day	10-100km
	Determining Types of Discharge	-	-	-	-
	Determining Extent of Pollutant Effect	100km	1/hr	1 day	100km
	Determining Assimilative Capacity	10km	1/wk	1 mo	to 100km
	Optimal Siting of Effluent Producing Ind.	-	-	-	-
	Effect Enforcement Action	-	-	-	-
	Assist Rapid Cleanup of Accidents	10km	1/hr	inst	to 100km
Fisheries	Location of New Fishing Areas	-	-	-	-
	Improve Scouting Operations	10km	1/hr	1 hr	to 100km
	Improve Catching Operations	10km	1/hr	1 hr	to 100km
	Forecast Seasonal & Long Term Variations	100km	1/wk	1 mo	to 100km
	Provide Scientific Basis For Mgmt.	-	-	-	-
Hazards to Shipping & Coastlines	Identify Hazards to Navigation	10km	1/hr	1 hr	to 100km
	Provide Climatological Information	10km	cont	1 hr-inst	to 100km
	Monitor Hazardous Ocean Phenomena	10km	cont	1 wk	to 100km
	Assist Rescue Operations	10km	cont	1 hr-inst	to 100km
Coastal Geography & Cartography	Assess Mineral Resources	-	-	-	-
	Complete and Update Coastal Surveys	-	-	-	-
	Identify Coastal Land Use Patterns	-	-	-	-
	Monitor & Control Shoreline Processes	1 km	1/day	1 wk-1 mo	to 10km

- Not relevant to the issue.

TABLE 2-8

MEASUREMENT SPECIFICATIONS - COLOR

NEED	ISSUE	SPATIAL RESOLUTION	FREQUENCY OF MEASUREMENT	DATA RESPONSE TIME	SIZE OF FIELD OF INTEREST
Pollution	Locating Sources of Discharge	10-1000m	cont	inst	to 100km
	Determining Types of Discharge	10-1000m	cont	1 wk	to 100km
	Determining Extent of Pollutant Effect	1-100km	1/day	1 wk	to 500km
	Determining Assimilative Capacity	-	-	-	-
	Optimal Siting of Effluent Producing Ind.	1-10km	1/day	1-6 mo	to 100km
	Effect Enforcement Action*	10-100m	cont	1 wk	to 10km
	Assist Rapid Cleanup of Accidents	-	-	-	-
Fisheries	Location of New Fishing Areas	1 0-10km	1/day	24 hrs	to 100km
	Improve Scouting Operations	0.1-10km	1/hr	inst	to 100km
	Improve Catching Operations	-	-	-	-
	Forecast Seasonal & Long Term Variations	-	-	-	-
	Provide Scientific Basis For Mgmt.	1-100km	1/day	1 mo	to 500km
Hazards to Shipping & Coastlines	Identify Hazards to Navigation	10-100m	1/day	24 hrs-inst	to 100km
	Provide Climatological Information	-	-	-	-
	Monitor Hazardous Ocean Phenomena	0 1-100km	1/day	inst	to 500km
	Assist Rescue Operations	-	-	-	-
Coastal Geography & Cartography	Assess Mineral Resources	0 1-100km	1/mo	1-6 mo	to 500km
	Complete and Update Coastal Surveys	10m-10km	1/mo-1/wk	1 mo	to 100km
	Identify Coastal Land Use Patterns	1 0-100km	1/mo	1-6 mo	to 500km
	Monitor & Control Shoreline Processes	1 0-1000m	1/wk	1 mo	to 100km
	- Not relevant to the issue.				

TABLE 2-9

MEASUREMENT SPECIFICATIONS - PLANKTON

NEED	ISSUE	SPATIAL RESOLUTION	FREQUENCY OF MEASUREMENT	DATA RESPONSE TIME	SIZE OF FIELD OF INTEREST
Pollution	Locating Sources of Discharge	100-1000m	1/wk	1 wk	to 100km
	Determining Types of Discharge	100-1000m	1/wk	1 wk-1 mo	to 100km
	Determining Extent of Pollutant Effect	1-10km	1/wk	1 wk-1 mo	to 100km
	Determining Assimilative Capacity	1-10km	1/wk	1-6 mo	to 100km
	Optimal Siting of Effluent Producing Ind	100-1000m	1/wk	1-6 mo	to 100km
	Effect Enforcement Action	100-1000m	1/wk	inst	to 100km
	Assist Rapid Cleanup of Accidents	100m-10km	1/day	inst	to 100km
Fisheries	Location of New Fishing Areas	1-100km	1/wk	24 hrs	to 500km
	Improve Scouting Operations	1-10km	1/day	24 hrs	to 100km
	Improve Catching Operations	1-10km	1/day	24 hrs	to 100km
	Forecast Seasonal & Long Term Variations	1-100km	1/wk	1 wk	to 500km
	Provide Scientific Basis For Mgmt	1-100km	1/wk	1 mo	to 500km
Hazards to Shipping & Coastlines	Identify Hazards to Navigation	-	-	-	-
	Provide Climatological Information	-	-	-	-
	Monitor Hazardous Ocean Phenomena	-	-	-	-
	Assist Rescue Operations	-	-	-	-
Coastal Geography & Cartography	Assess Mineral Resources	-	-	-	-
	Complete and Update Coastal Surveys	1-100km	1/wk	1-6 mo	to 500km
	Identify Coastal Land Use Patterns	.1-100km	1/wk	1-6 mo	to 500km
	Monitor & Control Shoreline Processes	-	-	-	-
	- Not relevant to the issue.				

TABLE 2-10

MEASUREMENT SPECIFICATIONS - SALINITY

NEED	ISSUE	SPATIAL RESOLUTION	FREQUENCY OF MEASUREMENT	DATA RESPONSE TIME	SIZE OF FIELD OF INTEREST
Pollution	Locating Sources of Discharge	10-100m	1/wk	24 hrs	to 10km
	Determining Types of Discharge	10-100m	1/wk	1 wk	to 10km
	Determining Extent of Pollutant Effect	100-1000m	1/wk	24 hrs-1 wk	to 100km
	Determining Assimilative Capacity	100-1000m	1/wk	1 wk	to 100km
	Optimal Siting of Effluent Producing Ind.	100-500m	1/wk	1-6 mo	to 100km
	Effect Enforcement Action	100m	1/wk-1/day	24 hrs	to 10km
	Assist Rapid Cleanup of Accidents	100-1000m	1/hr	1 hr	to 100km
Fisheries	Location of New Fishing Areas	1000m	1/wk	24 hrs	to 100km
	Improve Scouting Operations	-	-	-	-
	Improve Catching Operations	-	-	-	-
	Forecast Seasonal & Long Term Variations	1-10km	1/wk	1 mo	to 100km
	Provide Scientific Basis For Mgmt	-	-	-	-
Hazards to Shipping & Coastlines	Identify Hazards to Navigation	-	-	-	-
	Provide Climatological Information	-	-	-	-
	Monitor Hazardous Ocean Phenomena	1-10km	cont	inst-1 hr	to 100km
	Assist Rescue Operations	-	-	-	-
Coastal Geography & Cartography	Assess Mineral Resources	1-10km	1/mo	6 mo	to 100km
	Complete and Update Coastal Surveys	01-1km	1/wk	1 mo	to 10km
	Identify Coastal Land Use Patterns	1-100km	1/mo	6 mo	to 500km
	Monitor & Control Shoreline Processes	-	-	-	-

- Not relevant to the issue.

TABLE 2-11

MEASUREMENT SPECIFICATIONS - VEGETATION

NEED	ISSUE	SPATIAL RESOLUTION	FREQUENCY OF MEASUREMENT	DATA RESPONSE TIME	SIZE OF FIELD OF INTEREST
Pollution	Locating Sources of Discharge	100-1000m	2/mo	1 mo	to 100km
	Determining Types of Discharge	100-1000m	1/mo	1 mo	to 100km
	Determining Extent of Pollutant Effect	100m-10km	2/mo	1 mo	to 100km
	Determining Assimilative Capacity	100m-1000m	1/wk	1 mo	to 100km
	Optimal Siting of Effluent Producing Ind	100m-10km	1/mo	6 mo	to 100km
	Effect Enforcement Action	-	-	-	-
	Assist Rapid Cleanup of Accidents	100m-10km	1/wk	1 wk	to 100km
Fisheries	Location of New Fishing Areas	1-10km	1/mo	1 wk	to 100km
	Improve Scouting Operations	-	-	-	-
	Improve Catching Operations	1-1km	1/mo	1 wk	to 10km
	Forecast Seasonal & Long Term Variations	1-10km	1/mo	1 mo	to 100km
	Provide Scientific Basis For Mgmt	1-10km	1/mo	1 mo	to 100km
Hazards to Shipping & Coastlines	Identify Hazards to Navigation	1 0-1km	1/mo	1 wk	to 10km
	Provide Climatological Information	-	-	-	-
	Monitor Hazardous Ocean Phenomena	-	-	-	-
	Assist Rescue Operations	-	-	-	-
Coastal Geography & Cartography	Assess Mineral Resources	1-10km	1/yr	6 mo	to 100km
	Complete and Update Coastal Surveys	01-1km	1/mo	6 mo	to 10km
	Identify Coastal Land Use Patterns	1-10km	2/mo	1 mo	to 100km
	Monitor & Control Shoreline Processes	01-1km	1/wk	1 wk	to 10km
	- Not relevant to the issue				

TABLE 2-12

MEASUREMENT SPFCIFICATIONS - PRECIPITATION

NEED	ISSUE	SPATIAL RESOLUTION	FREQUENCY OF MEASUREMENT	DATA RESPONSE TIME	SIZE OF FIELD OF INTEREST
Pollution	Locating Sources of Discharge	10-100km	cont	1 hr	to 500km
	Determining Types of Discharge	-	-	-	-
	Determining Extent of Pollutant Effect	10km	cont	24 hrs	to 100km
	Determining Assimilative Capacity	100km	cont	2 mo	to 500km
	Optimal Siting of Effluent Producing Ind.	100km	cont	1-6 mo	to 500km
	Effect Enforcement Action	10km	cont	<24 hrs	to 100km
	Assist Rapid Cleanup of Accidents	100km	cont	1 hr	to 500km
Fisheries	Location of New Fishing Areas	-	-	-	-
	Improve Scouting Operations	10km	cont	1 hr	to 100km
	Improve Catching Operations	10km	cont	1 hr	to 100km
	Forecast Seasonal & Long Term Variations	100km	cont	1 mo	to 500km
	Provide Scientific Basis For Mgmt.	-	-	-	-
Hazards to Shipping & Coastlines	Identify Hazards to Navigation	1-10km	cont	1 hr	to 100km
	Provide Climatological Information	1-10km	cont	1-24 hrs	to 100km
	Monitor Hazardous Ocean Phenomena	1-10km	cont	1 hr	to 100km
	Assist Rescue Operations	1-10km	cont	inst	to 100km
Coastal Geography & Cartography	Assess Mineral Resources	-	-	-	-
	Complete and Update Coastal Surveys	-	-	-	-
	Identify Coastal Land Use Patterns	1 0-100km	1/mo	1-6 mo	to 500km
	Monitor & Control Shoreline Processes	-	-	-	-

- Not relevant to the issue

TABLE 2-13

MEASUREMENT SPECIFICATIONS - FISH
(Presence, Occurrence of)

NEED	ISSUE	SPATIAL RESOLUTION	FREQUENCY OF MEASUREMENT	DATA RESPONSE TIME	SIZE OF FIELD OF INTEREST
Pollution	Locating Sources of Discharge	10-100m	1/hr-cont	1 wk-1 day	to 100km
	Determining Types of Discharge	10-100m	1/day	1 wk	to 100km
	Determining Extent of Pollutant Effect	10m-1km	1/hr-1/day	1 day-1 wk	to 100km
	Determining Assimilative Capacity	-	-	-	-
	Optimal Siting of Effluent Producing Ind	10-100m	1/wk	1 mo	to 100km
	Effect Enforcement Action	10-100m	1/wk	1 day	to 10km
	Assist Rapid Cleanup of Accidents	-	-	-	-
Fisheries	Location of New Fishing Areas	100-1000m	1/day-1/wk	1 day	to 100km
	Improve Scouting Operations	100-1000m	1/hr-cont	inst	to 100km
	Improve Catching Operations	100-1000m	1/hr-cont	inst	to 100km
	Forecast Seasonal & Long Term Variations	1-10km	1/day	1 mo	to 100km
	Provide Scientific Basis For Mgmt	1-10km	1/day	1 mo	to 100km
Hazards to Shipping & Coastlines	Identify Hazards to Navigation	-	-	-	-
	Provide Climatological Information	-	-	-	-
	Monitor Hazardous Ocean Phenomena	100-1000m	1/wk	1 wk	to 100km
	Assist Rescue Operations	-	-	-	-
Coastal Geography & Cartography	Assess Mineral Resources	-	-	-	-
	Complete and Update Coastal Surveys	100-1000m	1/day	1 wk	to 100km
	Identify Coastal Land Use Patterns	100-1000m	1/day	1 mo	to 100km
	Monitor & Control Shoreline Processes	-	-	-	-

- Not relevant to the issue

TABLE 2-14

MEASUREMENT SPECIFICATIONS - BIOASSAYS

NEED	ISSUE	SPATIAL RESOLUTION	FREQUENCY OF MEASUREMENT	DATA RESPONSE TIME	SIZE OF FIELD OF INTEREST
Pollution	Locating Sources of Discharge	10-100m	1hr-cont	1/wk-1/da	to 10km
	Determining Types of Discharge	100-1000m	1/day	1/wk	to 100km
	Determining Extent of Pollutant Effect	1-10km	1/day	-	to 100km
	Determining Assimilative Capacity	1-10km	1/wk	1/da-1/wk	to 100km
	Optimal Siting of Effluent Producing Ind	100-1000m	1/hr-cont	1/wk	to 100km
	Effect Enforcement Action	10-100m	1/hr-cont	1/da	to 500km
	Assist Rapid Cleanup of Accidents	100-1000m	1/hr	1/da	to 100km
Fisheries	Location of New Fishing Areas	100-1000m	1/day-1/wk	1/da	to 100km
	Improve Scouting Operations	1-10km	1/day-1/wk	1/hr	to 100km
	Improve Catching Operations	-	-		to 100km
	Forecast Seasonal & Long Term Variations	10-100km	1/wk		to 500km
	Provide Scientific Basis For Mgmt	10-100km	1/wk		to 500km
Hazards to Shipping & Coastlines	Identify Hazards to Navigation	-	-	-	-
	Provide Climatological Information	-	-	-	-
	Monitor Hazardous Ocean Phenomena	-	-	-	-
	Assist Rescue Operations	-	-	-	-
Coastal Geography & Cartography	Assess Mineral Resources	-	-	-	-
	Complete and Update Coastal Surveys	-	-	-	-
	Identify Coastal Land Use Patterns	10-100m	1/wk	1/mo	to 500km
	Monitor & Control Shoreline Processes	-	-	-	-
	- Not relevant to the issue				

TABLE 2-15

MEASUREMENT SPECIFICATIONS - NUTRIENTS

NEED	ISSUE	SPATIAL RESOLUTION	FREQUENCY OF MEASUREMENT	DATA RESPONSE TIME	SIZE OF FIELD OF INTEREST
Pollution	Locating Sources of Discharge	10-100m	1/hr-1/da	1/wk	to 10km
	Determining Types of Discharge	10-100m	1/hr-1/da	1/da	to 10km
	Determining Extent of Pollutant Effect	-	-	-	-
	Determining Assimilative Capacity	10-100m	1/hr-1/da	1/da	to 10km
	Optimal Siting of Effluent Producing Ind	100-1000m	1/da-1/wk	1/wk	to 100km
	Effect Enforcement Action	10-100m	1/hr-1/da	1/wk	to 10km
	Assist Rapid Cleanup of Accidents	-	-	-	-
Fisheries	Location of New Fishing Areas	100-1000m	1/hr-cont.	1/da-1/wk	to 100km
	Improve Scouting Operations	100-1000m	1/hr-cont.	1/hr-1/da	to 100km
	Improve Catching Operations	-	-	-	-
	Forecast Seasonal & Long Term Variations	100-1000m	1/da	1/wk	to 100km
	Provide Scientific Basis For Mgmt	10-100m	1/da-1/wk	1/wk	to 100km
Hazards to Shipping & Coastlines	Identify Hazards to Navigation	-	-	-	-
	Provide Climatological Information	-	-	-	-
	Monitor Hazardous Ocean Phenomena	-	-	-	-
	Assist Rescue Operations	-	-	-	-
Coastal Geography & Cartography	Assess Mineral Resources	-	-	-	-
	Complete and Update Coastal Surveys	100-1000m	1/da-1/wk	1/wk	to 100km
	Identify Coastal Land Use Patterns	100-1000m	1/da	1/wk	to 100km
	Monitor & Control Shoreline Processes	-	-	-	-

- Not relevant to the issue.

TABLE 2-16

MEASUREMENT SPECIFICATIONS - TOPOGRAPHY

NEED	ISSUE	SPATIAL RESOLUTION	FREQUENCY OF MEASUREMENT	DATA RESPONSE TIME	SIZE OF FIELD OF INTEREST
Pollution	Locating Sources of Discharge	-	-	-	-
	Determining Types of Discharge	-	-	-	-
	Determining Extent of Pollutant Effect	-	-	-	-
	Determining Assimilative Capacity	-	-	-	-
	Optimal Siting of Effluent Producing Ind	100-1000m	1/mo	6/mo	to 100km
	Effect Enforcement Action	-	-	-	-
	Assist Rapid Cleanup of Accidents	100-1000m	1/mo	1/mo	to 100km
Fisheries	Location of New Fishing Areas	1-100km	1/mo	1/mo	to 500km
	Improve Scouting Operations	-	-	-	-
	Improve Catching Operations	-	-	-	-
	Forecast Seasonal & Long Term Variations	-	-	-	-
	Provide Scientific Basis For Mgmt	-	-	-	-
Hazards to Shipping & Coastlines	Identify Hazards to Navigation	10-100km	1/wk	24/hrs	to 10km
	Provide Climatological Information	10-100km	1/mo	6/mo	to 500km
	Monitor Hazardous Ocean Phenomena	-	-	-	-
	Assist Rescue Operations	100-1000m	1/wk	24/hrs	to 100km
Coastal Geography & Cartography	Assess Mineral Resources	1-10km	1/mo	1/mo	to 100km
	Complete and Update Coastal Surveys	10m →	1/mo	1/mo	to 100km
	Identify Coastal Land Use Patterns	1-10km	1/mo	6/mo	to 100km
	Monitor & Control Shoreline Processes	1-1000m	1/da	2/wk	to 100km

\- Not relevant to the issue.

TABLE 2-17

MEASUREMENT SPECIFICATIONS - WATER DENSITY

NEED	ISSUE	SPATIAL RESOLUTION	FREQUENCY OF MEASUREMENT	DATA RESPONSE TIME	SIZE OF FIELD OF INTEREST
Pollution	Locating Sources of Discharge	10-100m	1/wk	24 hrs	to 10km
	Determining Types of Discharge	10-100m	1/mo	1 wk	to 100km
	Determining Extent of Pollutant Effect	10-100m	1/da	24 hrs	to 100km
	Determining Assimilative Capacity	10-100m	1/wk	2 wk	to 100km
	Optimal Siting of Effluent Producing Ind.	10-100m	1/wk	1-6 mo	to 100km
	Effect Enforcement Action	-	-	-	-
	Assist Rapid Cleanup of Accidents	10-100m	1/hr	1/hr-inst	to 10km
Fisheries	Location of New Fishing Areas	1km	1/wk	24 hrs	to 100km
	Improve Scouting Operations	-	-	-	-
	Improve Catching Operations	1km	1/da	24 hrs	to 100km
	Forecast Seasonal & Long Term Variations	1-100km	1/wk	1wk-6 mo	to 500km
	Provide Scientific Basis For Mgmt	-	-	-	-
Hazards to Shipping & Coastlines	Identify Hazards to Navigation	-	-	-	-
	Provide Climatological Information	1-100km	1/da	inst	to 500km
	Monitor Hazardous Ocean Phenomena	1-10km	cont	inst	to 100km
	Assist Rescue Operations	-	-	-	-
Coastal Geography & Cartography	Assess Mineral Resources	-	-	-	-
	Complete and Update Coastal Surveys	-	-	-	-
	Identify Coastal Land Use Patterns	-	-	-	-
	Monitor & Control Shoreline Processes	1-1-km	1/wk	1wk 1mo	to 100km
	- Not relevant to the issue				

TABLE 2-18

MEASUREMENT SPECIFICATIONS - FRESH WATER INFLOW

NEED	ISSUE	SPATIAL RESOLUTION	FREQUENCY OF MEASUREMENT	DATA RESPONSE TIME	SIZE OF FIELD OF INTEREST
Pollution	Locating Sources of Discharge	10m	1/da-1wk	1 wk	to km
	Determining Types of Discharge	-	-	-	-
	Determining Extent of Pollutant Effect	1000m	1/da-1/wk	1 wk	to 100km
	Determining Assimilative Capacity	1000m	1/hr-cont	1 wk	to 100km
	Optimal Siting of Effluent Producing Ind	-	-	-	-
	Effect Enforcement Action	-	-	-	-
	Assist Rapid Cleanup of Accidents	1000m	-	1/da	to 100km
Fisheries	Location of New Fishing Areas	1000m	1/hr-1/da	1/da	to 100km
	Improve Scouting Operations	1000m	1/da-1/wk	1/da	to 100km
	Improve Catching Operations	1000m	1/da-1/wk	1/da	to 100km
	Forecast Seasonal & Long Term Variations	100km	1/da-1/wk	1/da	to 500km
	Provide Scientific Basis For Mgmt.	-	-	-	-
Hazards to Shipping & Coastlines	Identify Hazards to Navigation	-	-	-	-
	Provide Climatological Information	1000m	<1/da	1/da	to 100km
	Monitor Hazardous Ocean Phenomena	-	-	-	-
	Assist Rescue Operations	-	-	-	-
Coastal Geography & Cartography	Assess Mineral Resources	-	-	-	-
	Complete and Update Coastal Surveys	10km	1/wk	1/mo	to 100km
	Identify Coastal Land Use Patterns	1000km	1/wk	1/mo	to 100km
	Monitor & Control Shoreline Processes	100m	1/wk	1/mo	to 10km

- Not relevant to the issue

TABLE 2-19

MEASUREMENT SPECIFICATIONS - PARTICULATES

NEED	ISSUE	SPATIAL RESOLUTION	FREQUENCY OF MEASUREMENT	DATA RESPONSE TIME	SIZE OF FIELD OF INTEREST
Pollution	Locating Sources of Discharge	10-100m	1/hr-1/day	1 day	to 10km
	Determining Types of Discharge	10-100m	1/hr-1/day	1 day	to 10km
	Determining Extent of Pollutant Effect	10-100m	1/hr-1/day	1 day	to 100km
	Determining Assimilative Capacity	100-1000m	1/hr-1/da	1 day	to 100km
	Optimal Siting of Effluent Producing Ind	100-1000m	1/wk	1 wk	to 100km
	Effect Enforcement Action	10-100m	1/hr-1/day	1 wk	to 10 km
	Assist Rapid Cleanup of Accidents	100-1000m	1/day	1 day	to 100km
Fisheries	Location of New Fishing Areas	100-1000m	1/hr-1/day	1 day	to 100km
	Improve Scouting Operations	100-1000m	1/hr-1/day	1 day	to 100km
	Improve Catching Operations	100-1000m	1/day-1/mo	1 day	to 100km
	Forecast Seasonal & Long Term Variations	-	-	-	-
	Provide Scientific Basis For Mgmt	-	-	-	-
Hazards to Shipping & Coastlines	Identify Hazards to Navigation	10-100m	1/hr-1/da	1 wk	to 10km
	Provide Climatological Information	-	-	-	-
	Monitor Hazardous Ocean Phenomena	-	-	-	-
	Assist Rescue Operations	-	-	-	-
Coastal Geography & Cartography	Assess Mineral Resources	100-1000m	1/wk-1/mo	1 mo	to 100km
	Complete and Update Coastal Surveys	100-1000m	1/wk-1/mo	1 mo	to 100km
	Identify Coastal Land Use Patterns	100-1000m	1/day-1/wk	1 mo	to 100km
	Monitor & Control Shoreline Processes	100-1000m	1/day-1/wk	1 mo	to 100km
	- Not relevant to the issue				

TABLE 2-20

MEASUREMENT SPECIFICATIONS - METALS

NEED	ISSUE	SPATIAL RESOLUTION	FREQUENCY OF MEASUREMENT	DATA RESPONSE TIME	SIZE OF FIELD OF INTEREST
Pollution	Locating Sources of Discharge	10-1000m	contin	24 hrs	to 100km
	Determining Types of Discharge	100-1000m	1/day	2 wk	to 100km
	Determining Extent of Pollutant Effect	100m-10km	1/day	2 wk	to 100km
	Determining Assimilative Capacity	100-1000m	1/day-cont	1 mo	to 100km
	Optimal Siting of Effluent Producing Ind	1-10km	1/day	6 mo	to 100km
	Effect Enforcement Action	10-1000m	contin	24 hrs	to 100km
	Assist Rapid Cleanup of Accidents	100m-10km	1/day-1/wk	1 wk	to 100km
Fisheries	Location of New Fishing Areas	1-10km	1/day-1/wk	1 wk	to 10km
	Improve Scouting Operations	-	-	-	-
	Improve Catching Operations	-	-	-	-
	Forecast Seasonal & Long Term Variations	-	-	-	-
	Provide Scientific Basis For Mgmt	-	-	-	-
Hazards to Shipping & Coastlines	Identify Hazards to Navigation	-	-	-	-
	Provide Climatological Information	-	-	-	-
	Monitor Hazardous Ocean Phenomena	-	-	-	-
	Assist Rescue Operations	-	-	-	-
Coastal Geography & Cartography	Assess Mineral Resources	1-10km	1/mo	6 mo	to 100km
	Complete and Update Coastal Surveys	1-10km	1/mo	6 mo	to 100km
	Identify Coastal Land Use Patterns	.1-100km	1/mo	6 mo	to 500km
	Monitor & Control Shoreline Processes	-	-	-	-
	- Not relevant to the issue.				

TABLE 2-21

MEASUREMENT SPECIFICATIONS - LAND USE

NEED	ISSUE	SPATIAL RESOLUTION	FREQUENCY OF MEASUREMENT	DATA RESPONSE TIME	SIZE OF FIELD OF INTEREST
Pollution	Locating Sources of Discharge	-	-	-	-
	Determining Types of Discharge	-	-	-	-
	Determining Extent of Pollutant Effect	1-100km	1/wk	1 mo	to 500km
	Determining Assimilative Capacity	-	-	-	-
	Optimal Siting of Effluent Producing Ind	1-100km	1/mo	6 mo	to 500km
	Effect Enforcement Action	-	-	-	-
	Assist Rapid Cleanup of Accidents	0 1-10km	1/wk	1 mo	to 100km
Fisheries	Location of New Fishing Areas	-	-	-	-
	Improve Scouting Operations	-	-	-	-
	Improve Catching Operations	-	-	-	-
	Forecast Seasonal & Long Term Variations	1-100km	1/mo	6 mo	to 500km
	Provide Scientific Basis For Mgmt	1-100km	1/mo	6 mo	to 500km
Hazards to Shipping & Coastlines	Identify Hazards to Navigation	-	-	-	-
	Provide Climatological Information	-	-	-	-
	Monitor Hazardous Ocean Phenomena	-	-	-	-
	Assist Rescue Operations	-	-	-	-
Coastal Geography & Cartography	Assess Mineral Resources	0 1-100km	1/mo	6 mo	to 500km
	Complete and Update Coastal Surveys	0 1-10km	1/mo	6 mo	to 100km
	Identify Coastal Land Use Patterns	Full Range			to 500km
	Monitor & Control Shoreline Processes	10 m-1 0km	1/wk	1 mo	to 100km
	- Not relevant to the issue				

TABLE 2-22

MEASUREMENT SPECIFICATIONS - WAVES

NEED	ISSUE	SPATIAL RESOLUTION	FREQUENCY OF MEASUREMENT	DATA RESPONSE TIME	SIZE OF FIELD OF INTEREST
Pollution	Locating Sources of Discharge	-	-	-	-
	Determining Types of Discharge	-	-	-	-
	Determining Extent of Pollutant Effect	-	-	-	-
	Determining Assimilative Capacity	-	-	-	-
	Optimal Siting of Effluent Producing Ind	100m	1/wk	1 mo	to 100km
	Effect Enforcement Action	-	-	-	-
	Assist Rapid Cleanup of Accidents	100m	1/hr	1 hr	to 100km
Fisheries	Location of New Fishing Areas	-	-	-	-
	Improve Scouting Operations	-	-	-	-
	Improve Catching Operations	1000m	1/day	1 da	to 100km
	Forecast Seasonal & Long Term Variations	-	-	-	-
	Provide Scientific Basis For Mgmt	-	-	-	-
Hazards to Shipping & Coastlines	Identify Hazards to Navigation	10m	1/day	</wk	to 10km
	Provide Climatological Information	100m	1/hr-1/da	1/hr-1/da	to 100k
	Monitor Hazardous Ocean Phenomena	100m	1/hr-1/da	1/hr-1/da	to 100km
	Assist Rescue Operations	1000m	1/day	1/day	to 100km
Coastal Geography & Cartography	Assess Mineral Resources	-	-	-	-
	Complete and Update Coastal Surveys	1000m	1/wk	1/mo	to 100km
	Identify Coastal Land Use Patterns	-	-	-	-
	Monitor & Control Shoreline Processes	100m	1/wk	1/wk	to 100km

\- Not relevant to the issue

TABLE 2-23

MEASUREMENT SPECIFICATIONS - ICE

NEED	ISSUE	SPATIAL RESOLUTION	FREQUENCY OF MEASUREMENT	DATA RESPONSE TIME	SIZE OF FIELD OF INTEREST
Pollution	Locating Sources of Discharge	0 1-1km	1/day	24 hrs	to 100km
	Determining Types of Discharge	-	-	-	-
	Determining Extent of Pollutant Effect	-	-	-	-
	Determining Assimilative Capacity	-	-	-	-
	Optimal Siting of Effluent Producing Ind	-	-	-	-
	Effect Enforcement Action	-	-	-	-
	Assist Rapid Cleanup of Accidents	-	-	-	-
Fisheries	Location of New Fishing Areas	-	-	-	-
	Improve Scouting Operations	-	-	-	-
	Improve Catching Operations	-	-	-	-
	Forecast Seasonal & Long Term Variations	-	-	-	-
	Provide Scientific Basis For Mgmt	-	-	-	-
Hazards to Shipping & Coastlines	Identify Hazards to Navigation	0 1-1km	1/day	1mm-24 hrs	to 100km
	Provide Climatological Information	1-100km	1/wk	24 hrs	to 100km
	Monitor Hazardous Ocean Phenomena	0 1-1km	1/day	24 hrs	to 100km
	Assist Rescue Operations	1-10 0km	1/day	1mm-24 hrs	to 100km
Coastal Geography & Cartography	Assess Mineral Resources	-	-	-	-
	Complete and Update Coastal Surveys	0 1-10km	1/wk	1-6 mo	to 100km
	Identify Coastal Land Use Patterns	-	-	-	-
	Monitor & Control Shoreline Processes	0 1-10km	1/wk	1 mo	to 100km

- Not relevant to the issue.

the need for contiguous vs. noncontiguous coverage, and the desired frequency of measurements. All of these in turn are influenced either by the operating characteristics of the sensors themselves or the orbital characteristics of the spacecraft operating with nominal altitude and orbital characteristics, then each data type can be evaluated using the above criteria to determine its suitability of measurement from spacecraft using remote sensors. The following is a discussion of primary factors which influence measurement and sensor selection.

a) Energy Characteristics of Coastal Zone Phenomena

The most important criteria to be considered in remote sensor selection relates to the type of energy transmitted by the feature or phenomena to be measured. This energy will either be emitted by the feature or it will consist of energy reflected by the feature from the sun or some other active energy source. In general, the reflected energy is of shorter wavelength and can be observed in visible and near IR portions of the electromagnetic spectrum while the emitted energy is of longer wavelength and can be observed in the infrared and microwave portions of the spectrum. In the coastal zone it is desirable to make measurements of phenomena which exhibit both reflective and emissive characteristics. It is, therefore, necessary to choose sensors which encompass the visible, infrared and microwave regions of the spectrum.

b) Spectral Resolution and Accuracy Requirements

The type of energy received from the scene will determine the overall operating region within the electromagnetic spectrum. However, the number of specific bands and their spectral bandwidths within that region will be determined by the atmospheric "windows" of operation, the amount of energy being transmitted to the sensor and, if spectral signatures are to be determined, the spectral signature of the feature under scrutiny. Spectral signatures are variations in the reflectance or emittance of objects as a function of wavelength.

There is considerable atmospheric scattering and absorption by ozone in the UV while the visible and near IR portions of the spectrum (0.4 - 1.2 μ) are relatively free from excessive scattering and absorption effects. Both the infrared and microwave regions of the spectrum contain strong absorption bands caused by carbon dioxide and water vapor. In order to "see" the earth's surface it is important to steer around those bands. Otherwise, the precise locations of operating bands are determined by the characteristics of the features to be detected.

Basically, spectral bandwidths and center frequencies are determined on the basis of trade-offs. In general, the desire is to use small, discrete bands in order to provide spectral separation and in some cases to sense energy variations which may be unique to a given phenomenon. On the other hand, the use of small bandwidths, particularly if small fields of view (FOV) are used, may prevent sufficient energy from reaching the sensor in the spacecraft. To resolve this trade-off it is necessary to know the energy levels exhibited by the desired feature as a function of wavelength and the sensor aperture or FOV. This also holds true for determining the number of bands. If spectral signatures are desired, the number of bands must be commensurate with the energy levels or peaks and their rise and fall rates as a function of wavelength.

Spectral accuracy as used in the context of this report refers only to the accuracy with which sea surface temperature can be determined since it is not possible to establish the spectral accuracies required for unique color determinations. For some of the CZ issues both relative and absolute temperature measurements are required. The degree to which this can be done will vary depending on the type of sensor chosen, sensor FOV, and the intervening environmental factors.

c) Spatial Resolution and Accuracy Requirements

The spatial resolution and accuracy required for a specific measurement will depend on how the data is to be used, i.e., the specific coastal zone issue. The ground resolution that can be obtained with a given sensor will depend on three factors: detector capability, the optics used, and the orbital altitude of the sensor. For example, in a single detector IR radiometer the spatial resolution may be improved by increasing the dwell time on the ground element being sampled. This enables the energy which is emitted from a smaller ground area to be integrated for a longer period of time thereby permitting a smaller detector sensing element to be used. The ground resolution can also be increased by enlarging the optics or operating at lower altitudes. In a TV camera the inherent high resolution capability is limited by the photoconductor surface and finite size of the electron beam that scans the surface. Again, higher ground resolution can be obtained by increasing the optics size or lowering the orbit altitude. Since many of the coastal zone measurements call for high resolution, the above trade-offs must be carefully considered in selecting sensor types for coastal zone measurements.

The location of various features, both absolute and relative, needs to be determined to a certain accuracy commensurate with spatial resolution requirements. The accuracy to which this can be done will depend on how accurately spacecraft attitude errors can be determined and on how well sensor errors can be corrected. Also of importance in the determination of location is the number of benchmarks found in the scene for an imaging sensor or benchmarks that can be related to the scene. This will vary depending on the amount of data taken over land vs. that taken over water in a given scene. Thus, in this case, the advantage of large area, contiguous coverage can be seen in that there is more opportunity to obtain imagery which shows recognizable ground features.

The preceding are several examples of the criteria that were used as a basis for measurement selection. When these are applied to the data types associated with the major issues of the coastal zone, then a good indication can be obtained as to which of the data types are measurable and which are not measurable from spacecraft.

2.2.2 Correspondence of Sensing Methods to Data Types

The following chart lists the data types which are likely to be measurable from space and indicates the type of sensing method to be employed.

The sensing methods chosen were derived as a result of evaluating each data type as described in 2.2.1, using as a basis the information found in Tables 2-1 through 2-23, Section 2.1. The feasibility of performing the measurement is indicated by a (Y) yes or (M) maybe. The extent to which each data type can be measured will ultimately depend on measurement requirements, the type of specific sensor selected, and future state-of-the-art in sensor development. These will be discussed at length in Section 3.2.

In the absence of pollution and sediments, which in many cases are good indicators of currents, the programmed release and tracking of dyes using time lapse color photography is recommended for determining the rate of flow and extent of estuary currents. Two or more pictures can be obtained of the dye tracks either on the same orbit or on adjacent orbits if pointing capability is provided. Rate of flow or the extent of currents can then be calculated. In some cases, thermal gradients between currents and the surrounding area will permit monitoring using a temperature sensor.

Water temperature can be measured using either IR or passive microwave devices. The latter device is necessary for "all weather" observations since IR sensors cannot penetrate clouds or rain. However, the IR sensor in good weather can obtain more reliable temperature measurements than the microwave device since the IR sensor is not as subject to water emissivity changes. The comparison of these two sensors for performing temperature measurements will be discussed in more detail in the next section.

TABLE 2-24

MEASURABLE DATA TYPES

Measurable Data Types	Sensing Method	Feasibility
Currents	Color/Temperature Marker Tracking	Y
Water Temperature	IR* or Passive MW*	Y
Bathymetry	Color/Noncolor Imagery	Y
Petroleum	Color Imagery IR Spectrometry	Y
Wind Field**	Sea State--Active or Passive (MW)	M
Sediments (Distribution and Description)	Color Imagery	Y
Plankton	Color Imagery and Spectrometry	M
Fish	Temperature, Color Imagery, Spectrometry	M
Particulates	Color Imagery	Y
Nutrients	Color Imagery and Spectrometry	M
Wave Characteristics (Ht, period, direction)	Active and Passive MW	M
Coastal Land Images	Visual and Near IR	Y
Ice	Visual, IR and Passive MW	Y

* IR - Infrared, MW - Microwave

** In Section 2.2.3, wind fields is included as a possible measurement and it is also included as a nonmeasurement, the reason being that it can probably best be made using ground techniques.

Bathymetry, underwater shoreline depth, sediments and particulates can best be detected using color or non-color visual imagery. Experiments performed in the Ben Franklin submersible program indicate the blue-green region of the visible spectrum to be the best for water penetration. Depth penetration of up to 15 meters has been accomplished. Ross points out that a narrow band (0.46 - 0.5 μ) in the blue-green would be quite valuable for water penetration studies. Depth determination from spacecraft altitudes at best will be qualitative. Indications of depth in many cases can be obtained by observing sediment and particulate distributions, particularly if the types can be identified. More quantitative determinations may be possible in the future using laser techniques (see Section 3.6.4).

Color imagery and spectrometry (UV visible and infrared) offer the best potential for the detection of petroleum, plankton, fish and nutrients. Observations of the Santa Barbara "slick" show that the far UV and the infrared provide the best contrast for the delineation of oil. Recent observations indicate that plankton blooms can be detected by their characteristic pinkish color.

Barringer theorizes that the presence of fish might be determined by observing the absorption characteristics of fish oil and iodine vapors which are associated with the movement of large schools of fish. In addition to these, the observation of chlorophyll which is characterized by absorption bands in the visible spectrum can likely be accomplished with absorption spectrometry.

The degree to which nutrients (phosphates, nitrates, silicates, etc.) can be detected is in doubt for two reasons. First of all there have been few or no ground measurements made of the significant spectral properties of the various nutrients. Hence there is no indication as to which spectral regions would be suitable for observations. Secondly, it is difficult to determine the geographical extent of various nutrients. As a result, it is difficult to calculate energy levels that would have to be observed from spacecraft altitudes. This lack of knowledge places severe restrictions on the definition of spectral regions, numbers of bands, bandwidths, etc.

Wind field and wave characteristics can be determined to a certain extent using active and passive microwave radiometry. The degree to which this can be achieved and the usefulness of these data to the coastal zone is uncertain. These techniques will be discussed in the next section.

Coastal land images which denote land use will be obtained primarily by the visual and near IR sensors. Resolution requirements for these data are similar to those for ERTS A and B. Coastal zone land use has a direct bearing on essentially all coastal zone processes.

The detection and monitoring of ice is important primarily for coastal zone navigation and transportation and can be accomplished by sensing both the reflective and thermal properties of ice. High reflective properties provide good contrast between ice and its background in the visible portion of the spectrum.

2.2.3 Non-Measurable or Unselected Data Types

The following data types in Tables 2-1 to 2-23 were not selected as measurables for one of two reasons: the data cannot be measured from spacecraft altitudes or currently used measurement techniques are more suitable

Unselected Data Types

Salinity
Tidal Characteristics
Wind Field
Precipitation
Bioassays
Water Density
Fresh Water Inflow

Changes in surface salinity can be detected using microwave techniques. However, salinity as a function of depth cannot be measured using microwave. Also the low frequencies ($\leq$ 3 GHz) required necessitate the use of large size antennas making this measurement prohibitive from space.

The determination of shoreline, bay and estuary tidal characteristics requires high resolution because of small near shore areas. Low resolution microwave measurements will not suffice since sizable amounts of land area within the sensor FOV will interfere; i.e., the sensor output will be an integrated combination of both land and water. Therefore, this data type cannot be measured from space.

Wind field, precipitation and air temperature measurements can best be done using current techniques. However, surface wind field inferences may be possible from microwave sea state measurements.

Bioassays is a laboratory or field in-situ measurement which cannot be conducted from a spacecraft platform.

Water density falls into the same category as salinity and cannot be measured from spacecraft altitudes.

The determination of fresh water inflow from spacecraft would entail a knowledge of precipitation, snow melt, water runoff and land drainage characteristics. This can best be done using stream gages.

2.2.4 Candidate Sensors and Measurement Parameters

As a result of considering each measurable data type and evaluating its varying measurement requirements in terms of the issues of the coastal zone, the following sensors were selected as prime candidates for ERTS E&F coastal missions.

TABLE 2-25

PRIME SENSOR CANDIDATES

Sensors	Ground Resolution (Design Goal)	Ground Resolution and Bandwidth	Comments
a) Low Resolution Multispectral Imager	50-75 M ($150\ km^2$ FOV)	4 bands 3-vis, 1 near IR	Contiguous coverage (coastline tracking)
b) High Resolution Multispectral Imager	10-20 M ($30\ km^2$ FOV)	4 bands 3-vis, 1 near IR	Selective samples Pointing capability
c) Low Resolution IR Scanner Imager	200 M (150 km swath width)	10-12 μ	Contiguous coverage (coastline tracking)
d) High Resolution IR Radiometer (Non-imager)	10-20 M	10-12 μ	Selective samples Pointing capability
e) High Resolution Spectrometer (Non-Imager)	10-20 M	.40-15 μ Many bands	Selective samples Pointing capability
f) Microwave Radiometer (Non-imager)	5 km for Sea Temp.	30-40 GHz	Point, line samples
g) Radar Scatterometer (Non-imager)	5 km for Sea State	1-15 GHz Single Frequency	Point, line samples

As shown in Table 2-25, seven types of sensors are called for to perform the measurements of the data types listed in Table 2-24. The ground resolution design goals are consistent with the requirements as indicated in Tables 2-1 through 2-23. During the study, several other sensors were also considered for coastal zone applications. Some of these are new devices in an early stage of development. There is some question as to their availability for a 1975 mission. However, they are promising for the future and are briefly described in Section 3.6, New Sensors. One additional sensor, an imaging radar, was also briefly considered but not examined in detail because of its limited usefulness for the coastal zone requirements emphasized during our study. Radar imaging is useful for ice detection and mapping, all-weather imaging, and geologic and topographic land mapping applications from aircraft. From spacecraft, high resolution would be difficult to obtain with a radar without severe requirements for weight and power. On a large spacecraft such as Skylab or other manned space stations, these requirements are reasonable, and such experiments are being planned. For an ERTS spacecraft, they did not seem reasonable, especially for the coastal zone where the emphasis is for high resolution. Therefore, imaging radars were not investigated in depth in our study.

It should be noted that of the seven sensors recommended, it is desirable that all of them be provided with pointing capability. The three high resolution devices which consist of the multispectral sensor, the IR radiometer and the spectrometer should be pointable to any location within the scene imaged by the low resolution multispectral sensor and IR scanner. These latter two devices should be provided with coastline tracking capability. The microwave radiometer and the radar scatterometer should have the capability of being pointed to obtain measurements at various fixed angles (see Sections 3.4 and 3.5).

In general, the imagery obtained by the low resolution multispectral sensor and the low resolution IR scanner will be vertical. However, interest has been expressed in providing these sensors with coastline tracking capability. For certain orbital inclinations the time spent over the coastal zone is rather small. The tracking capability provides a technique for increasing that time. The usefulness of the data obtained will vary, depending on the size of the off-vertical angle. However, based on an analysis of Gemini and Apollo photography, off vertical viewing angles of 30-40° can still provide much useful information. Orbital configurations for obtaining off-track coverage are discussed in Section 4.1. It may be desirable to point the whole sensor platform rather than individual sensors, so that all sensors can track the coast simultaneously.

As indicated previously, the extent to which measurement goals can be met will depend largely on the choice of specific sensors and the current and future state-of-the-art in sensor development. In addition, spacecraft orbital configurations and constraints placed on the spacecraft will also play a role (perhaps negatively) in fulfilling these goals. The first of these, specific sensors and current state-of-the-art in sensor development, is discussed in the next section.

SECTION 3.0

REMOTE SENSING TECHNIQUES

This portion of the report provides a description of at least one instrument for each of the types of sensors selected for the CZ. The status of current sensors is discussed and the capability of each device is compared to CZ requirements to determine its applicability for performing the desired measurements. Modifications to current sensors where necessary to meet the requirements are described.

3.1 Visible-Near IR Imagers (Multispectral)

3.1.1 Status of Current Sensors

3.1.1.1 Return Beam Vidicon Camera

This sensor is now being developed for inclusion on the ERTS A & B spacecraft. The RBV Camera, as shown in Fig. 3-1 is a magnetically deflected, magnetically focused imaging device with a 5 cm (2 in) diameter faceplate. The detected ground area is imaged in the form of a charge pattern onto the vidicon faceplate or target, in this case a photoconductive surface. An electron beam is scanned over the charged surface and the return beam is modulated in proportion to the intensity and distribution of the charge pattern. Dark areas act as electron mirrors and reflect all the electrons while light areas in the scene become partially absorbing. The modulated return beam after being preamplified in a dynode multiplier is scanned out in the form of an image of the original scene.

The active image area on the photoconductor is about 2.5 cm^2 (1 in^2). Present photoconductor and beam technology limits the number of lines to approximately 4200 over the 1" format. For a ground area coverage of 150 Km (80 n.mi.) this would correspond to 45 M (150 ft)/TV line for high contrast targets. For low contrast scenes the resolution would be approximately 90 M (300 ft)/TV line. The present scanning rate of the electron beam is 1250 lines/second for a readout time of 3-4 seconds. This corresponds to a video bandwidth of about 3 MHz.

As envisioned for ERTS A and B, three RBV cameras will take simultaneous pictures of the same scene, each camera operating in a different portion of the electromagnetic spectrum - .47 - .57μ, .58 - .68μ, .69 - .83μ. Operating at an altitude of 925 Km (500 n.mi.) and for an area coverage of 180 Km the focal length of each sensor is 13 cm (5 in). For an f2 system the lens diameter for each sensor is 6.3 cm (2.5 in). Camera exposure time can be varied from 8-16 milliseconds.

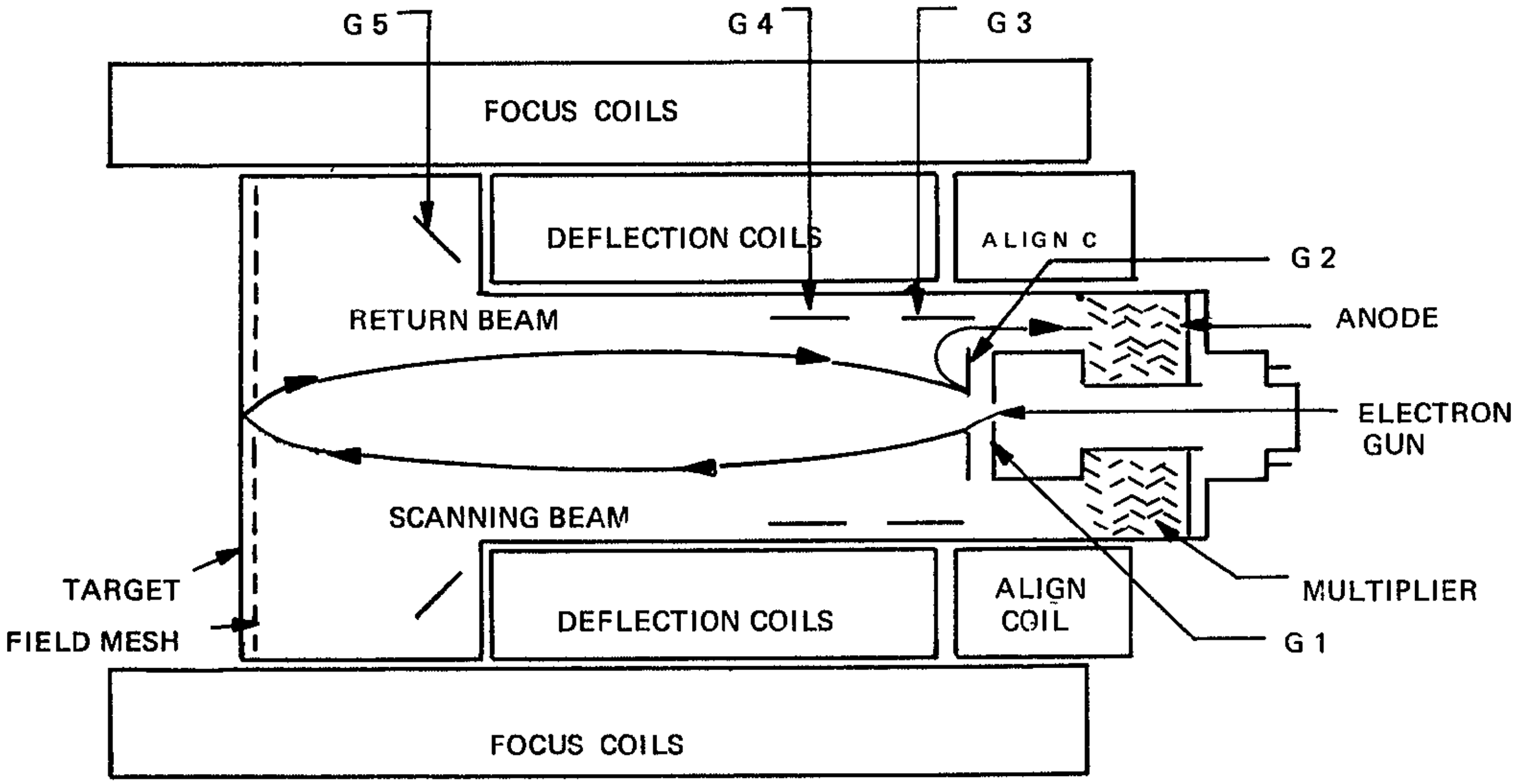

Figure 3-1. Simplified Diagram of Return Beam Vidicon

The prime concerns for TV sensors such as the 2" RBV are those of photometric and geometric distortion caused primarily by vidicon shading and non-linearity of the scanning beam respectively. However, it is expected that these effects can be corrected to a large extent in the output image. Geometric corrections to 1/2 TV lines will permit accurate registration of the three images to produce color. RBV characteristics are summarized in Table 3-1.

TABLE 3-1

CHARACTERISTICS OF 2" RETURN BEAM VIDICON

System Resolution (limiting)	4200 TV lines
Gnd resolution (from 925 KM)	50-90 M/TV line
SNR (peak-to-peak rms)	35 db
Scan Rate	1250 lines/sec.
Readout Time	3.4 sec.
Video Bandwidth	3 0 MHz

3.1.1.2 Multispectral Point Scanner (MSPS)

This sensor is also being developed for inclusion on the ERTS A & B spacecraft. The MSPS is an Object Plane Scanner which provides cross track scanning by the use of a high duty cycle "rocking mirror" located in front of the telescope collector. The mirror rocks at rate of approximately 15 Hz and covers a swath on the ground of 180 Km. The image produced at the primary image plane of the telescope is relayed by use of fiber optic bundles to detectors where conversion to an electrical signal is accomplished. Optical filters are used to select the optical pass-band corresponding to each spectral band. A small mirror, located on a 45° angle with respect to the optical axis, is planned to be used for calibration of the scanner. Six detectors are employed in each spectral band to permit a slower scanning motion of the mirror system, thus improving the response of the system. Each square detector is roughly 0.0064 cm on a side and provides a usable ground resolution of 75 M from ERTS altitudes. Table 3-2 summarizes the important characteristics of MSPS.

TABLE 3-2

CHARACTERISTICS OF ERTS MSPS

1.	Spectral Bands	0.5-0.6 microns 0.6-0 7 microns 0.7-0.8 microns 0.8-1.1 microns
2.	Inst. Field of View (Ground Resolution for High Contrast Targets)	75 meters
3.	Weight - Scanner and Signal Processor	36 Kg (80 lbs.)
4.	Power	45 watts (ave.)
5.	Bandwidth	4 MHz

A major disadvantage of the MSPS compared to the 2" RBV is that elements within the scene are not observed simultaneously but sequentially. Correction must be made to remove S/C attitude errors if photogrammetric data is desired. The sensor also has limitations in spectral and spatial resolutions determined by considerations in size of optics, number of detectors and signal to noise requirements. One current problem with the MSPS is that of mirror scan efficiency. It is difficult to design a scan mechanism that will provide a smooth and linear rocking motion of the mirror at the rate of 15 Hz over an IFOV of 10^o. Difficulties occur with mirror trace, retrace and mirror stop.

3.1.2 Applicability to Coastal Zone Measurements

Of the measurable data types indicated in Table 2-24 of Section 2.2.2 the visual and near IR sensors will be used for 9 out of the 13. The low resolution imagery will provide contiguous coverage and require a ground resolution of 50-75 M and a FOV of 150 Km^2. The high resolution sensor will be used for selective sampling and will require a ground resolution of 10-20 M and a FOV of 30 Km^2. Four spectral bands are indicated for each device, three in the visible and one in the near IR. This will permit both color and false color imagery to be obtained.

The return beam vidicon and MSPS systems currently under construction for ERTS A and B will provide contiguous coverage and ample resolution capabilities to meet the low resolution need, especially if a 540 Km orbit is used instead of the 925 Km orbit planned for ERTS. Only slight modifications to the optical systems would be necessary. For the 10-20 M high resolution case, however, current sensors are not applicable because of the requirement for large optics, image motion compensation and pointing. Either the current sensors would have to be modified or new sensors developed.

With regard to the number of bands and spectral bandwidths, those specified for ERTS A&B will, in general, be sufficient for coastal zone measurements. However, one band should be added to the three that now exist so that both color and false color imagery can be obtained. There may be some modificiation of bandwidths and the positioning of bands for the coastal zone. For example, as discussed in the last section, it may be desirable to have a band between .46μ and .5μ for water penetration studies.

To summarize, the visual and near IR devices designed for ERTS A&B are applicable to the low resolution needs of the coastal zone. However, these sensors as they now stand are not applicable for the high resolution requirements.

3.1.3 Modifications

To meet both the low resolution and high resolution requirements of the coastal zone as described in the previous section, several modifications will be necessary if current sensors are used. For this discussion it is assumed that EOS will be in a 540 Km altitude orbit instead of the 925 Km orbit planned for ERTS. Design changes for both the return beam vidicon and the MSPS will be discussed.

For the RBV's to meet the low resolution requirements (150 Km FOV and 50-75 meter resolution) in a 540 Km altitude orbit, the focal length of the lens must be reduced from 13 cm to 7.6 cm if the same size detector area (2.5 cm) is to be maintained. For an f2 system the lens diameter could then be reduced to 3.75 cm.

To achieve the high resolution capability (30 Km FOV and 10-20 meters resolution), the focal length of the lens must be increased to 38 cm, still maintaining the 2.5 cm image format. For a f2 system the lens diameter would then become 19 cm. Reducing the lens diameter without changing the focal length results in a slower system, i.e., such as f3 or f4. However, the exposure time would have to be increased and this would necessitate image motion compensation. However, the 38 cm focal length and the 19 cm lens diameter are not prohibitive.

For the MSPS sensor in a 540 Km orbit the focal length and optics size could be correspondingly reduced to obtain the lower resolution requirement. These modifications would not be difficult to perform. However, in the case of the high resolution requirement a problem would exist providing the present detector size format of 0.0064 cm is maintained. The focal length of the present system is approximately 1 M. To achieve 10 meter resolution the focal length would need to be 4M. A 2M FL would be necessary for 20 meters. These numbers assume, of course, that the present detector size format is maintained. If so, such large size optics and the necessity for scanning them would prohibit the use of this device. One alternative would be to maintain the present size optics or slightly increase them but then reduce the detector size. Required energy levels could be maintained by increasing the number of elements in order to increase the dwell time on each ground element or by using a more sensitive detector. This solution is not practical for the MSPS since the dwell time in the high resolution case for the coastal zone must be decreased by a factor of five (30 Km instead of 150 Km) to maintain contiguous coverage. This would require a 75 Hz rocking motion of the mirror instead of the present 15 Hz. This is beyond the state of the art in mechanical scanning technology. Besides, as indicated earlier, problems exist with the present 15 Hz system. In addition, at the 75 Hz scanning rate the energy levels would be so low that they could not be recouped by using higher sensitivity detectors.

The only scanning technique that might be applicable to the high resolution requirement is a device which employs image plane scanning. An example of this device is the Hycon Image Plane Scanner. The image plane scanner provides cross track scanning by the motion of a wheel rotating in the image plane of a telescope system. This wheel contains a series of optical probe assemblies (each identical) which "pick off" the telescope image. This image is relayed out of the center of the wheel and presented to a dispersion prism which separates the energy into spectral bands. A series of detectors, one for each spectral band, senses the energy and converts it to an electrical signal.

This device as in the case of the RBV's will require large optics in order to obtain ground resolutions of 10 to 20 meters. Otherwise the applicability of this sensor will depend on how fast the wheel can be made to scan out the image. As indicated previously, with six detectors per channel 75 Hz or revolutions/sec. will be required for each channel for contiguous coverage. This is well within the state of the art of mechanical design.

It would appear that the low resolution requirement for the coastal zone can be met by state of the art modifications of current sensors. However, the high resolution requirement cannot be met using the object plane mechanical scanner and can be met by the RBV's only through the use of larger optics. Several new techniques for accomplishing the high resolution requirement are described in Section 3.2.3. However, in each case large optics are required.

3.2 IR Devices

3.2.1 Status of Current Sensors

Of all remote sensors for earth resources observation this device has had the most experience in S/C applications. IR radiometers have been flown on several ESSA and Nimbus satellites to measure temperature of both and the earth's surface and cloud tops and the vertical temperature profile of the earth's atmosphere.

In general, the scanning IR radiometer is quite similar to the MSPS. The major difference being wavelength of operation and the fact that the output may or may not result in imagery. However, provisions are being made to add channels to the MSPS for imaging in the infrared portion of the spectrum. If successful, the ERTS B MSPS will contain a channel for sensing in the 10.4-12.6μ region with a ground resolution of 260M. Likewise, provisions are being made to add visual channels to the IR radiometers for meteorological applications. However, in the context of this study, the visual and IR devices are considered to be two different sensors, primarily because of the optical problems encountered in constructing a dual system. If these problems can be overcome, then the MSPS and the IR radiometer may be considered one and the same.

IR radiometers come in different sizes and shapes and have varying numbers of channels. A two channel radiometer has been used on ITOS for observing both cloud cover and surface temperature. However, the spatial resolution of this and similar devices is several kilometers. For meterological applications the concern has been for low resolution global coverage. High resolution radiometers (few tenths of a Km or less) are in the state of design and evaluation but have yet to be flown on spacecraft.

The components of the infrared radiometer developed for ITOS are shown in Figure 3-2. The radiometer assembly is oriented on the satellite so that axis A-A is parallel to the orbital velocity vector. Orbital motion provides for scanning of the object field in one direction. Scanning of the field in the perpendicular direction is accomplished by continuous rotation of the plane mirror about the axis A-A, so that, each revolution of the mirror scans a line from horizon to horizon perpendicular to the direction of orbital travel. During earth scan time, radiation from the earth is reflected onto the paraboloidal mirror by the scanning mirror, which causes it to converge toward the focal point of the paraboloid. The converging cone is intercepted by the infrared filter before reaching the focal point. The infrared energy transmitted by the filter is essentially undeviated by the filter, and proceeds toward the initial focal point. For the visible energy, the filter serves as a plane mirror, and the reflected

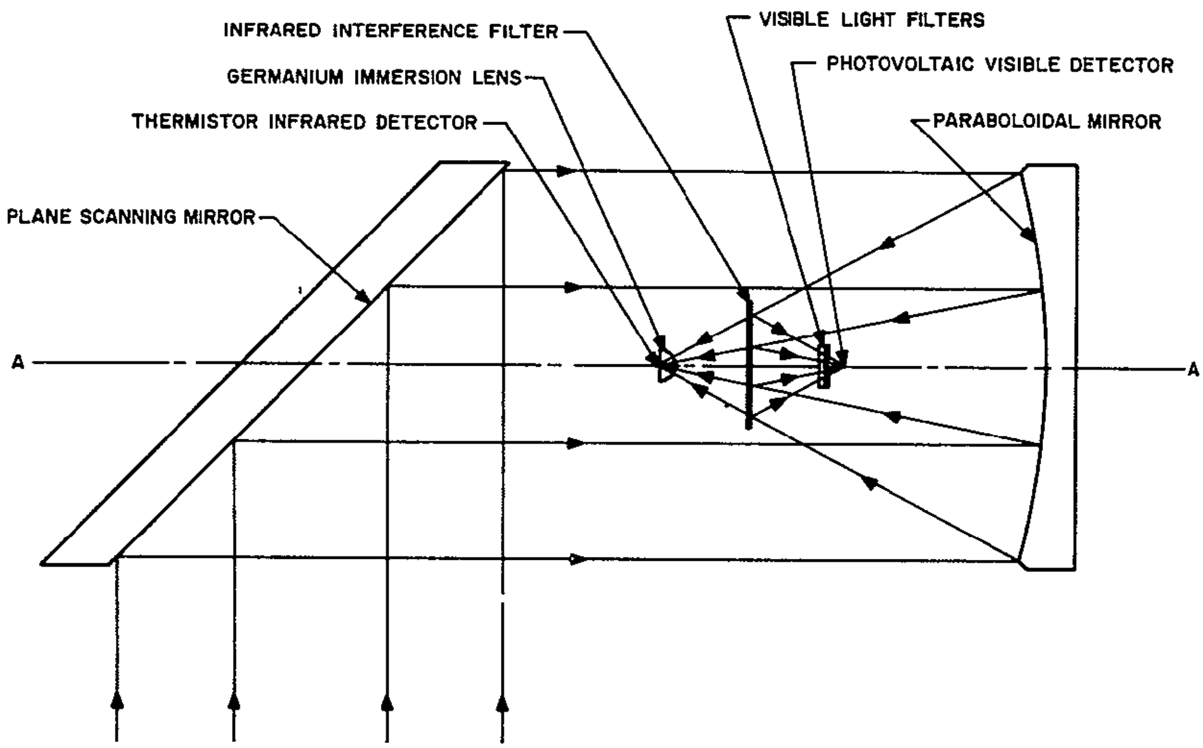

Figure 3-2. ITOS IR Radiometer

energy converges towards the mirror image of the initial focal point. Table 3-3 summarizes the characteristics of this sensor.

TABLE 3-3

CHARACTERISTICS OF ITOS SCANNING RADIOMETERS

1.	Inst. FOV	5.3 milliradians
2.	Spatial Resolution	7 Km at alt of 1400 Km
3.	Temp. Resolution	$1.0^{o}K$ @ $300^{o}K$ $4.5^{o}K$ @ $185^{o}K$
4.	Infrared Bandwidth	10.5-12.5 μ
5.	Collecting Optics	13 cm
6.	Mirror Speed	48 rpm
7.	Bandwidth	455 Hz
8.	Weight	8 kg (18 lbs)
9.	Power	6.5 watts

3.2.2 Applicability to Coastal Zone Measurements

The low resolution IR scanner and high resolution IR radiometer for ERTS E&F will be used to obtain thermal imagery and point temperature data, respectively. Primary applications are for sea surface temperature, detection of oils and ice monitoring. The low resolution sensor will provide contiguous coverage and will require a ground resolution of 200 meters*. The high resolution IR sensor will be used for selective sampling and will require a spatial resolution of 10-20 meters**. As in the case of the visual device the across orbit swath length of the low resolution device or FOV will be 150 Km. Across orbit swath length has not been determined for the high resolution sensor and will depend on whether this sensor is scanned or pointed. Options for this sensor are discussed later on in this section. Temperature accuracy and sensitivity requirements will vary depending on the application but the most stringent requirements are $\pm 1^{o}C$ and $\pm .1^{o}C$, respectively. Measurements in the 10-12μ region are required.

* 200 meters ground resolution corresponds to a spatial resolution of 1000 meters for imagery applications. This means that 5 lines of 200 meters each are needed to interpret an object 1000 meters in size on the basis of its spatial properties.

** i.e., 10-20 times better than low resolution device. Non-imagery data will be provided by this device.

As previously indicated the IR devices that have been flown to date on spacecraft do not meet any of the resolution requirements indicated for CZ measurements. However, the IR sensor planned for ERTS B, if successful, will come reasonably close to meeting the low resolution requirements indicated above. Across orbit swath length of 150 Km, as discussed previously may provide a mechanical scanning problem (see Section 3.1.3) since it is considerably easier to scan from horizon to horizon utilizing a 360° scan.

Temperature accuracies and sensitivities in the low resolution case should not be a problem since they are within the state of the art of current devices. In fact the IR radiometer is a better temperature measuring device than the microwave radiometer assuming that all-weather capability is not a factor The sensitivity of the IR radiometer varies as the fourth power of temperature and linearly with emissivity. The microwave radiometer as described later in this report is as sensitive to emissivity as to temperature.

Any modifications that may be necessary to current IR radiometers to meet the low resolution requirements of the coastal zone are minor and can be readily accomplished. However to meet the high resolution requirements (assuming for the moment that they can be met) extensive modifications of current sensors will be required. The problems encountered with the high resolution IR device are similar to those described for the high resolution visible scanner in Section 3.1.3. The problems are primarily those of scanning large optics at rather high rates over a small FOV. Such requirements are not compatible with the use of scanning devices.

To summarize, the low resolution IR requirements for the coastal zone can be met by current sensors. The high resolution IR requirements cannot be met by current devices. An alternative that offers potential as a high resolution IR device is a non-scanning, small FOV radiometer. This technique is described in the next section under modifications although in some respects it is a new sensor development.

3.2.3 Modifications

The high resolution non-scanning radiometer, or "comb scanner" is illustrated in Fig. 3-3. There is no across-the-swath scanning, the only scanning is performed along the orbit due to spacecraft motion. This kind of device can be useful as a sampling substitute for a high resolution thermal imager. Boundaries or edges of currents or thermal effluents are desired accurately. Typically the area of interest might be on the order of 1 Km^2. If we assume a spacecraft attitude control system capability of about ± 0.1°, there is a ground error of ± 1 Km from a 540 Km orbit. Thus a series of lines across a 4 Km width would be pointed to intersect

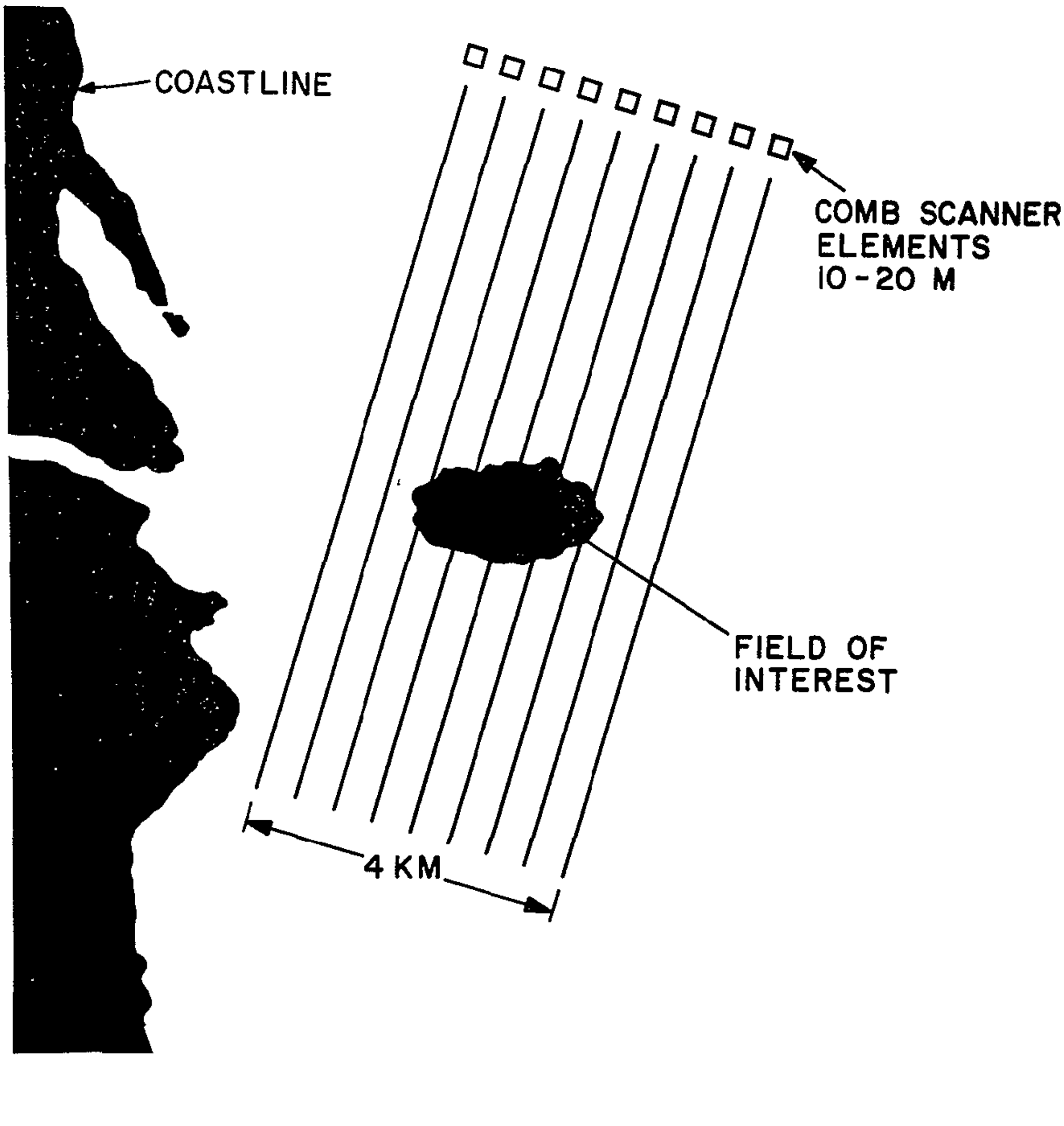

Figure 3-3. Illustration of Comb Scanner Concept

the area of interest and obtain (along the lines) accurate information about its edges.

The comb scanner which has a fixed array of N elements across a field of view of 4 kilometers can be built for the 10.5 μ to 12 5 μ band. However, the two principle governing parameters that limit the IFOV are optics size and a practical detector size. At 925 Km altitude 30 M resolution is possible with 50 cm optics. An altitude of 465 Km would be required to achieve 15 M resolution in the infrared. Calculations have been performed for various parameters such as collector size, detector element size, f_{no}, temperature sensitivity, etc., for an altitude of 465 Km. The results are:

CHARACTERISTICS OF THE IR COMB SCANNER

Altitude	465 Km
IFOV (rad)	33×10^{-6}
Collector Size	50 cm
Detector Element Size (cm)	25×10^{-4}
No. of Elements (cont'g coverage)	60
Ground Element Size	15 M
f_{no}	1.5
Temperature Sensitivity (at 300^{o}K)	.1^{o}K

Parameter characteristics for 925 Km altitude or 30 M resolution are quite similar to those above except for slightly lower bandwidth Resolutions higher than 15 M do not appear practical for the infrared. However the above resolution does correspond quite closely to the 10-20 meter resolution requirement for the coastal zone.

The size of each detector element is fixed by the size of the ground element for a given altitude. However, the number of detector elements within the total 4 Km FOV will vary depending on whether contiguous coverage is desired. For contiguous coverage over the FOV, 60 detector elements are required Indications are that such numbers can be readily achieved.

3 3 Spectrometers

3.3 1 Status of Current Sensors

The definition of a spectrometer in the context of this report refers to a device which senses in discrete portions of the electromagnetic spectrum to obtain information on the spectral properties of specific phenomenon within a scene. Although some spectrometers are capable of obtaining imagery the devices that appear to be of most use in the coastal zone are high resolution non-imaging sensors. As such, spatial properties of the scene are of lesser importance.

During recent years there have been numerous spectrometers flown in aircraft and experimental data has been gathered on a variety of surface phenomena. These spectrometers have varying numbers of channels and most of them operate in the visible and near IR and infrared regions of the spectrum. UV and microwave spectrometers have been developed to a lesser extent.

Two different types of spectrometers will be described in this report. The first of these operates on the principles of sensing the reflected and emitted energy from the scene under observation. This type of device is exemplified by the 20 channel airborne multispectral scanner flown by the Univ. of Michigan. This device is rather complex and is primarily an airborne experimental tool. As such it would not be recommended for spacecraft applications. However, it is described here because it does represent a technology that needs to be developed for the coastal zone. The second type of spectrometer is the correlation spectrometer. It operates on the principles of absorption and was designed, built and flown in aircraft and balloons by Barringer Research Limited, Toronto, Canada.

3.3.1.1 Multiband Scanner (Univ. of Michigan)

The University of Michigan airborne multispectral scanner obtains data in 20 bands simultaneously in the wavelength interval from .32μ to 14μ. Actually two scanners with two telescopes each are used, resulting in 4 channels of data. Twelve spectral bands between .4μ and 1.0μ are collected in one channel with a multichannel spectrometer so that the signals are registered and can be mixed or processed electrically. Two of the channels are fitted with filtered three-element arrays of InSb and InAs detectors. These two channels cover the spectral range 1.0μ - 5.5μ, each channel covering three spectral bands. The detectors are aligned to scan a scene point sequentially and the video signal can be brought into registration through time-delay lines. The fourth channel can cover either the range from .32μ to .4μ or 8μ - 14 μ using in the first case a filtered ultraviolet (UV) photomultiplier or for the latter range a filtered single-element InSb and Ge.Hg detectors.

The output signal from each detector element is a video signal corresponding to the scene brightness in the particular wavelength region of operation. The tape recorded multichannel video signals can be displayed and analyzed in a number of ways to obtain information about the spectral characteristics of signatures.

To our knowledge a device of this type is not being developed now for spacecraft application. Therefore the performance characteristics of this device such as weight, power, etc., are not applicable to this study. It is anticipated that the performance characteristics of a sensor designed for satellite applications will be similar to those of the ERTS MSPS.

3.3 1.2 Correlation Spectrometer

The correlation spectrometer detects and operates on the absorption spectra of various gases or vapor constituents in order to determine specific information on path length and concentration. This is done by vibrating the observed spectrum of a given gas against a photographic replica correlation mask produced in the laboratory. Fig. 3-4 illustrates the basic correlation spectrometer used in ground, airborne and high altitude baloon flights. Mirrors M_1 and M_2, a cylindrical lens and the entrance slit form the field defining optics. The correlation mask is stationary and the spectrum of the incident light is spatially modulated at 100 Hz relative to the mask by means of the fork-driven quartz refractor plates. The mask/spectrum correlation function is detected by a photomultiplier tube and pre-amplifier. The output spectra are series of positive or negative peaks which represent a condition of maximum correlation of the slits in the mask, with the absorption bands in the spectrum. If the oscillation produces a periodic series of positive or negative peaks they represent a condition of maximum correlation of the slits in the mask with the absorption bands of the spectrum. Barringer (1969) indicates that even with very low signal-to-noise ratio these correlations can be detected. Since the radiant power reflected from the earth through the gas (and containing the signature) has to compete with backscattered flux from the atmosphere itself, the SNR is expected to be low The magnitude of the peak-to-peak deflection is a function of the difference in the energy content of the peaks and troughs in the spectrum which is a function of the gas concentration, the atmosphere scattering and the path length. Table 3-4 summarizes the characteristics of the correlation spectrometer.

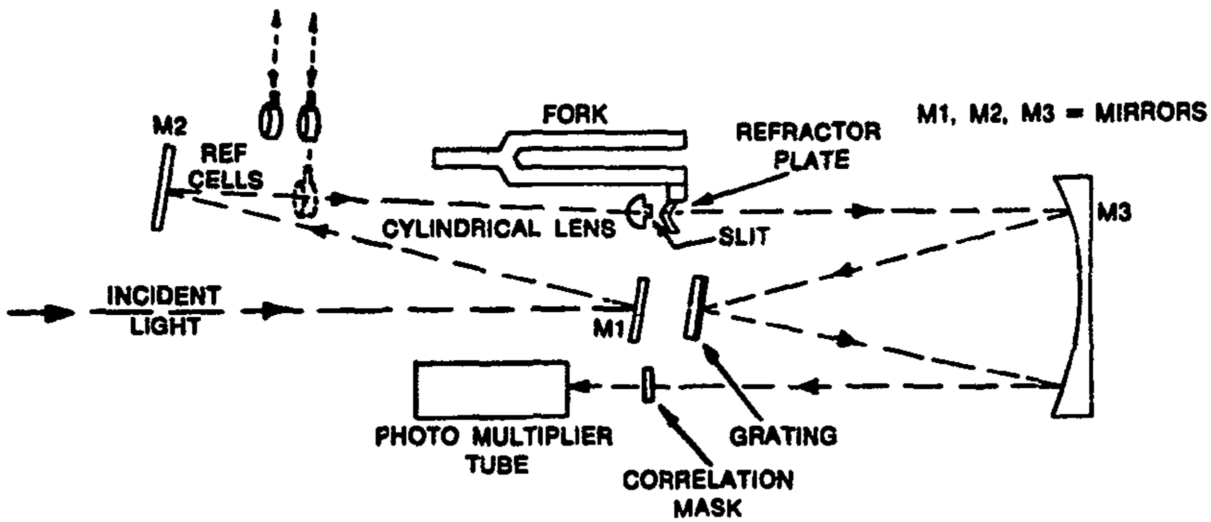

Figure 3-4. Dispersive System for Vapor Detection Using Spectrum Correlation Filter

TABLE 3-4

CHARACTERISTICS OF THE CORRELATION SPECTROMETER

Weight	43 Kg (95 lbs)
Size	1M x .6M x .5M
Power (ave)	22 watts
Total and Instant. FOV	1.0 degrees
Data Rate	50 samples/sec

A second similar device is the correlation interferometer which works in the frequency domain and uses an interferogram rather than a spectral band mask for correlation. Since it looks at all frequencies, it is theoretically more flexible than the correlation spectrometer. However, it is considerably harder to build requiring much larger optics and greater stability The spectrometer development is much further along at this point, although NASA is supporting R and D for an interferometer for CO monitoring.

3.3 2 Applicability to Coastal Zone

Coastal zone applications of the spectrometer will be primarily for petroleum, plankton, fish and nutrients. Like the high resolution IR radiometer the spectrometer will be a non-imagery device with a design goal resolution capability or 10-20 meters. Spectral bandwidths and the number of bands cannot be determined at present. However, it is expected that the bands will be discrete. (.02 - .03μ wide) and the number of bands will be a minimum of 6 or 7 to a maximum of 20 for the reflective device. The minimum number would be optimum for one or two applications whereas 20 or more bands would enable experiments to be performed to determine optimum bands for a number of applications. These bands will cover the region from .40 - 15 μ.

Because of the difficulty of implementation the absorption spectrometer will have a limited number of bands, perhaps 3 or 4. These bands will be in the visible portion of the spectrum and will be adjusted to observe specific phenomena. For example, as discussed in Section 2.2, iodine, fish oils, petroleum oils and chlorophyll are likely candidates for this type of measurement.

There are no existing spectrometers in their present mode of operation which can obtain the high resolution needed for the coastal zone. The closest thing would be the ERTS MSPS which can only image in discrete bands of the visible but cannot obtain a ground resolution of 10-20 meters. Also, as discussed in the last section, this resolution capability for the infrared has yet to be developed. The correlation spectrometer used in balloons and aircraft has an instantaneous FOV of 1.0^{o} and from spacecraft altitudes this would correspond to a resolution of approximately 10 kilometers from 540 Km. This could still be of interest in the CZ for detecting clouds of gaseous indicators although it does not meet the specific requirements for 10-20 M.

3.3 3 Modifications

As indicated in the previous Section (3.3.2) the multispectral scanner and the correlation spectrometer as they now stand are not applicable to the high resolution requirements of the coastal zone. Once again, as was the case with the high resolution radiometer, the problems are primarily those of scanning large optics over very small fields of view. Such experiments are not practical for operational unmanned spacecraft. The only plausible solution for the multiband reflective/emissive spectrometer would be to use a fixed mirror, comb scanning system similar to that suggested for the high resolution radiometer. The array of n elements could be designed to accommodate a number of spectral channels over a small field of view of 4 Km. This suggests the possibility that the high resolution infrared radiometer and the high resolution spectrometer could be combined into a single device if the optical problems as discussed in Section 3.2.1 can be overcome. Pointing capability would enable this device to scan out a 4 Km swath within the field of view imaged by the low resolution visual and infrared sensors.

Modifications to the correlation spectrometer would also be needed for space use. Longer focal length optics would be desirable to decrease the basic resolution size, although it does not seem practical to make large enough optics to get 10-20 M or even 100-200 M resolution. More likely 1 to 2 Km would be achievable from space (also useful for the CZ). It would also be desirable and undoubtedly possible to build a correlation spectrometer with several masks so that two or three gases could be detected with the same device.

3.4 Passive Microwave Devices

3.4.1 Status of Current Sensors

At present microwave radiometer technology is in a relatively undeveloped state. These sensors are characterized by relatively large antennas necessitated by the long wavelengths of microwave energy. Several experimental microwave sensors have been flown on aircraft to measure sea surface temperature and sea state but as yet none have flown in spacecraft. Typical of these are the NASA microwave scanners flown on MSC CV240 aircraft and the Convair 990. These are multifrequency devices operating in the range from approximately 1 GHz to 37 GHz. These sensors have been flown to obtain experimental data on terrain roughness, vegetation, water and ice. Typically, for a 10 Km altitude the swaths or elements on the ground have a dimension of approximately 500 x 500 meters. This would correspond to 45 x 45 Km from a 925 Km orbit.

To obtain large area coverage the antennas must be scanned. To avoid oscillating large antennas, electronically steerable beam phased-array antennas have been used in the NASA programs. These antennas consist of a large number of ferrite switching elements that change the effective pointing direction of the antenna by a phase cancellation and reinforcement technique Unfortunately, however, the use of phased array antennas instead of other types of antennas does not significantly reduce the antenna size requirements.

NASA is presently in the process of designing and building a microwave radiometer for flight on the Nimbus E spacecraft. The equipment is being procured from Space General Corporation. This device will also be electronically scanned and will operate at 19.35 GHz and will have an instantaneous FOV of 2.85°. This corresponds to a swath width of 35 x 35 Km on the ground for a 540 Km orbit. Its frequency of operation (19 GHz) is about halfway between the lower window of 1 GHz to 15 GHz and the water vapor absorption band at 22-23 GHz. Thus the sensor is designed to look both at the earth's surface for resource applications and the clouds for meterological applications. Table 3-5 indicates some of the important characteristics of the Nimbus Microwave Scanner.

TABLE 3-5

CHARACTERISTICS OF THE NIMBUS MICROWAVE SCANNER

1.	Frequency	19.35 GHz
2.	Weight	23 Kg (50 lbs) including antenna
3.	Power	25 watts
4.	Data Rate	100 bits/sec
5.	Scan	± 50° from nadir
6.	Temp. Res.	2°K
7	Ground Resolution (35 x 35 Km for 540 Km orbit)	2.85° x 2.85°

3.4.2 Applicability to Coastal Zone

The applicability of passive microwave devices to perform meaningful and reliable sea surface temperature and sea state measurements from spacecraft altitudes is in doubt primarily because of the low resolution nature of the measurements for reasonable size antennas and because of intervening environmental factors which affect the quality of the data.

Sea temperature and sea state can, at best, only be determined indirectly from the measured or "apparent" temperature. The apparent temperature of the sea, when measured from space, consists of three elements:

$$T_B = \frac{\varepsilon T_o}{L} - \frac{(1-\varepsilon)\ T_{sky}}{L} + T_{sky}$$

where ε is the emissitivity of water

$1-\varepsilon$ is the reflectivity

T_o is the actual water temperature

$\frac{1}{L}$ is the atmospheric loss

T_{sky} is the apparent sky temperature

The emissivity will depend on the observation wavelength, incidence angle, the temperature of the water itself, polarization, sea state and to a lesser degree salinity and pollution effects. Therefore to obtain actual water temperature the various parameters just mentioned must either be calculated out or some method must be found to eliminate them from the measurement.

Sea state is one of the major factors in emissivity variations. Stogryn has shown that for a given altitude the apparent radiometric temperature of water varies with sea state and incidence angle for horizontally polarized signals. He also shows that apparent radiometric temperature is invariant to sea state at a particular incidence angle for vertically polarized signals. This invariant angle is found to occur at an incidence angle of 40°. Aukland et al (1969) suggests from this, therefore, that dual polarized measurements made at 50° at a frequency relatively insensitive to temperature changes (say 30 GHz) permit elimination of atmosphere effects and permit sea state to be determined. Likewise if another measurement is made at another frequency, which is not invariant to thermometric temperature changes, at the same incidence angle, then sea surface temperature can be obtained.

Hence two measurements at different frequencies must be made if both sea state and sea surface temperatures are desired However, if only changes in SST and SS are desired, then the measurements can be made at the invariant incidence angle with the use of only one frequency. The frequency selected should be one at which the radiometric temperature varies with thermometric temperature. Figure 3-5 is a plot of the variation in the radiometric sensitivity with a 1°C change in thermometric temperature as a function of frequency. From this curve it can be seen that the optimum frequency ranges are from 10-14 GHz and perhaps from 25-40 GHz. From the standpoint of antenna size the 40 GHz frequency appears to be more attractive.

As indicated in Section 2, resolution requirements for sea surface temperature (SST) vary from 10 meters to 100 Km. The temperature accuracy desired is ±1°C with a minimum sensitivity of ±.1°C Resolution for sea state (SS) varies from 100 meters to 1 Km. Wave height requirements vary from 1-15 ft , direction ±10° and wave period 2 to 40 sec. The ground resolution required for sea ice varies from 10 to 100 M. The requirements enumerated here are felt to be minimum requirements if the data is to be utilized fully in solving the problems of the coastal zone. Because of the small width of the coastal zone (as compared to the open oceans), smaller scale phenomenon occur, thus dictating the need for high resolution. In addition, if large area, low resolution ground elements are obtained they will contain on the average a considerable amount of land area. This obviously will invalidate measurements such as SST or SS. Accordingly it is felt that sampled ground elements larger than 5 Km in size will have little or no value. Therefore, the ground resolution design goal for SST and SS is 5 Km or less.

At present there are no active or passive microwave devices either in existence or planned that will provide a resolution capability of 5 Km or less from spacecraft altitudes. Both the passive device designated for Nimbus E and the active/passive radiometer that will be flown on Skylab will provide low resolution on the order of 40-60 Km. In order to provide the high resolution capability required for the coastal zone large antennas will need to be provided. In addition current microwave devices will not provide the accuracy and sensitivity required for coastal zone SS and SST measurements primarily due to intervening environmental factors which affect the data and uncertainty in the state of the art of how the devices should be deployed. Adequate models for data interpretation, processing and correction also have not been fully developed.

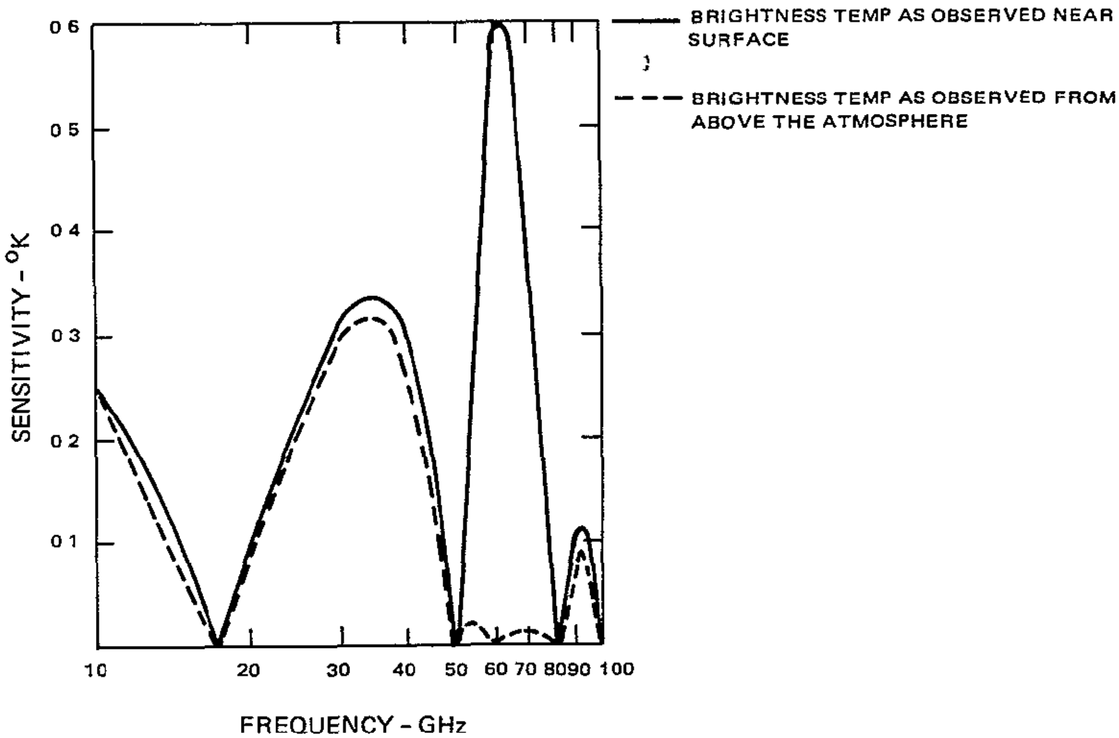

Figure 3-5. Variation in the Radiometric Sensitivity with a 1° C Change in Thermometric Temperature

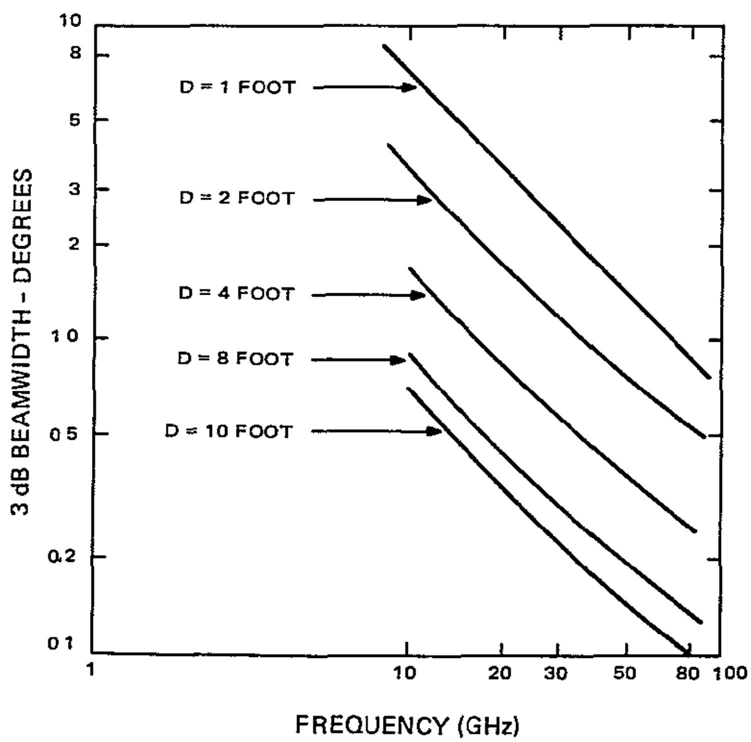

Figure 3-6. Beamwidth vs Freq for Various Antenna Diameters

To summarize, the present state of the art in active and passive microwave devices will not permit sea surface temperature and sea state to be measured to the accuracies required for the coastal zone. These problems and possible solutions to them will be discussed in the next section of the report.

3.4.3 Modifications Required

The spatial resolution design goal for SS and SST for the coastal zone is 5 Km. To achieve such a high resolution may require rather large antennas depending on the spacecraft altitude of operation. In addition other problems may be encountered in terms of pointing or moving these antennas if scanning is desired. One alternative would be to fix the antenna or antennas at a certain incidence angle and sweep out a 5 Km swath parallel to the spacecraft orbit. However, in the case of the passive microwave experiment there is considerable uncertainty as to what this angle (the invariant incidence angle for SST measurements) should be. As indicated previously Stogryn found this angle to be 50° Hollinger in one such experiment found it to be 55°. Data from the Rockfish experiment indicates the invariant angle to be 70°. This uncertainty in the invariant angle would suggest that the measurement be performed at different angles and hence variable pointing of the antenna might be desirable for experimentation (but probably is better done first in A/C)

Scanning the antenna to sweep out any reasonable size area, assuming 5 Km ground elements, would undoubtedly be out of the question. The short integration times that would be required for a sequence of 5 Km ground elements across the satellite ground track would cause severe post-detection bandwidth problems that would severly limit the sensitivity of the temperature measurement. Present state of the art radiometric sensitivity for a one second integration time is approximately .3°K at 40 GHz;with data reduction this gives approximately a 1° change in thermometric temperature. Only about 0.7 second integration is the longest time that could be tolerated for a 5 Km ground area from spacecraft altitudes unless the sensor can be pointed to increase the dwell time.

As pointed out earlier to perform SST and SS measurements from spacecraft altitudes large antennas will be required. The beamwidth (3 db) of a parbolic antenna is approximated by

$$\theta = \frac{2.16 \times 10^4}{FD}$$

where θ = 3 db beamwidth in degrees

F = frequency in MHz

D = diameter in meters

The beamwidth versus frequency for various antenna diameters is shown in Figure 3-6. For high spacecraft altitudes the beamwidth must be smaller to accommodate the same field of view. Hence the antenna diameter must become larger. However, if we assume that the sea surface temperature is measured at 40 GHz from a 540 Km altitude and over a ground area of 5 Km, then the antenna size required would be 1 M. Such an antenna would be quite manageable regardless of the type of antenna used.

3.5 Radar Scatterometer

3.5.1 Status of Current Sensors

The radar scatterometer is like other radar systems in that the basic elements of the system consist of a transmitter and a receiver. The primary difference between the scatterometer and other forms of radar is that the scatterometer can determine the scattering or reflective properties of surfaces by measuring the variation of differential scattering cross section (or scattering coefficient) of a surface with angle of incidence. While ordinary radar imagers can measure scattering coefficients, if calibrated properly, they can do so for any point in the image at only the particular angle of incidence with which that point is illuminated. Most scatterometers use a fan beam and can measure the scattering properties at various angles. The angle of incidence may vary from zero (normal incidence) to 90° (grazing incidence). However, few systems operate over this entire range since at grazing incidence the range is so great that the signals received are too small.

In actual practice, a transmitter sends a signal to the surface being studied and the return signal is scattered to the receiver. Synchronization is maintained between the transmitter and receiver, in fact, a copy of the transmitted signal may be delayed and compared in the receiver with the received signal. The receiver output is processed to determine the scattering coefficient at a particular point.

The following table summarizes the characteristics of the system presently being used for aircraft application.

TABLE 3-6

CHARACTERISTICS OF RADAR SCATTEROMETER

Frequency	13.3 GHz
Resolution	15M (330 Meter alt.)
	45 Km (925 Km alt. - extrapolated)
Weight	33 Kg (74 lbs)
Power	135 watts

3 5 2 Applicability to Coastal Zone

Studies of potential applications of radar scatterometry have been conducted by many investigators for several years, and further investigations are still necessary before definite conclusions can be reached. The most complete summary of these studies is by Pierson and Moore (1970). Measurements of the radar return from the ocean surface are substantially affected by sea surface roughness. Most investigators agree that these measurements primarily indicate the "chop" from small waves of the same magnitude as the radar wavelength or even smaller, rather than the "swell" or long waves from a developed sea. The chop is due to surface wind conditions. Pierson (1970) has shown theoretically the large effects due to local winds and a small, but calculable, "perturbation" effect due to long waves.

A major uncertainty in the theory is concerned with the speed above which measurements of radar return saturate (i.e., changes in wind give too small a change in radar return to be reliably detected). Guinard (1970) and Wright (1968) indicate that saturation begins to occur at 5 meters/sec whereas Pierson (1970) indicates that by processing the data differently, or by using more data (from a fan beam rather than pencil beam antenna), increases can be well defined to 25 meters/sec. or more. In addition, uncertainties as to the exact meaning of the measurements arise from foam, spray, whitecaps, non-linear waves, and the intervening atmosphere. NASA (Jaffe, 1970) is planning to use a microwave radiometer in conjunction with its scatterometer on Skylab A. The radiometer will not only be used to detect surface temperature changes, but also to detect changes in the atmosphere (e.g., Singer and Williams (1968) calculated a 56^{o}K rise in brightness temperature due to a cloud -- including the effects of 1 db attentuation as well as increased reflection). This measurement could be used to correct scatterometer readings for cloud effects.

Actually the combined use of radars and radiometers is attractive from several viewpoints. The radiometer measures the product of emissivity and temperature. The emissivity is closely related to the radar cross section. Thus, making both measurements together may well permit using the radiometer as a temperature-measuring device, even with varying emissivities. Since the microwave radiometer and the radar use the same high gain antenna, power requirements are quite reasonable.

Although the theories are still questionable and obviously in need of more research (especially experimental measurement), it would appear that radar scatterometry does offer some potential for the ERTS E&F missions.

3.5.3 Modifications

As in the case of the passive microwave radiometer, the radar scatterometer will require relatively large antennas to obtain high ground resolutions on the order of 5 Km. Since previous scatterometers have been designed primarily for aircraft and manned spacecraft applications some consideration must also be given to the reduction of size, weight and power requirements to facilitate use on a smaller unmanned satellite.

3.6 New Sensors

3.6.1 The 4.5" Return Beam Vidicon

One technique that might be used to overcome the inherent resolution limitations of the 2 inch RBV is to increase the detector format size. The 4.5" return beam vidicon does just that. With a useful image area of 5 cm square instead of the 2.5 cm square for the 2 inch device, the resolution of the vidicon can be improved by a factor of two. This would mean a ground resolution of 25-50 M with the same focal length optics instead of 50-100 M resolution for the 2 inch device. At present this device is still under development but it should offer possibilities by the 1975 time period. Principal problems that must be overcome if it is to be used for S/C application are those of size, weight and power.

3.6.2 Silicon Line Scan Vidicon

The silicon line scan vidicon which is envisioned as a replacement for the vidicons on ERTS A and B is a new sensor that offers the potential of high sensitivity, wide dynamic range, and high resolution capability. The sensor as shown in Figure 3-7 contains a silicon target consisting of six electrically isolated lines of uniformly spaced p-n diodes formed on a strip of n-type silicon. Although only

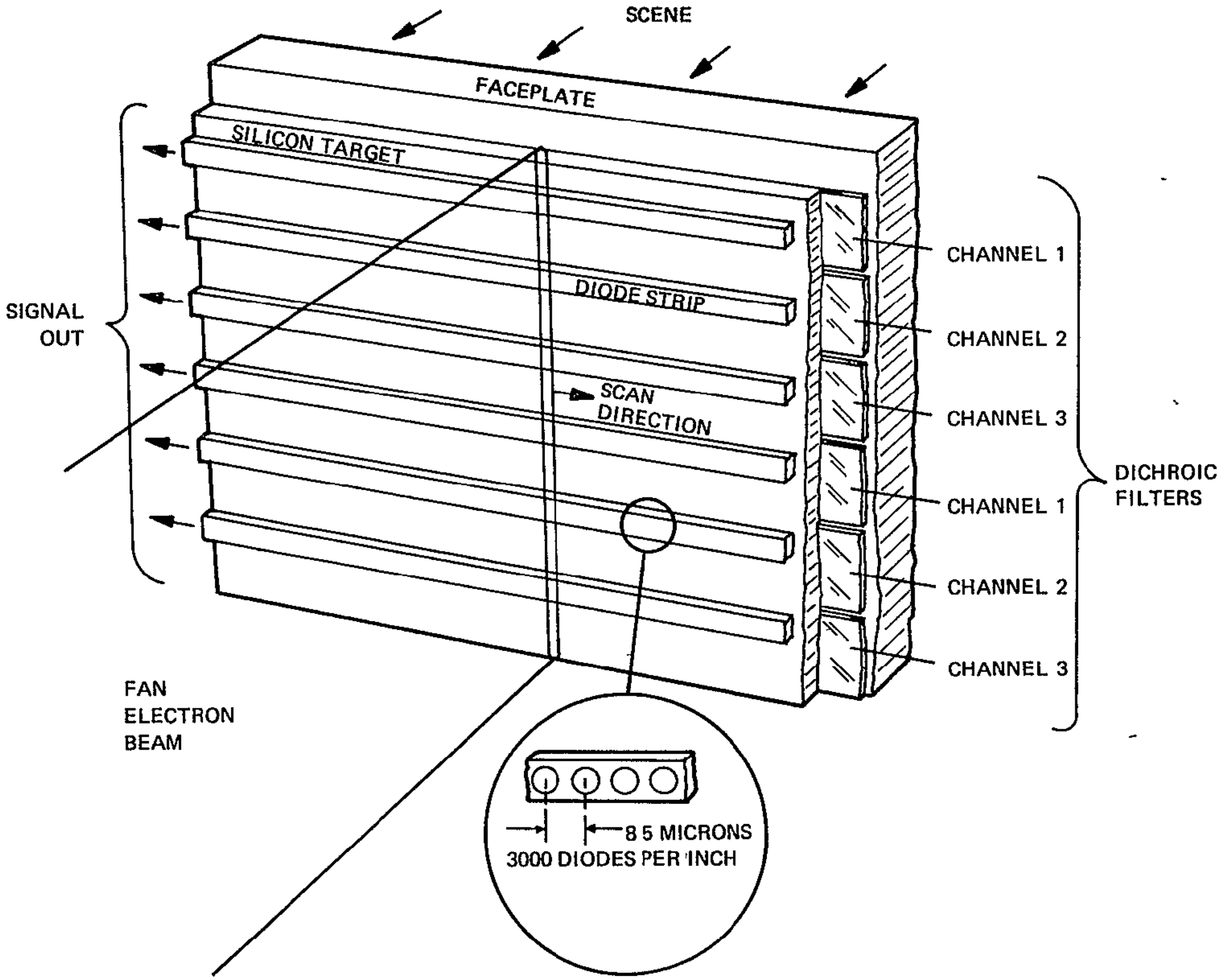

Figure 3-7. Multi-Spectral Silicon Line Scan Sensor

six outputs (2 for each of three spectral channels) are shown here, provisions can be made to accommodate 8 outputs corresponding to four spectral channels. The diode element density will be 1180 diodes per cm along a 3.3 cm line resulting in 4000 diodes per line. The 150 Km ground swath will be imaged by a dual optical system (Figure 3-8) with each half covering 75 Km. Therefore, each 150 Km swath is imaged on two lines of diodes containing a total of 8000 diodes, thus providing better than 30 M per element spatial resolution. A fan-beam 18 x 625 μ, will be used to obtain a simultaneous readout from the diode lines in a single 4 millisecond sweep of the scanning beam.

Preliminary sensor and optical design specifications were determined for both the high resolution and low resolution requirements of the coastal zone. Specifically, as discussed previously, the requirements called for a 150 Km FOV with a 50 M resolution for the low resolution case and a 30 Km FOV with a 10 M - 20 M resolution for the high resolution case. The spectral range of operation is from .4μ to 1.1μ.

The current state of the art in vidicon manufacture is that a resolution of 8μ at the tube target can be achieved. 20 M from an orbit of 540 Km is approximately 0.04 milliradians. This implies a focal length of 20 cm for 20 M ground resolution or an overall telescope length of about 40 cm (assuming a Schmidt optical system). This length is inversely proportional to the resolving power. For a 10 M ground resolution a 80 cm telescope will be necessary.

Scaling numbers from previous work indicates that a clear aperture of 100 cm^2 will be necessary to provide sufficient energy for an adequate signal. Taking account of the central obscuration a 13 cm diameter would appear reasonable to extract the image.

For the 20 M resolution case this would imply an F/1.6 system which is rather fast, but preliminary estimates of the resolution at the extreme edge of the required angular field indicate that it is within the desired range. However, very little margin is left for additional aberrations due to field flatteners, the vidicon face plate, etc.

The 10 M resolution approach appears possible but has not been investigated numerically.

An approach was investigated to scanning the high resolution, smaller field of view over the low resolution, larger picture by rotating the folding mirror. Although desirable, the amount of central obscuration resulting when the folding optics are made adequate to catch the extreme rays in the field, precludes this approach. It will therefore be necessary to swivel the entire telescope in order to select the desired section of the wide angle field of view.

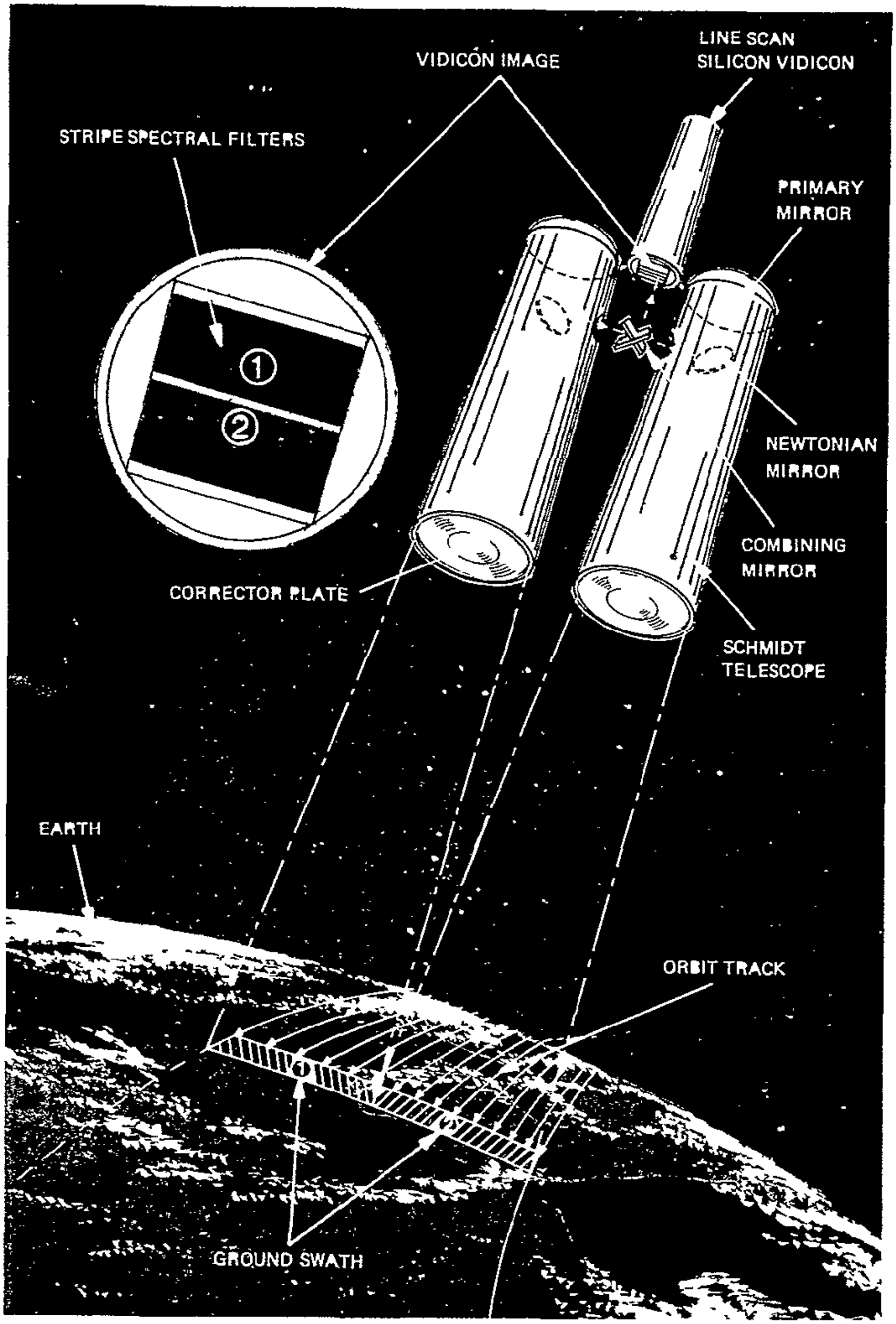

Figure 3-8. Multi-Spectral Line Scan Sensor System

The focal length of the wide angle viewer is calculated by taking the total angular field of view and fitting it into the standard vidicon surface. This implies a 10 cm focal length which means that the ground resolution will be on the order of 50 M. Aperture considerations indicate that an aperture of 40 cm^2 is adequate which implies (allowing for central obscuration) a diameter of 3.75 cm. This yields a F/3.2 system which has perfectly adequate resolving power for the desired measurement.

To sum up

	Low Res.	High Res.
Focal Length	10 cm	40 cm
Aperture	40 cm^2	100 cm^2
Diameter	3.75 cm	13 cm
F No.	3.2	3.2
Overall Length	20 cm	80 cm
Ground Resolution	50 M	10 M

The mode of operation of the optical sensor is envisioned as being the line scan mode (sometimes called the push broom) as opposed to the frame-at-a-time mode. The mode of spectral separation envisaged is that of interference filters applied as stripes across the face of a line scan vidicon which is operated in the fan beam mode. This offers several advantages. The optical system can be made more compact, more efficient and less complex than in any alternate mode. Registration difficulties are almost completely eliminated since all channels are sensed simultaneously by what is physically a single sensor. This approach also somewhat simplifies the data handling and synchronization problem.

3.6.3 Solid State Diode Array

Another possible approach is to replace the vidicon with an array of photo sensitive diodes addressed by logic techniques. Work is being done on these techniques by NASA and such a device is under active development. Unfortunately, in the present state of the art, the current devices are not suitable to be used as a solution to this particular program. Close attention is being paid to the progress of the development program by NASA and industry however, and should any further advance be made it will be seriously considered for space use.

3.6.4 Laser Devices

The laser offers much promise as a new remote sensing tool for water depth measurements. Trade-off studies show that presently available components and reasonable system sizes will provide laser systems that can measure depth to 50 M from an aircraft flying at 500 M altitude over coastal waters (Polcyn, 1969). Design studies show that a laser system with state of the art components and with a receiver-collector area of at least 1.6 square M can detect depths of 20 M in coastal waters. However, spacecraft systems tend to be large, so that component and subsystem development must be carried out to assure that these systems are practical in size and reasonable in cost.

SECTION 4.0

ORBIT AND SPACE OPERATIONS CONSIDERATIONS

4.1 Orbit Alternatives

4.1.1 Orbit Selection Factors

The optimum orbit for a satellite performing an earth observational mission is determined by the orbit geometry and the geographical coverage requirements. The orbit geometry involves the shape, the altitude and period, and the inclination of the orbit while the geographical coverage requirements are defined in terms of the area to be covered, the frequency with which data is to be taken and the ground illumination necessary.

Satellite earth orbits are elliptical in shape with the earth located at one focus of the ellipse. Circular orbits are special cases of elliptical orbits (the semi-major and the semi-minor axes are equal).

The altitude of a circular orbit determines the orbital period (i.e. the time from one northward crossing of the equator to the next) as well as the satellite orbital lifetime. Fig. 4-1 shows typical lifetimes (time to reentry into earth's atmosphere) for satellites in both circular and elliptical orbits. Fig. 4-2 is a graph of the orbit period as a function of altitude for circular orbits.

The inclination of a satellite orbit is the angle between the orbit plane and the earth's equatorial plane (see Fig. 4-3). If the angle is less than 90°, the orbit is a posigrade orbit (i.e. the satellite has a velocity component in the same direction as the earth's rotation). If the angle is greater than 90°, the orbit is called a retrograde orbit. An orbit of 105° inclination can be specified as a 75° retrograde orbit (i.e. the angle specified is the supplement of the angle of inclination). The orbit inclination determines the highest latitude a satellite will pass over.

The projection of a satellite orbit on the surface of the earth is called the subpoint track. Since the earth is rotating around its own axis from west to east, the subpoint track of succeeding orbits is displaced westward in proportion to the orbital period. A plot of several typical successive ground tracks is shown in Fig. 4-4.

In order to plot the exact ground track of a satellite, the effect of perturbations caused by the oblateness of the earth must also be included in the orbit parameter calculations.

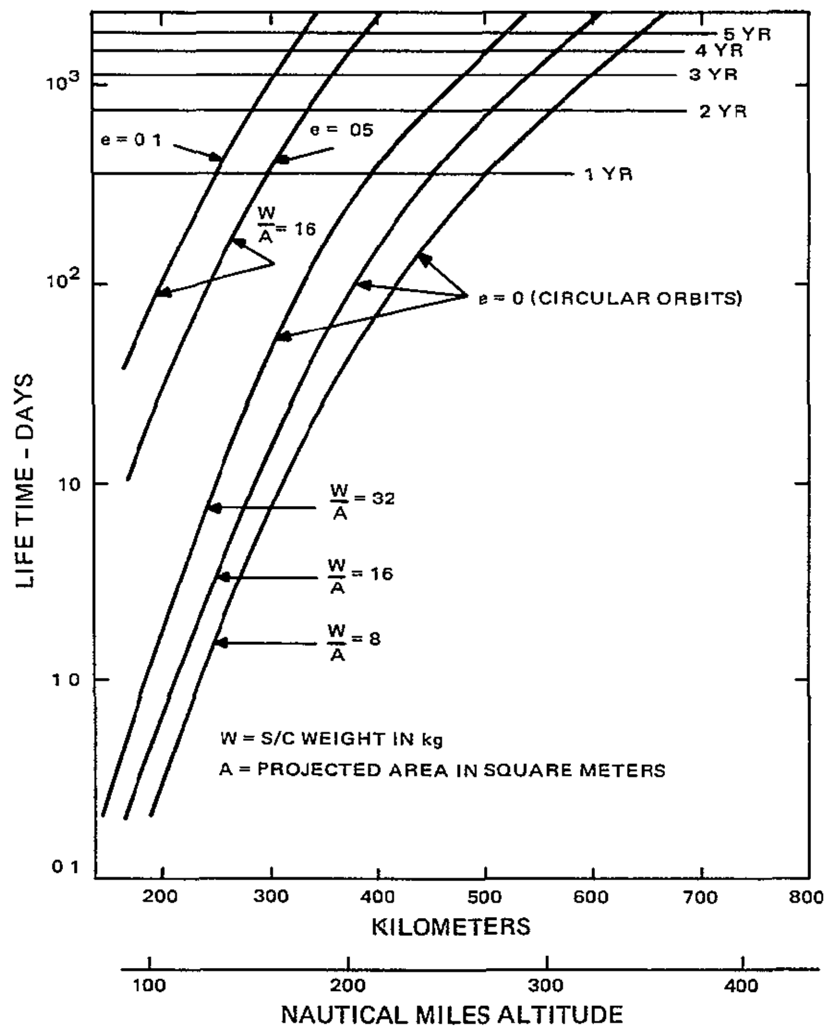

Figure 4-1. Typical Satellite Lifetimes vs Altitude

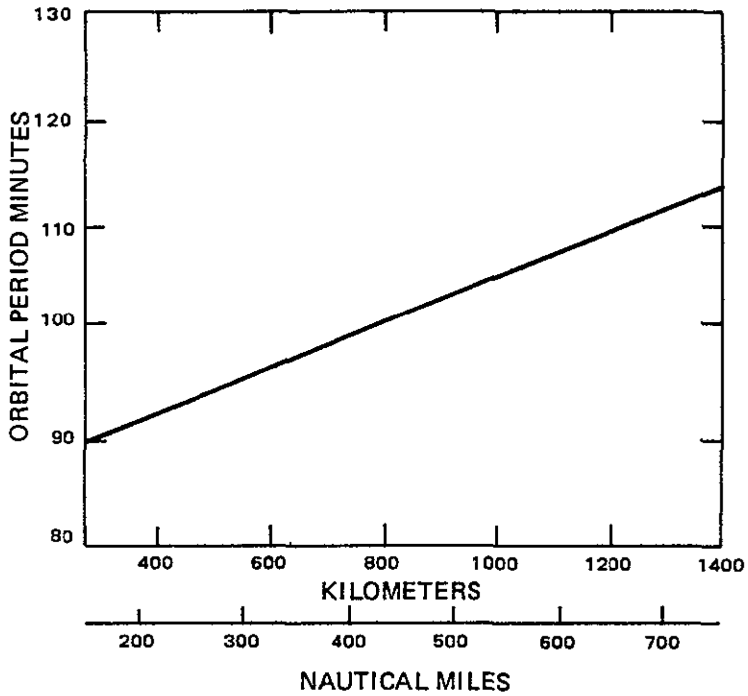

Figure 4-2. Orbit Period vs Altitude

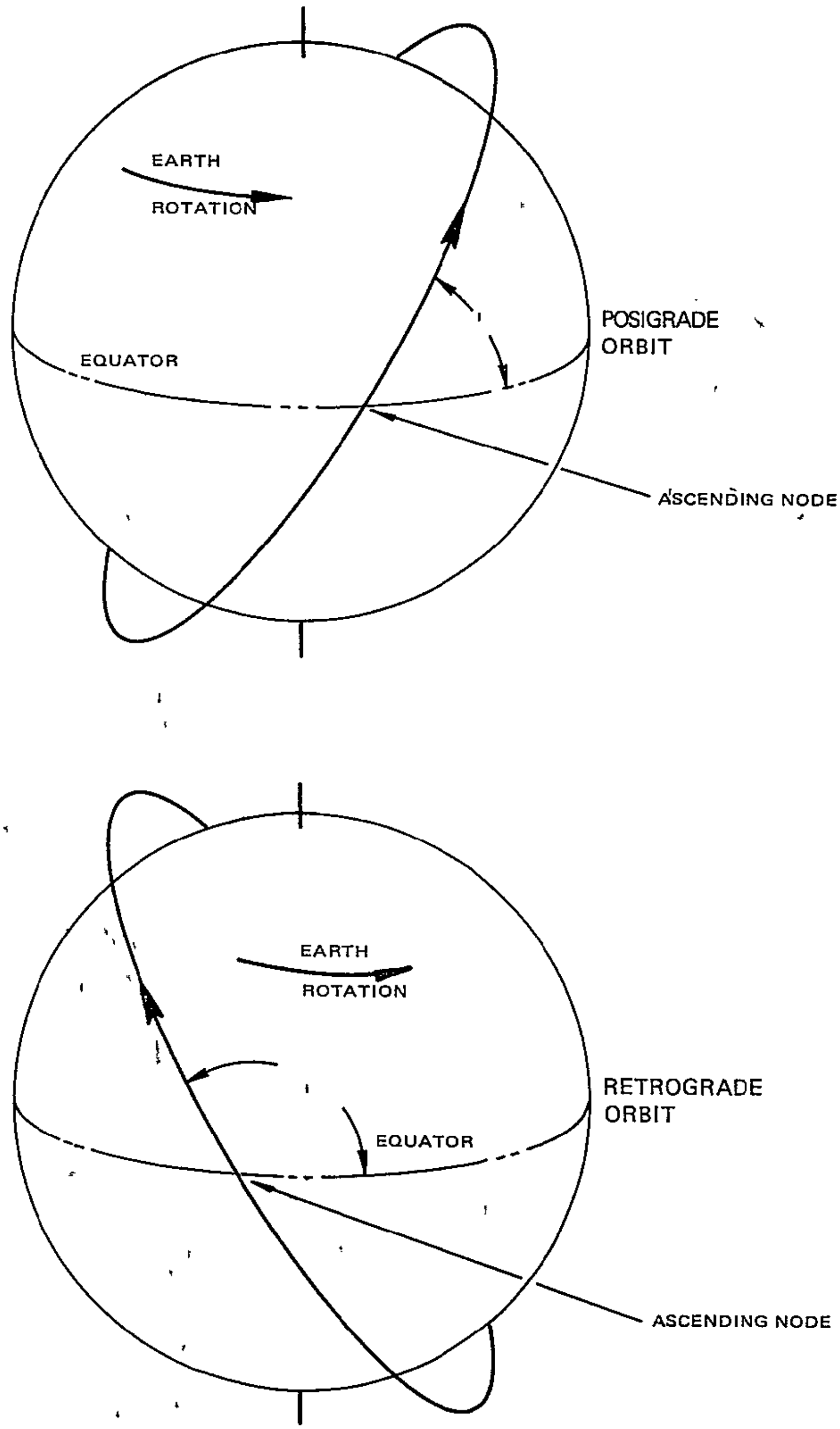

Figure 4-3. Satellite Orbits

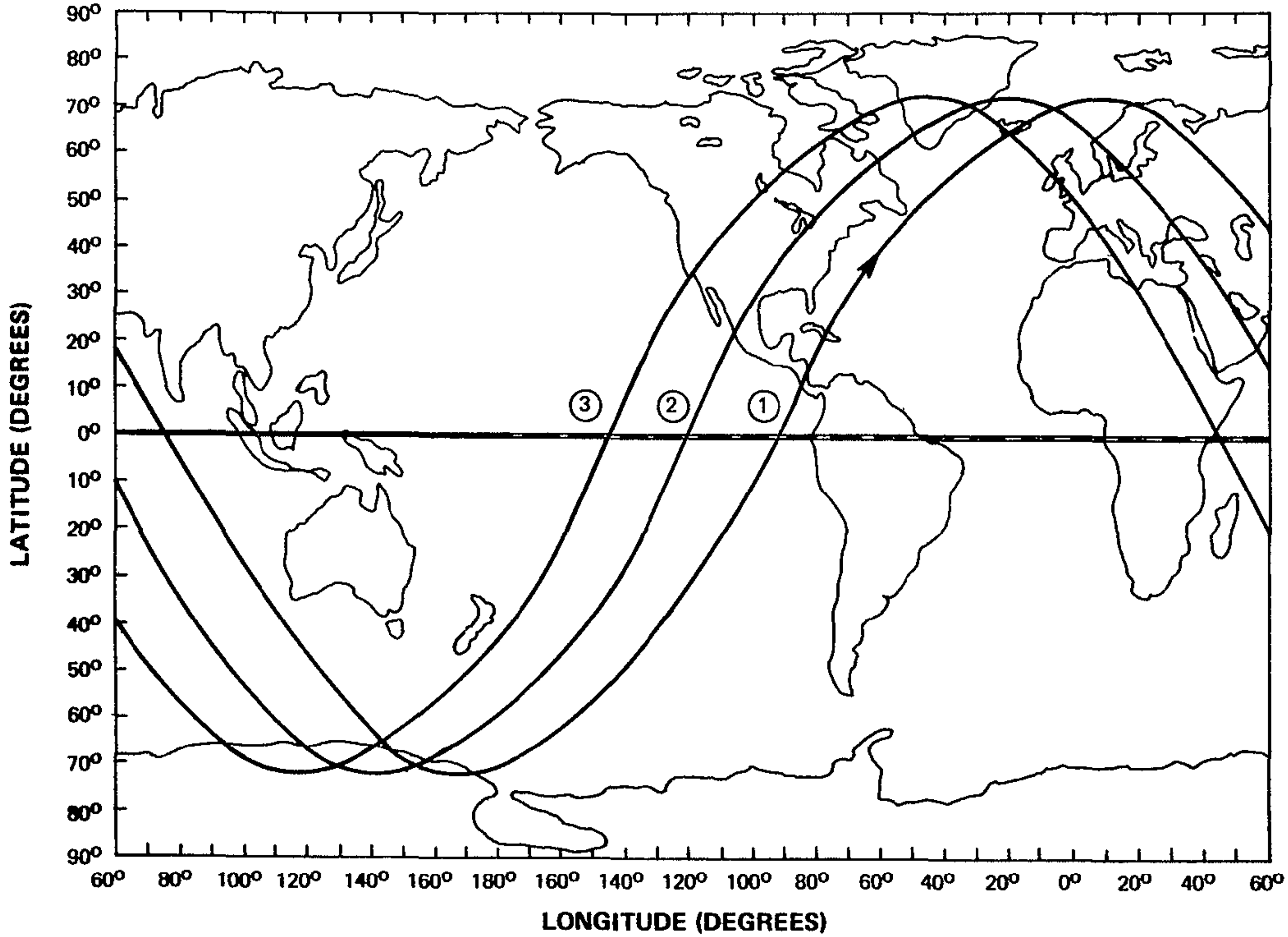

Figure 4-4. Typical Satellite Subpoint Tracks

If the earth were a perfect sphere, an earth satellite orbit would be fixed in inertial space. Because the earth is an oblate spheroid, a satellite orbit will drift or precess with respect to a fixed celestial reference. Thus, the ascending nodes of succeeding orbits will be displaced as shown in Fig. 4-5. The ascending node of an orbit is that point in the orbit where a north headed satellite cuts the equatorial plane.

Time on earth is reckoned by the sun. Thus, a solar day (synodic day) will differ in length from a sidereal day. A sidereal day is the time required for a point on the surface of the earth to rotate 360°. In Fig. 4-6, a sidereal day is the time required for point A on the earth to rotate back to its initial position in inertial space, point A'. A synodic day is the time required for point A to rotate to the same position relative to the sun, point B. The correction factor for this time difference is equal to the rate of the earth's rotation around the sun -- .9856° of longitude per day.

If the rate of nodal regression due to orbit precession is made just equal to the effect of the earth's rotation around the sun, a group of orbits with a unique property is obtained. A satellite in one of these orbits will cross a particular latitude at the same local time each day, i.e., the angle between the sun and the subpoint track will be relatively constant from day to day. This type of orbit is called a sun synchronous orbit and is used by satellites such as Nimbus and ITOS and will be used by ERTS A and B. Fig. 4-7 shows the relationship between altitude and inclination for obtaining sun synchronism.

For an observational satellite mission it is important to establish how frequently a satellite will pass over the same point on the earth. The satellite subpoint will retrace the same track only if the satellite crosses a particular longitude in an integral number of orbits. Control of the ground track retrace is achieved through selection of the proper orbital elements.

The orbit track repeat cycle is a function of the altitude and inclination as shown in Fig. 4-8. Thus, if it is desired to have a satellite repeat a particular track each day, it can be done, for example, every 15 orbits with an inclination of 72° at an altitude of 600 kilometers. Each track will then be displaced from the preceding track by 24° (1440 nautical miles at the equator). If it is necessary to have the subpoint track displacement 12.4° (744 nautical miles at the equator), then an inclination of 72° and an altitude of approximately 700 kilometers are needed. However, this combination will repeat the same track once every twenty-nine orbits. The closer together the ground tracks are, the longer it takes to repeat the same track.

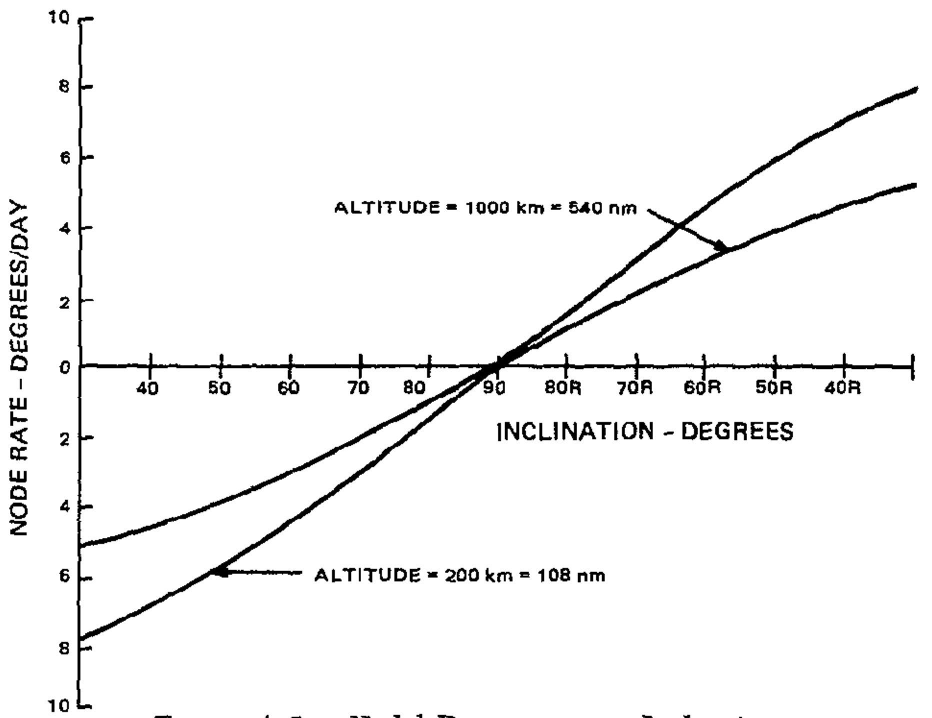

Figure 4-5. Nodal Precession vs Inclination

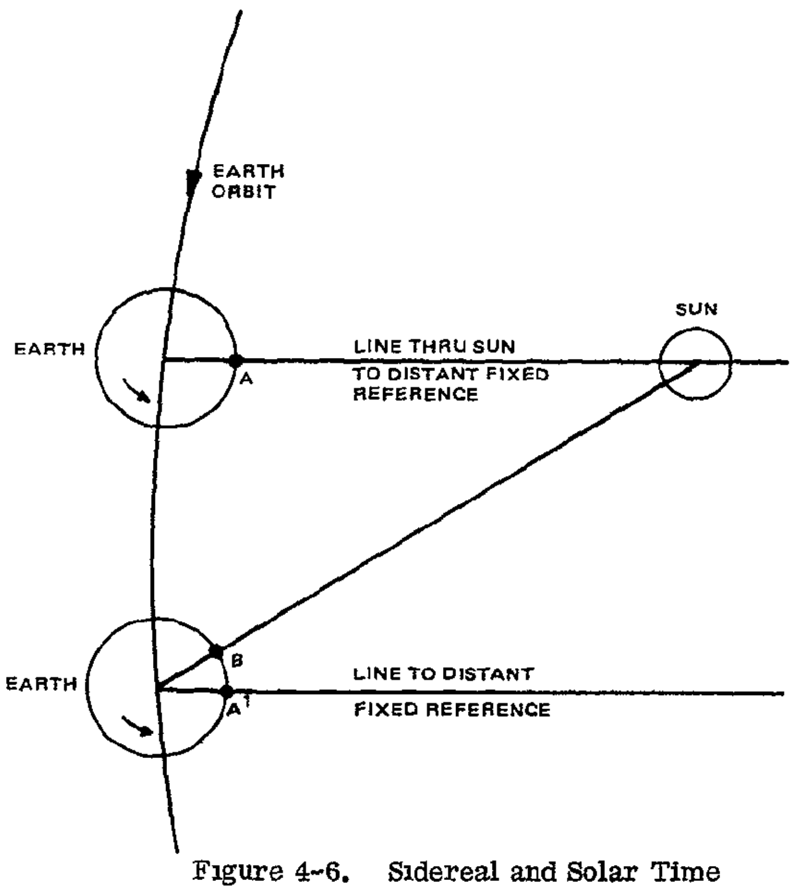

Figure 4-6. Sidereal and Solar Time

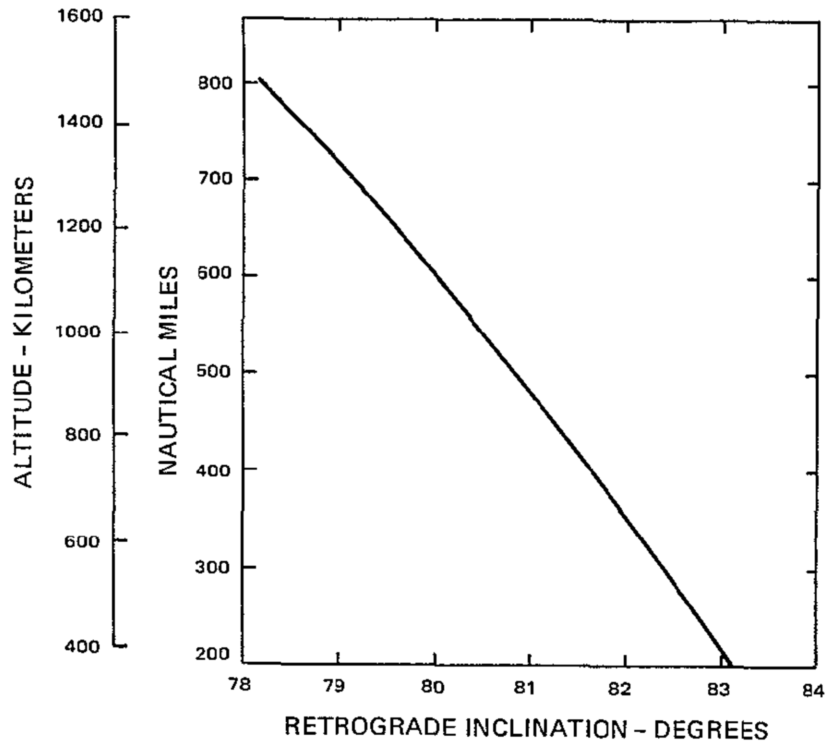

Figure 4-7. Sun Synchronous Orbits

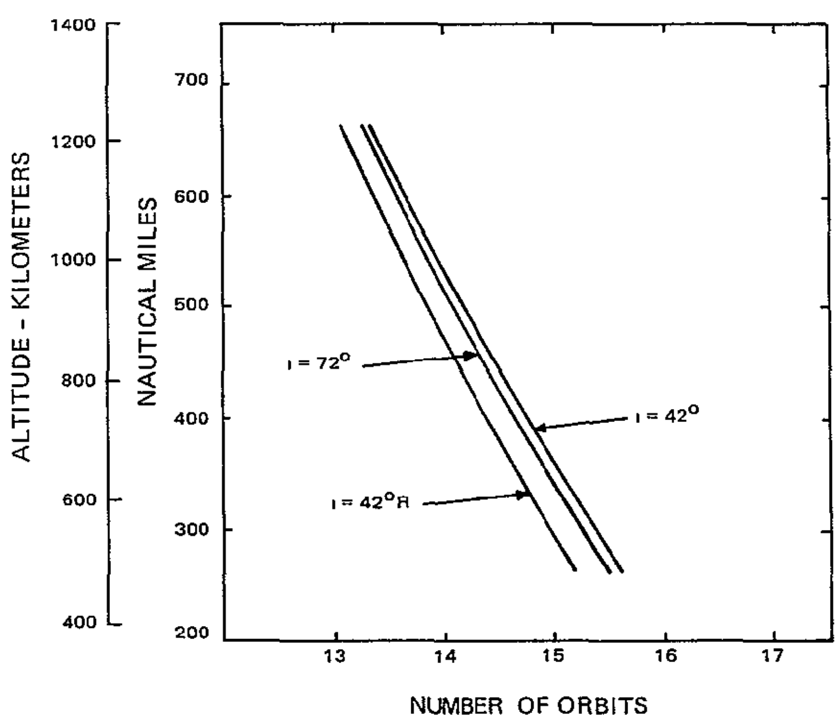

Figure 4-8. Number of Orbits Between Repeat Longitude Crossings

4.1.2 Alternative Orbits

For the coastal zone oceanographic mission, the selection of orbit altitude will require consideration of ground station contact time and sensor ground resolution. These two requirements are conflicting though, since the ground contact time increases with altitude while sensor resolution decreases. Since reasonably high resolution sensor performance is necessary, altitudes below 1100 kilometers should be utilized. As shown in Fig. 4-1, though, low altitude circular orbits have a very limited lifetime. If the orbit altitude is to be held relatively constant over a one year mission, (necessary for image and data comparison purposes), then lifetimes in excess of 5 years would have to be considered (with no on-board propulsion). With the addition of on-board propulsion capability, though, a lifetime of 2 to 3 years can be considered without imposing too great a weight penalty. Therefore, circular orbits must be limited to those above approximately 550 kilometers. Elliptical orbits, on the other hand, can permit the perigee to dip quite low and still provide a relatively good decay rate for a 1 year mission, (less than 185 kilometers for highly elliptical orbits, i.e., $e > .3$). Three factors, though, preclude use of elliptical orbits for the coastal zone mission:

1. The line of apsides (apsides are perigee and apogee) rotates within the orbit plane creating satellite altitude variations at a particular latitude with time.

2. The subpoint of the satellite is moving at its greatest velocity at perigee (necessitating faster response time in sensors).

3. Attitude control implementation will be more difficult due to the non-linear orbital rate.

For these reasons only circular orbits will be considered although for special applications elliptical orbits may be desirable.

The area of coverage will be of prime importance. Table 4-1 provides a tabulation of the latitude and longitude ranges of the United States and its territories. As stated earlier, the highest latitude traversed by a satellite orbit is equal to the orbit inclination. Thus, if all the states and territories are to be covered, the minimum acceptable inclination would be 72° or 108°. If Alaska can be excluded, then a 49° or 131° inclination can be used. This inclination can provide complete coverage of the 48 contiguous states as well as Hawaii and all of the United States territories and protectorates.

STATES	LATITUDE RANGE	LONGITUDE RANGE
Contiguous States	24.5°N to 49°N	67.5°W to 124.5°W
Alaska	51.5°N to 71.5°N	130°W to 170°E
Hawaii	19°N to 22°N	155°W to 160°W
TERRITORIES AND PROTECTORATES		
Puerto Rico	18.5°N	65°W to 67.5°W
Virgin Islands	18.5°N	64°W to 65°W
Guam	14°N	155°E
Midway	28°N	177°W
Wake	19°N	167°W
Samoa	14°S	171°W
Palmyra	6°N	162°W

THE COASTAL ZONE

TABLE 4-1

A third possibility is an inclination of 64° or 116°. This orbit track will very nearly parallel a line drawn from the southern part of Florida to the Boston area of Massachusetts and thus provide excellent East Coast coastal zone coverage as well as reasonable West Coast coverage.

It is important to note that these three orbit inclinations will provide coverage with scene illumination that varies from one orbital pass to the next. The amount of variation will be determined by the frequency of coverage. If a particular ground track is repeated each day, the scene illumination angle could change up to 6° per day (i.e. 24 minutes in time) depending on the inclination and altitude (see Fig. 4-5). If repetition is once in four days, nearly 2 hours change in scene illumination could take place between repeat tracks. In addition, there may be several periods per year when the areas of primary interest are in eclipse and visible band imaging may be impossible. On the other hand, these changes in scene illumination may be desirable in order to permit observation of certain phenomena at different hours of the day. Another potentially desirable feature is the illumination of all ground track areas during some portion of the one year mission. Thus, early in a mission, the east coast may be illuminated during orbital passes while the west coast is in darkness. Later on in the year, the west coast will be lighted while the east coast is in darkness.

A fourth candidate is a sun synchronous orbit. As indicated previously, the scene illumination remains relatively constant for this type of orbit. In addition, the orbit may be selected so that areas of specific interest remain in sunlight during the periodic satellite transits.

The frequency with which a particular area is covered will be determined by the amount of coverage required. In Fig. 4-9, the distance between ground tracks at the equator is ℓ while the distance between centers of the field of view (d) is $\ell \sin i$. Then, as d is decreased to provide more complete coverage, the number of orbits necessary will be increased

$$N = \frac{360}{\ell}$$

where N = number of orbits required

ℓ = distance in degrees between tracks

With the number of orbits per day limited to the range of 13 to 16 (in order to have a realistic altitude in the range of 550 to 1100 kilometers, the number of days required to repeat coverage can be calculated.

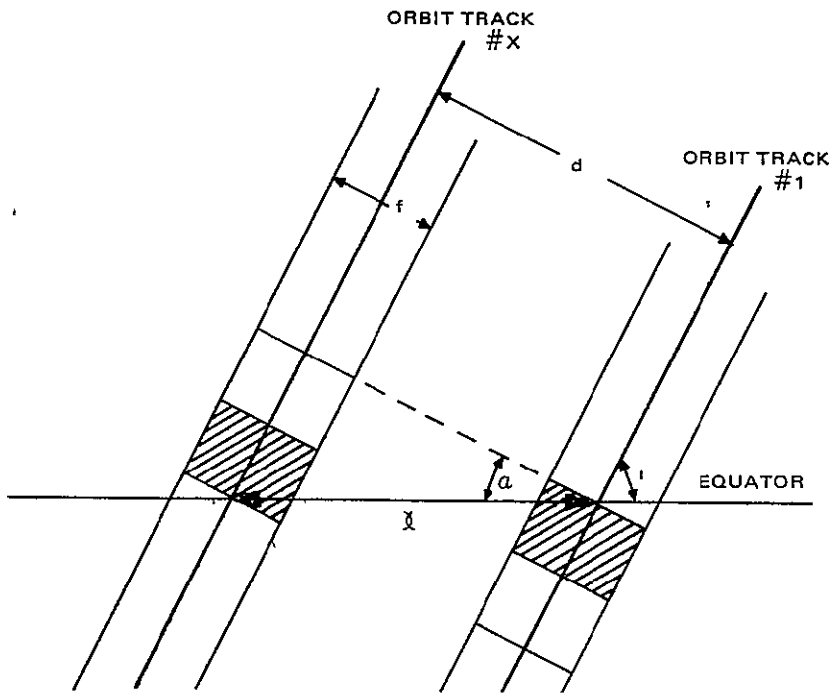

Figure 4-9. Satellite Subpoint Tracks

$$D = \frac{N}{n}$$

where D = number of days required to repeat

n = number of orbits per repeat longitudinal crossing

The altitude necessary to give a specific number of orbits per repeat longitudinal crossing is plotted in Fig. 4-10 for orbit inclinations of 49°, 64° and 72°.

If a sensor field of view is a track 185 kilometers wide, then complete coverage at the equator would require adjacent tracks to be 185 sin i Km apart at the ascending nodes. For 90 - 110 minute orbital periods (altitudes in the range of 550 to 1100 Km) 13 to 15 orbit repeat cycles can be achieved with approximately 15 - 20 days required to complete full coverage. More frequent coverage of specific areas will require elimination of all coverage of some areas. Thus, for coverage of a particular area every four days, the ground tracks will, for successive days, be separated by approximately 678 Km at the equator.

4.1.3 Recommendations

In selecting the orbit for a coastal zone oceanographic mission, the following boundaries should be utilized:

1. Only circular orbits should be considered.

2. Altitudes in the range of 550 to 1100 Km should be used.

3. Orbit inclinations should be 98° (for sun-synchronous orbits) 49°, 64°, or 72°.

4. For covering a limited number of areas on a daily basis, an integral number of orbit per repeat cycle (14, 15) should be utilized. For providing more extensive area coverage on a two, three or four day cycle, a fractional number of orbit repeat cycles (14.33, 14.5, 14.75) should be used.

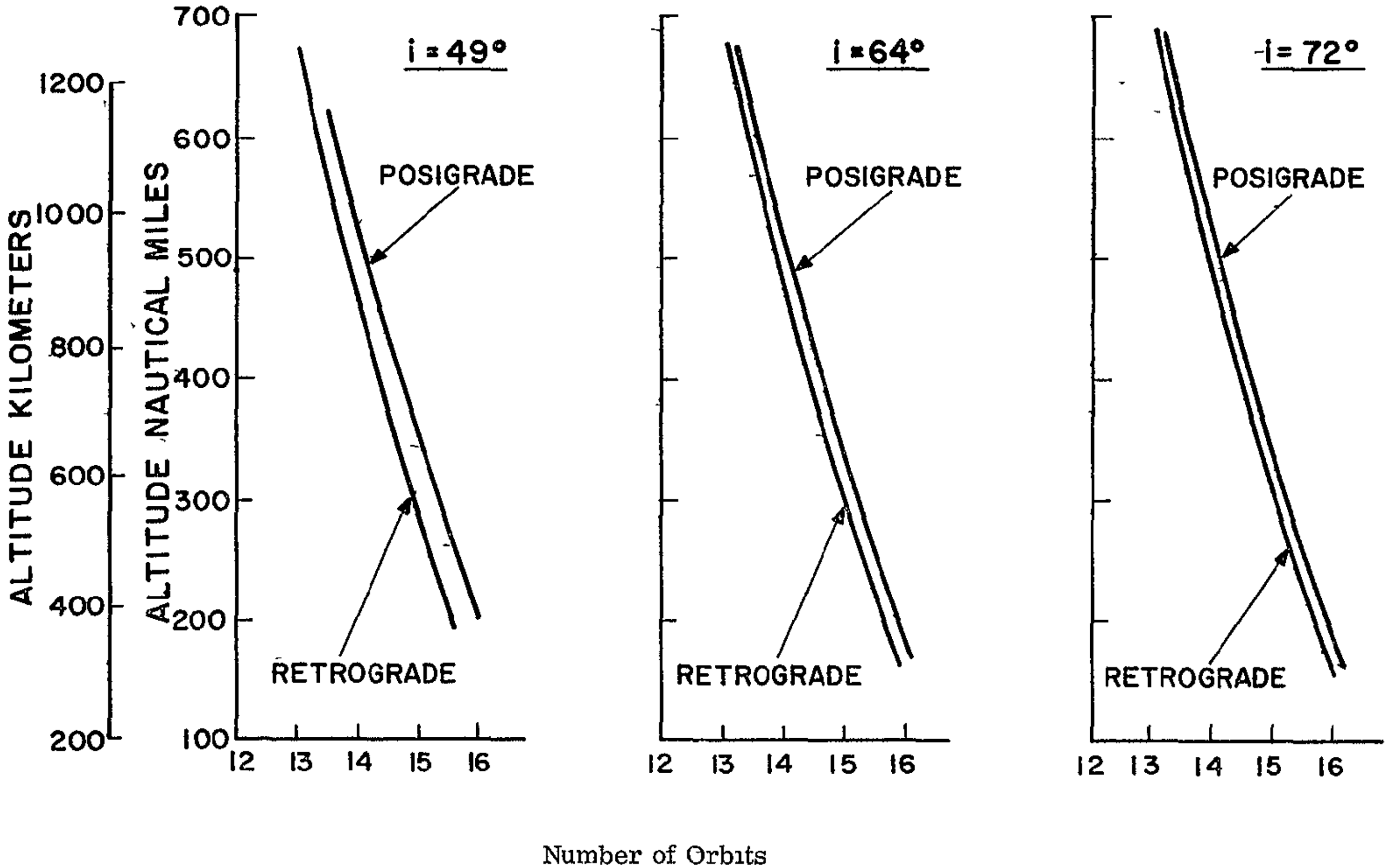

Figure 4-10. Orbit Repeat Track Cycles

4.2 Spacecraft Constraints

4.2.1 Attitude Determination and Control

Mission requirements dictate the degree to which an earth orbiting satellite's position and attitude must be known and controlled. Satellite tracking techniques, along with computerized data operations, permit accurate prediction of satellite position once an orbit is established. Correction of orbit parameters will be necessary for the Coastal Zone mission to assure the proper ground track coverage. This can be accomplished by providing on-board propulsion capability. Thrust applied along the orbit normal at the ascending or descending node can increase or decrease the inclination. Firing a thruster tangentially to the orbit will raise or lower the altitude or provide correction for ellipticity. The amount of mass expulsion required is dependent upon the spacecraft weight, the altitude, the mission duration, and the pointing control required. In addition, on-board propulsion is required to provide accurate initial orbit circularization and altitude correction.

High resolution imagery requires the ability to accurately locate the area being sensed. If the spacecraft attitude is measured and controlled with high absolute accuracies, image location can be assured within small tolerances. Figure 4-11 shows the geometry of a typical sensor field of view. The pointing error in meters (neglecting earth curvature effects) is

$$d = h \tan \Psi$$

where h = the altitude in meters

and Ψ = the attitude control error in degrees.

This relationship is plotted in Figure 4-12 for the 550 to 930 kilometer range.

On the other hand, the desired missions for the coastal zone may require that some or all of the sensors be pointed in a specific direction or at a particular target in order to get repeat pictures of an area for tracking currents or because an area is of special interest and not exactly on the orbit track. If each sensor contained its own pointing capability (e.g., a pointable mirror), then changing its viewing axis will impose a burden to be compensated for by the spacecraft attitude control system. The use of an isolated pointable platform on which all sensors are mounted, may be a better approach with less constraints and penalties. This platform could then be pointed or controlled so as to track the coastline or dwell for a minute or two on a particular area.

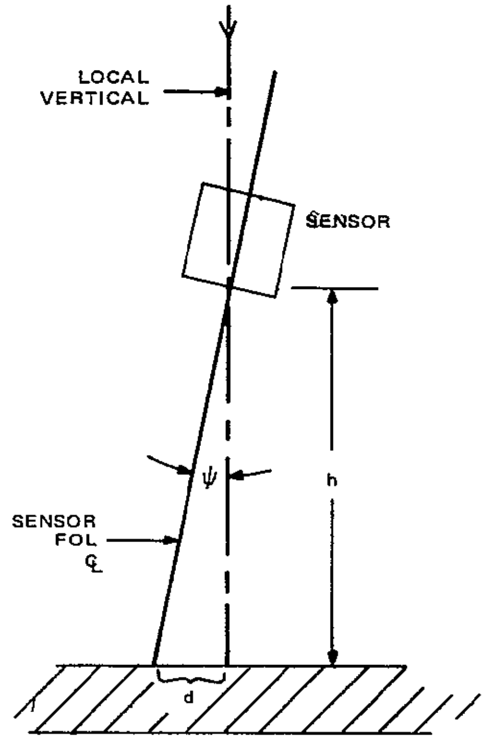

Figure 4-11. Sensor Pointing Geometry

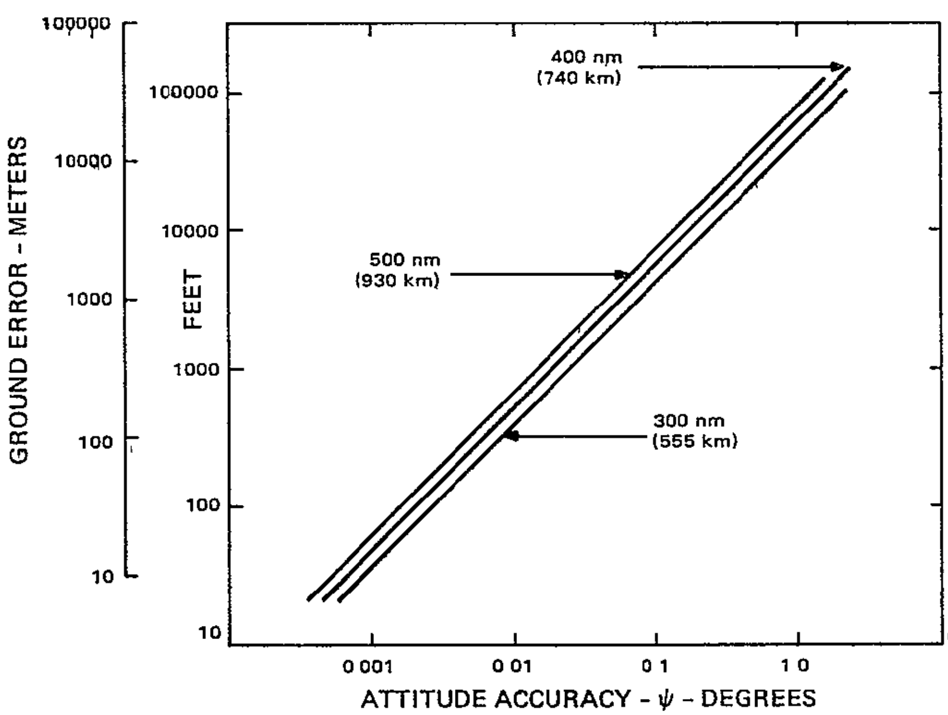

Figure 4-12. Attitude Accuracy vs Ground Pointing

With sensor resolutions of less than 30 meters, it will be desirable to provide pointing or attitude accuracies of $.001^{\circ}$ or better. Today's state of the art is, realistically, $\pm.01^{\circ}$ for low altitude missions. However, the weight and power required to achieve these accuracies are relatively large. $\pm.05^{\circ}$ to $\pm0.1^{\circ}$ are achievable with minimum spacecraft penalties.

An alternative approach, while not providing the same degree of pointing capability, can provide an accurate determination of where a high resolution sensor is aimed. If a high resolution sensor is physically coupled to a large area imaging sensor, the use of bore-sighting techniques can locate the high resolution target area in the low resolution sensor field of view with accuracies approaching $\pm.001^{\circ}$. Visual identification of landmarks and prominent features can serve to orient the low resolution image with respect to the satellite sub-point track and thus locate the high resolution target area accurately.

This concept could be utilized by taking advantage of the fact that the performance of an attitude control system is a function of time. For short periods, a system can supply accuracies approaching $\pm.001^{\circ}$ relative to the spacecraft (i.e. to the axis of the large area sensor). Thus, an accurate attitude error monitoring system employing high precision gyros coupled with a somewhat less accurate control system will supply short term accuracies (i.e. 1 to 5 minutes) suitable for the sensor requirements of coastal zone missions.

4.2.2 Weight and Launch Vehicle

For satellites in orbit altitudes under 1850 kilometers the sensor or experiment weight has historically been in the range of 20 to 25% of the total spacecraft weight. Thus, for Nimbus B, with a total weight of 571 Kg (excluding a 52.5 Kg adapter), the experiments were approximately 122 Kg. For the ERTS E and F Coastal Zone Oceanographic Mission, it is assumed that the ratio will be approximately the same.

Table 4-2 shows the currently available sensors and an estimate of the physical properties. Combinations of these sensors or modification of them will be selected in Section 5.2 for the specific missions.

Generally, spacecraft for posigrade orbits will be launched from the Eastern Test Range (ETR) and for retrograde orbits from the Western Test Range (WTR). Figure 4-13 shows launch vehicle capabilities for the range of altitudes under consideration in this study (i.e. 550 to 1100 Km).

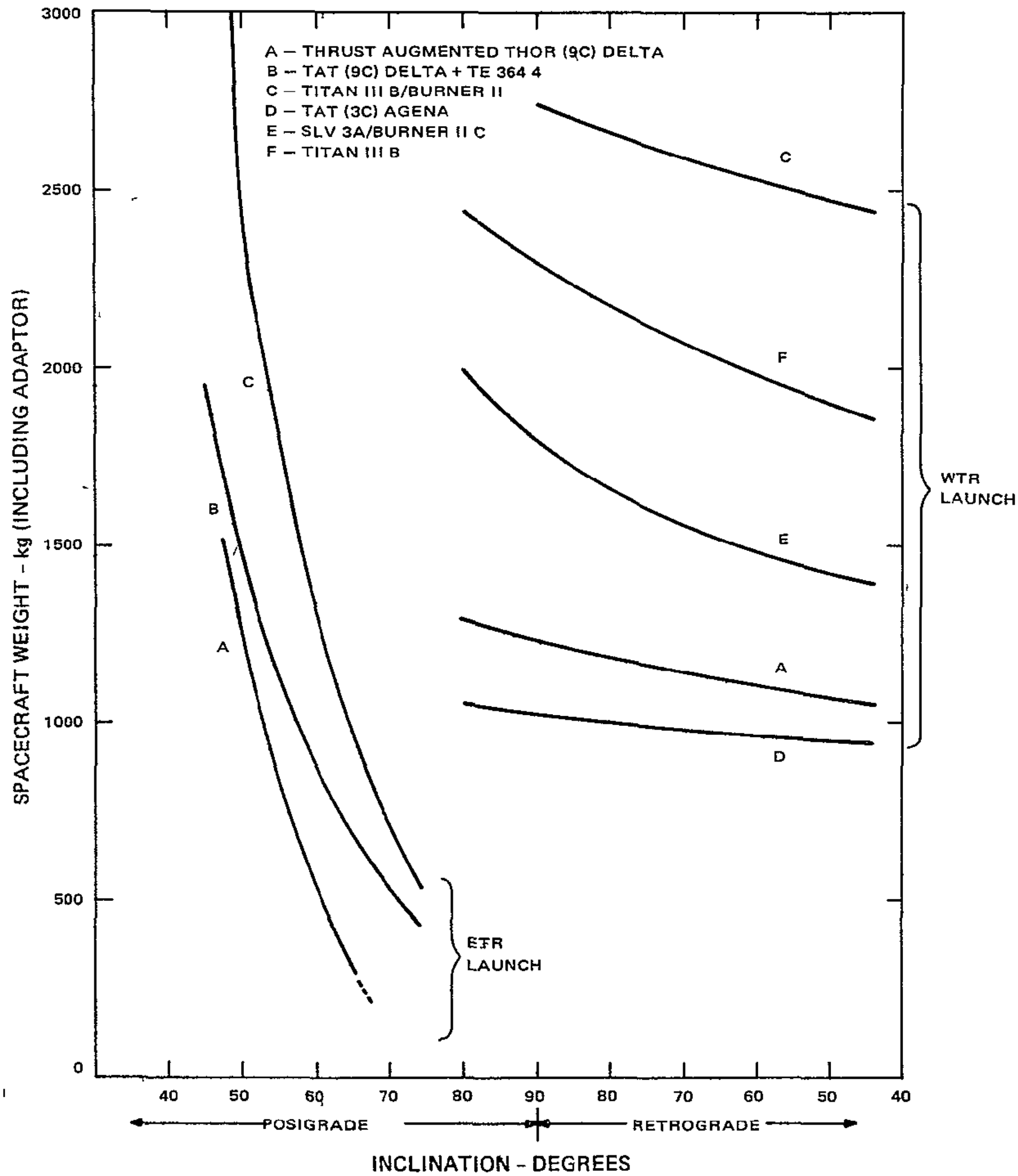

Figure 4-13. Booster Capability

The total weight of the sensor payload will have to be under 454 Kg for a launch from ETR into a 550 to 1100 Km 49° posigrade orbit with a TITAN IIIB/BURNER II booster. If a smaller and less expensive booster is used, such as the TAT(9C)DELTA+TE364-4, then 270-320 Kg of experiment payload can be accommodated. If the orbit inclination is increased to 72° posigrade, then the TITAN IIIB/BURNER II booster can place 135 Kg of sensor payload into orbit at 550 to 1100 Km.

A TITAN IIIB (without BURNER II) can place almost 410 Kg of sensor payload into a sun synchronous orbit at 550 to 1100 Km.

4.2.3 Power

The power subsystem will probably be a photo-voltaic-electrochemical system employing N-on-P solar cells and Nickel-Cadmium storage batteries. The area of the solar array will be dependent upon the sun angle (i.e., the angle between the orbit normal and the sun vector) which is a function of the orbit inclination and launch time and date. Generally, for the greatest versatility, a sun oriented solar array is preferred since it requires a minimum area for a specific power output. It does necessitate, though, a more complex spacecraft and control system -- one which must maintain the sensors in an earth oriented mode while the solar array is oriented toward the sun. For some missions a body mounted solar array similar to TIROS or fixed solar panels like ITOS may be adequate. These missions would be those where the sun angle variation during the life of the mission was within a 20 to 30 degree range centered around a 45 degree sun angle.

Satellite orbits in the 550 to 1100 Km range will have a maximum eclipse period of approximately 35 minutes. During this time the Ni-Cd batteries will supply the spacecraft power requirements.

For power systems operated at a 550 to 1100 Km altitude and with a 35% eclipse factor, the ratio of nominal array power output to the daytime load requirement lies in the range of 1.7 to 2.0. In this regime, the end of mission power from the 4.88 Kg/square meter solar array will be on the order of .75 watts per square meter.

The batteries may be operated at a 20% depth of discharge for the one year mission with a high reliability factor. Thus, the required battery capacity will be 5 times the nighttime energy requirement. Battery weight will be approximately .05 Kg per watt hours.

The power system electronics, including reasonable redundancy, will weigh about .022 Kg per watt of average load.

4.2.4 Size

The spacecraft size will be affected by a number of interrelated factors. Primary concern will be to provide sufficient earth oriented surface area for sensor location. Some of the sensors may require large base-plate areas for optics or other long path techniques (see Table 4-2). Other sensors may require large ground planes or special base plates for cooling. Microwave and radar devices will probably require antennae which are relatively large and which must be aimed toward the earth.

The solar array requirements will affect the spacecraft size If a body mounted array is used the spacecraft surface area may have to be somewhat greater than three times the projected area requirement of the solar array. If an oriented solar array is utilized, the spacecraft size may be reduced, but cost and complexity will be increased.

Thermal control of the various sensors and other subsystems will greatly affect the size. Sufficient area with a large view factor of deep space must be made available for cooling.

On the other hand, booster shroud clearances require that the spacecraft be kept to a minimum size compatible with spacecraft weight and vibrational characteristics. In addition, radar antennae and solar panels may have to be folded for launch with subsequent deployment once the proper orbit is achieved. Deployment mechanisms and techniques may require additional area and add extra weight.

4.2.5 Communications and Data Handling

The communication requirements for the spacecraft will be separated into two separate functions: Command and Control, and Sensor data handling.

The Command/Control (including beacon and telemetry) will require at least one up-down link between the satellite and the ground stations. This link will handle the commands for sensor operation (as well as command storage and timing) in addition to the spacecraft operational systems commands. Telemetry data from all subsystems will be multiplexed and transmitted to the ground as required. It is anticipated that this command and control function can be handled by the ERTS ground stations at Fairbanks, Alaska; Corpus Christi, Texas; and Rosman, North Carolina. It may be necessary to include telemetry data storage (a la Nimbus) for orbit inclinations that preclude use of the Fairbanks ground station or where blind orbits occur in succession. For the ERTS E and F missions, though, sufficient experience with the operational subsystems may permit exclusion of continuous telemetry.

SENSOR	WT. (Kg)	VOLUME (Meters ^{3})	POWER (Watts)
Return Beam Vidicon (Low Resolution) (Includes 20% base plate weight)			
1 Camera	32	.0	60
2 Camera	57	.10	105
3 Camera	81	.14	150
4 Camera	107	.17	190
Return Beam Vidicon (High Resolution) (Includes 20% base plate weight)			
1 Camera	36	.06	60
2 Camera	66	.10	105
3 Camera	93	.14	150
4 Camera	122	.20	190
Multispectral Point Scanner			
Low Resolution	36	.13	50
High Resolution	43	.17	55
Radar Scatterometer	34	.03	130
Infrared Scanning Radiometer			
Low Resolution	9	.03	10
Infrared Radiometer			
High Resolution	11	.03	10
Microwave Radiometer	23	.04	25
Correlation Spectrometer	43	.23	25

CURRENT SENSORS

TABLE 4-2

The second communications function, sensor data handling, will require a down link only. This link may be used for direct readout of multiplexed sensor data, direct sequential readout of sensor data, or for playback of stored sensor data. Data storage on Nimbus, and ITOS is accomplished through tape recorders which record data at a low tape speed and play it back at a high speed. This is necessary on these satellites because the data being generated by meteorological sensors is collected throughout the orbit and can be gathered only by the two or three specialized ground stations. Ground station contact time for these spacecraft is limited to about 7 to 8% of the orbital period.

For the Coastal Zone mission, storage requirements may be somewhat different since the satellite subpoint track may be in the coastal zone for as little as one or two minutes per orbit or as much as 5-10 minutes per orbit. Thus, only a limited amount of sensor operation is anticipated. It may, therefore, be desirable to utilize the same record and playback speed, thus simplifying tape recorder requirements. The volume of data (per unit time) generated by the Coastal Zone mission sensors will be from one to two times the amount generated by the ERTS A and B sensors. Thus, the frequency band allocations for data transmission will have to be relatively wide.

If new ground stations are added, if relay satellites are available, or if techniques for local readout of sensor data are available, the requirements for data storage may be reduced significantly and may even be eliminated.

4.3 Spacecraft Summary

The specific configuration of a spacecraft for the Coastal Zone Oceanographic mission cannot realistically be made at this time but some parameters can be identified with a reasonable degree of confidence.

1) The spacecraft weight will be in the range of 680 to 1360 Kg with approximately 20% allocated for sensors.

2) Power requirements will be in the range of 150 to 350 watts average load. Housekeeping (i.e., telemetry, communications, attitude control, thermal control, etc.), power requirements will be approximately 5 to 10 watts for every 45 Kg of baseline spacecraft weight.

3) On-board propulsion will be required in order to maintain orbital parameters for the mission duration.

4) Unless new ground stations are added, on-board storage for sensor data will be necessary. Direct readout capability could reduce spacecraft requirements.

SECTION 5.0

PAYLOAD CONFIGURATIONS

5.1 Selection Considerations

Selection of the payload configuration for each of the priority applications has been based on several factors:

a) Measurement needs ranked according to the usefulness of the data.

b) Sensor capabilities: to meet the data needs.

c) Coastal zone management experiments: definition of missions for spaceborne remote sensors which will determine if operationally useful data can be obtained.

d) Orbit requirements: to satisfy coverage and frequency needs.

e) Space operations procedures: feasibility of steps of obtaining and transmitting data from space to meet a specific experimental mission.

f) Spacecraft support and interface needs: other functions or physical characteristics necessary to permit use of the sensor payload package as desired.

The first four items were obviously the most significant with (a), (b), and (d) being specific subtasks of our study. Item (c), the missions for each of the four coastal zone applications areas are defined based both on the CZ oceanographic needs and on what seems feasible to implement.

The major needs which were used in each area were:

Pollution:

P-1) Frequent repeated coverage of same area (daily if possible).

P-2) Large area overview for detection of pollution or observing its dispersion with ability to concentrate on smaller areas of interest with pointable, high resolution sensors for greater detail.

P-3) Desire for total coastal coverage, but willingness to sacrifice complete coverage for repeatability in high population area.

P-4) Need for many spectral bands in sample areas to aid in identifying effluents, pollutants, and other indicators.

P-5) Need to monitor locations, identify elements, and locate and track dispersion and effects.

Fisheries:

F-1) Can transient fish location indicators be identified from space?

F-2) Daily repeat coverage of limited number of potential areas of interest.

F-3) Multispectral large area monitoring for seasonal and long term variations and for identifying changing areas of interest.

F-4) Need for rapid readout and data transmission.

Hazards to Shipping and Coastlines:

H-1) Good coverage over highest population areas (East Coast and South Pacific) and particular points such as river mouths, bays, etc.

H-2) Prime interest in observing varying physical phenomena and their effects.

H-3) Some observation, if possible, under adverse weather conditions.

H-4) Daily repeat coverage desirable to get changes - over the year and before and after storms.

Coastal Geography and Cartography:

G-1) Complete coverage of all coastal areas, seasonally at most.

G-2) Data should be obtained under same illumination conditions and viewing angle for comparison and mosaicing.

G-3) Multispectral low resolution imagery like ERTS A and B, but also try to cover as much of the coastline as possible with high resolution.

G-4) Many-band multispectral sampled data for mineral and other material identification.

G-5) Spectral bands should include water penetration bands.

The final two selection factors (e and f) were discussed briefly in the previous section since they relate directly to orbital and spacecraft operations limitations. No attempt has been made during this study to come up with even a preliminary design of an ERTS E/F spacecraft. That would have been beyond the scope of the contract and based on incomplete information since ERTS E/F (or now EOS, which replaces it) has other applications and sensors on it besides those for Coastal Zone Oceanography. Nevertheless, some size assumptions were made to bound our considerations (e.g. 680-1360 Kg for the total spacecraft, 160 to 340 Kg for sensor payloads) and these served as guides against which to check our payload configurations and desired orbits.

Table 5-1 provides a summary of sensor utilization potential.

5.2 Recommended Configurations

The purpose of this task is to identify optimum and minimum groupings of sensors for each of the four Coastal Zone Oceanography applications areas. Each optimum grouping is supposed to be limited to four sensors. Minimum configuration limitations are indicated by ranking the sensors in the optimum configuration in order of usefulness from highest (1) to lowest (4). Table 5-2 is a summary of the recommended configurations which are described in more detail below. Table 5-3 provides an engineering estimate of the weight, volume and power for the anticipated types of sensors.

5.2.1 Pollution

Based on the selection criteria indicated in Section 5.2 and the most significant pollution measurements identified in Section 2.0, the four sensors chosen for this application are the multispectral high resolution imager, the low resolution imager (combined for both visible and IR bands), the many-band spectrometer, and the IR comb radiometer. High resolution is obviously important in pollution detecting and monitoring and the 3 visible bands plus the near-IR should give color for discrimination and some identification.

The lower resolution imager would be used in the IR for thermal pollutant detection and in the visible/near IR for large area monitoring and detection and for determining the areas of interest for the higher resolution sensors. If the thermal and the four visible bands cannot be combined on a single device, then the low resolution visible sensor device can be dropped to third position or conceivably even fifth (if a single visible band can be combined with the IR to aid in large area pollution detection). The multiband spectrometer has potential for sampling effluent areas using many parts of the spectrum to help identify the effluent. The comb

TABLE 5-1

SENSOR/APPLICATION CORRESPONDENCE

	Low Res IR Im Rad	High Res IR Rad	Low Res MS Vis Im	High Res MS Vis Im	High Res Spect	MW Rad	Radar Scat
Current Flds	PFHG	P	FHC	PG			
SW Temp	PFHG	P				G	
Bathy & Topo			FG	PFHG			
Tid. Char				PHG			
Oil				PG	PG		
Wind Flds						H	H
Sed Desc & Dist			G	G			
Color			PFG	PFG	PF		
Plankton			F	F	F		
Fish			F	F	F		
Particulates			PG	PG			
Nutrients			F	F	F		
Wave Char							H
Land Use	G		G	G	G		
Metals				PG	PG		
Dis Orgs				F	F		
Vegetation	G		G	G	G		
Surf Cond				H			
Ice	H		H	H		H	H

P = Pollution
F = Fisheries
H = Hazards
G = Geography

TABLE 5-2 PAYLOAD CONFIGURATIONS

	Pollution		Fisheries		Hazards		Geog. & Cart	
	Rank	Comments	Rank	Comments	Rank	Comments	Rank	Comments
Sensors								
MS Vis/NIR Imager (Low Res)	2*	Combine with IR, pointable	3		4	Include water penetration	1	Include water penetration
MS Vis/NIR Imager (Hi Res)	1		1		1	Include water penetration	2	Include water penetration
Spectrometer	3	Reflective/ Emissive; many bands	4	Absorption (correlation) spectrometer	-		4	Reflective/ Emissive
IR Imager	2*	(See above)	2		2	Pointable	3	
IR "Comb" Radiometer	4	9 lines/ 3 7 Km	-		-		-	
MW Radiometer	-		-		3*	Combined device for roughness and temp	-	
Radar Scatterometer	-		-		3*		-	

* Combined device, if possible

TABLE 5-2 PAYLOAD CONFIGURATIONS (Continued)

	Pollution	Fisheries	Hazards	Geog & Cart
Orbit & Operation				
Inclination	64^{o}R or 72^{o}		49^{o}R or 72^{o}	Sun-synchronous (82^{o}R)
Altitude	630 or 705 Km	630 Km	540 or 630 Km	670 Km
Principal Coverage	East and West Coasts, Great Lakes	East Coast, Pacific N W	East and South Pacific Coasts	Full
Frequency Desired	3 of 4 consecutive days max	Daily	Daily	Seasonal

TABLE 5-3

ENGINEERING ESTIMATE OF CANDIDATE SENSORS

Sensor	Weight Kg	Volume Cu Meters	Power Watts
Multispectral Imager (Vis/Near IR)			
Low Resolution	45-90	09- 14	100-150
High Resolution	55-110	09- 14	100-150
MSLR Imager/IR Imager Combined	55-110	11- 17	100-150
Spectrometer	34-57	06- 11	25-50
Correlation Spectrometer	34-57	09- 17	25-50
IR Radiometer (Comb)	9-18	03- 06	10-20
Microwave Radiometer	18-27	03- 06	20-40
Radar Scatterometer	18-27	03- 06	100-150
IR Imager	9-18	03- 06	10-20
Microwave Radiometer/ Scatterometer	45-55	06- 09	40-60

radiometer will accurately give sample points along edges of effluent areas between which interpolations can be made.

A spacecraft containing the four sensors selected as most useful for gathering data to aid in resolution of pollution problems in the coastal zone, will weigh in the range of 680-1360 Kg and require a solar array of approximately 4.5 to 9.0 square meters of projected area.

Since it is desirable to observe all coastal zone areas even though daily observation is not achieved, a selection of repeat coverage every four days was made. It should be pointed out that some coverage of an area could be made on at least three out of the four days with a pointable sensor platform. Either a 64° retrograde orbit at 630 Km or 72° posigrade orbit at 705 Km will provide the necessary orbital elements.

As shown in Figure 5-1, the 64°R orbit will travel up the west coast and down the east coast with an interval of about eleven hours. Crossings of the coastlines will be made on succeeding days. The high population density areas of the Washington-Boston corridor will be traversed three times in a four day period. The Houston-Galveston area, the Los Angeles area, the San Francisco area, the Seattle area and the Portland area will all be covered at least twice in the four day cycle.

The 72° orbit as shown in Figure 5-2 will provide coverage of the high population density areas (not quite as well as the 64°R) but it will also cover the Alaskan north slope area where oil pollution may one day be a problem.

The 64°R orbit will have very limited access to the Fairbanks, Alaska ground station while the 72° orbit will have fairly extensive contact with it.

The 64°R mission would have to be launched from the Western Test Range using either a TAT(9C)DELTA for spacecraft up to 1100 Kg or a SLV 3A/BURNER II for spacecraft over 1100 Kg The 72°R orbit can be achieved from the Eastern Test Range only if the spacecraft weight is under 800 Kg.

The recommended orbit is the 64°R inclination even though ground station contact is not as advantageous.

5.2.2 Fisheries

The sensors for the fisheries mission were chosen in a fashion similar to the pollution mission. High resolution color data is most important followed by IR imagery (even at low resolution). The latter is significant by itself to identify potential fishing areas by their warmth. Low resolution color and near IR imagery should again be useful to

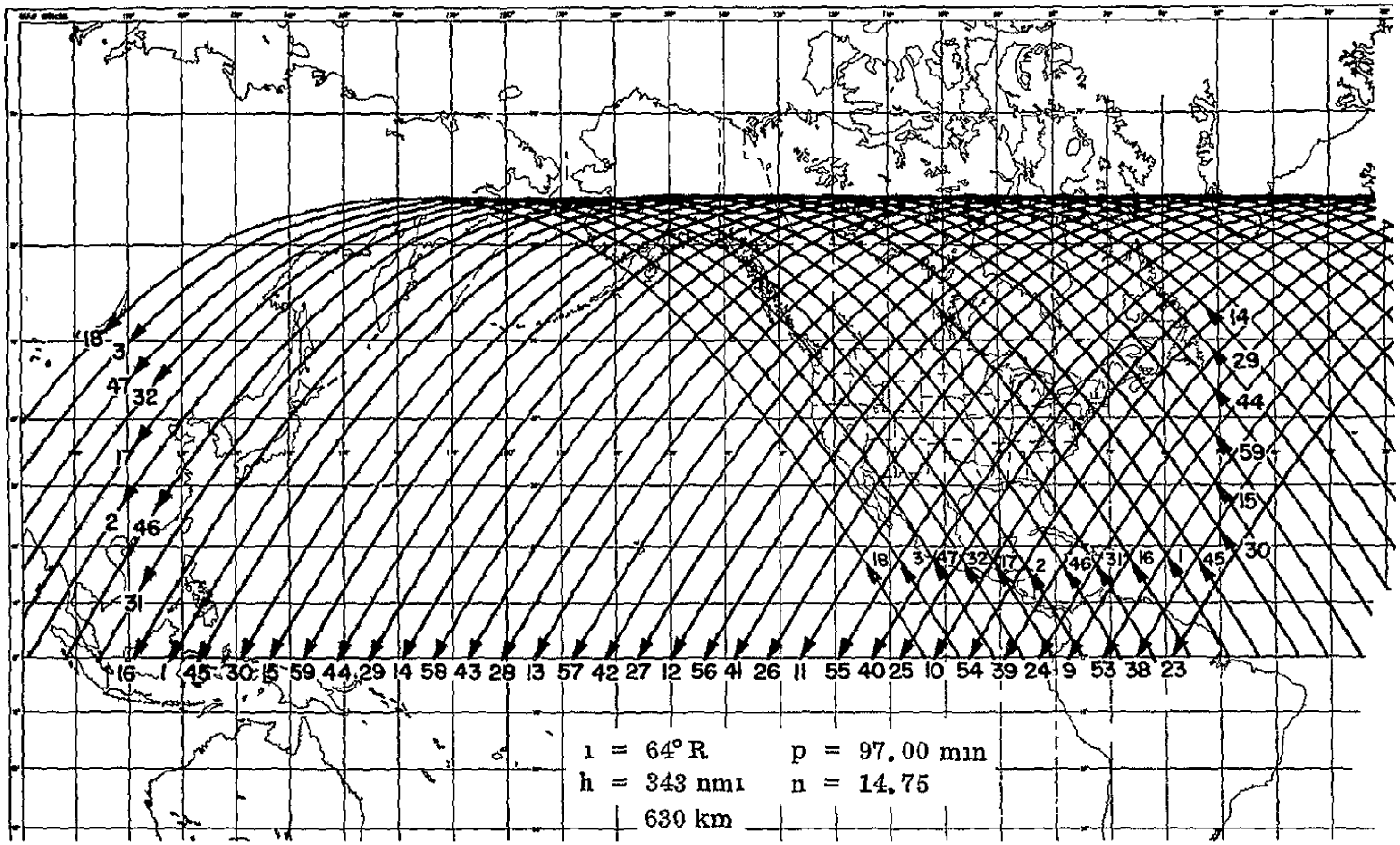

Figure 5-1. 64° Retrograde Orbit With 4 Day Repeats

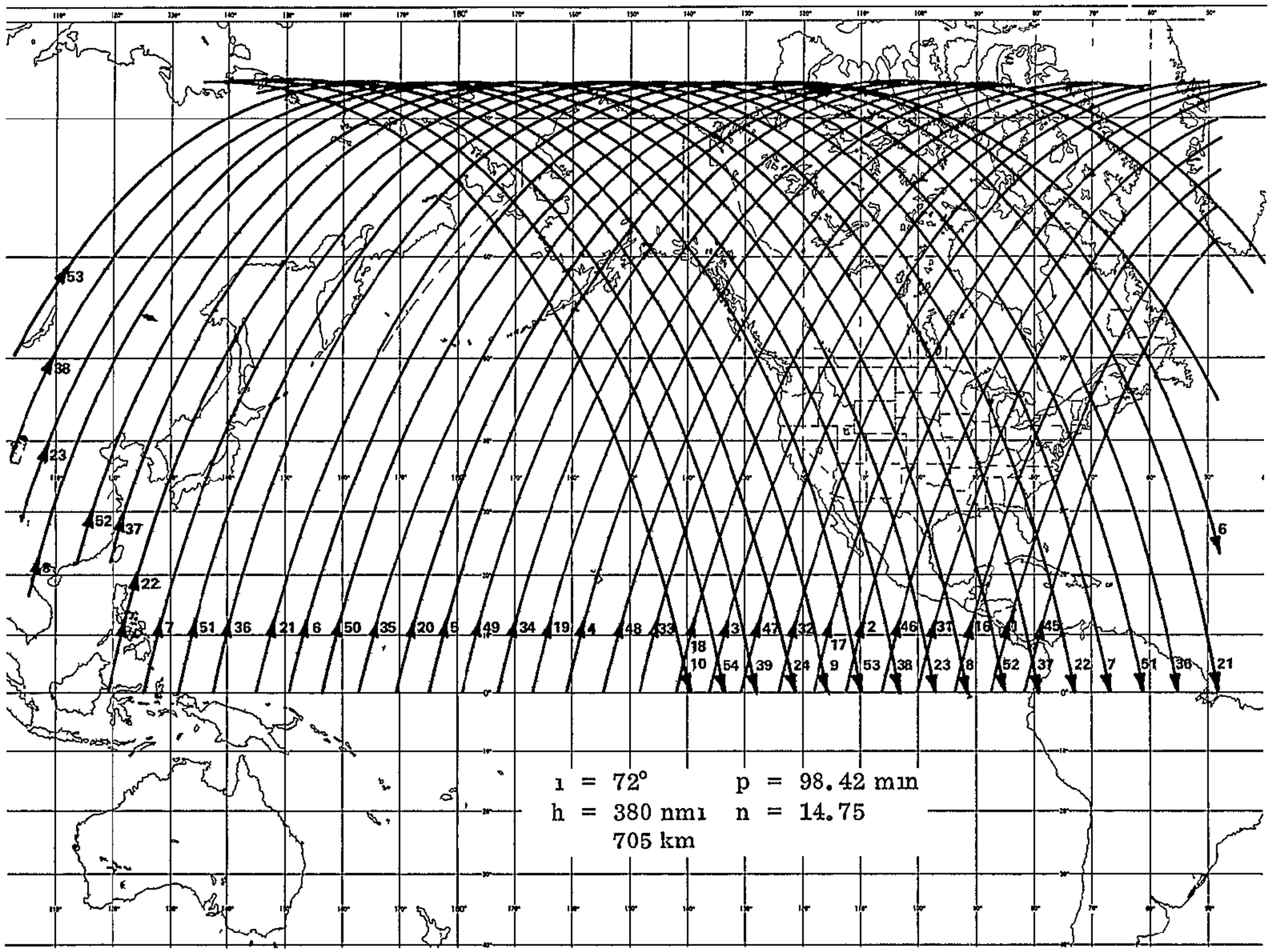

Figure 5-2. 72° Orbit With 4 Day Repeats

identify areas of interest for more detailed examination. This large area color information is important enough for this sensor to be third even if the IR and 4-band visible/near IR sensors cannot be combined. The correlation spectrometer should be useful to detect gaseous iodine (a plankton indicator) and fish oil vapors.

For the fisheries mission, a spacecraft weighing 680 to 1350 Kg will carry the sensors listed in Table 5-2. The anticipated power requirements dictate a solar array with a projected area of 4.5 to 9.0 square meters.

Again, two orbits are worth considering--a 64° and a 72° inclination. Each of these will provide repeat coverage of selected areas once each day from an altitude of 630 Km.

The 64° orbit could be reached from ETR with a TAT (9C) DELTA+TE364-4 for spacecraft up to 800 Kg. For those above that, a TITAN IIIB/BURNER II would have to be used. For the 72° orbit, this same booster could handle up to approximately 725 Kg while greater spacecraft weights would have to be launched from WTR which may require special range safety precautions.

Figure 5-3 shows that the 64° orbit does not give very good coverage of the west coast area but it does pick up the fishing areas off the coast of the Alaskan panhandle. Additionally, the coverage in the Gulf of Mexico is sparse. Ground station contact time with the Fairbanks station is somewhat limited.

The 72° orbit, as shown in Figure 5-4, provides relatively good coverage of the west coast and Alaskan fishing grounds. It too, though, has poor Gulf of Mexico coverage, although the Houston-Galveston fishing area is covered. Again, the ground station contact with Fairbanks, Alaska is relatively good.

The 72° orbit is recommended at an altitude of 630 Km.

5.2.3 Hazards to Shipping and Coastline

For hazards and damage detection missions the high resolution multispectral sensor is again most important because of the detail needed to spot coastal hazards and the extent of damage accurately. Care should be taken to include bands for deepest water penetration (blue) and best underwater contrast (yellow-green). The IR imager is useful to detect currents which may be distinguishable by temperature differences. The microwave devices not only can give water roughness and possibly surface winds and temperature, but offer the only bad weather penetration capability which may be important for this mission. They are therefore

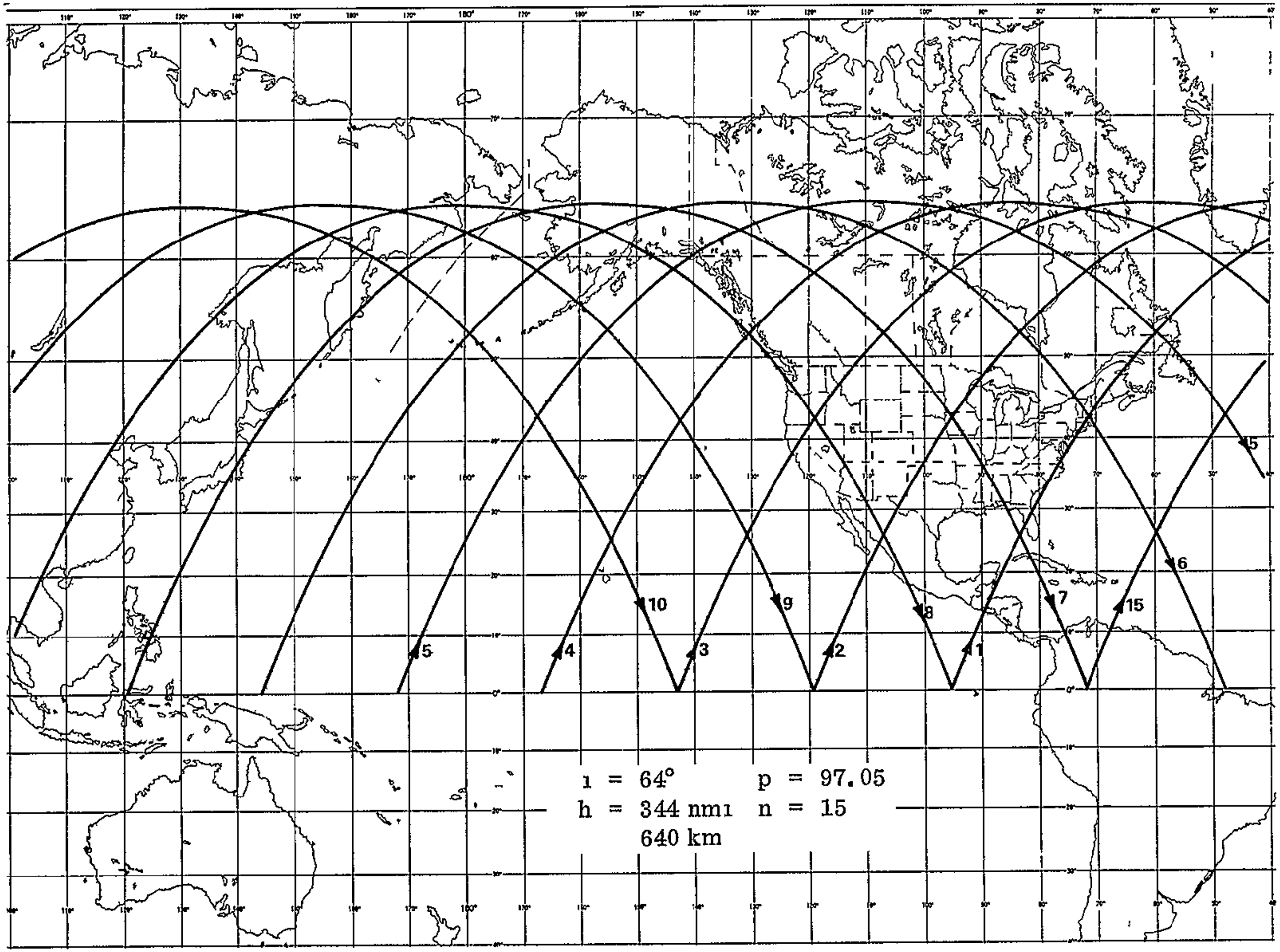

Figure 5-3. 64° Orbit with Daily Repeats

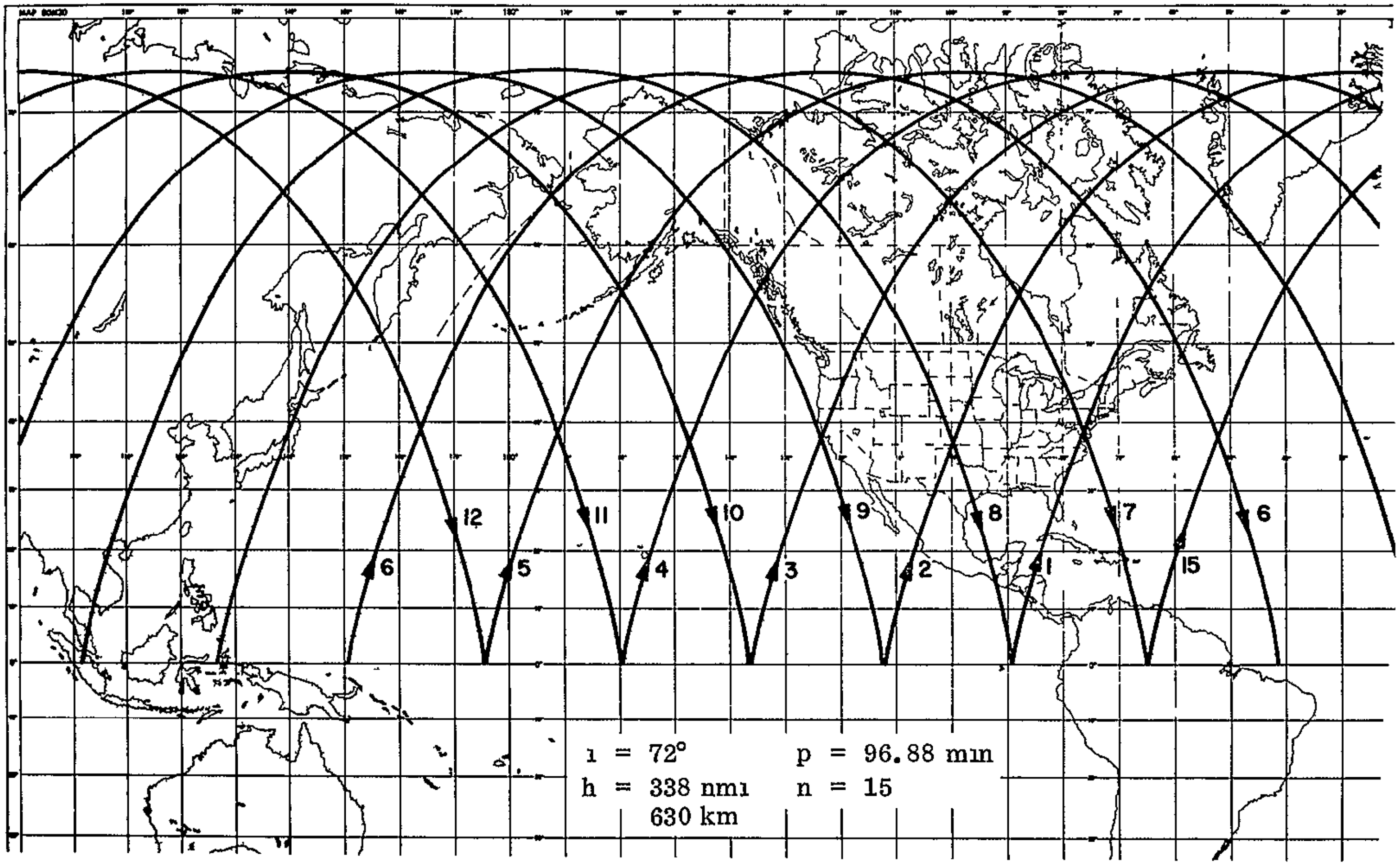

Figure 5-4. 72° Orbit With Daily Repeats

useful even with low (5 Km) resolution. The low resolution imager gives a useful "big" picture synoptically.

The spacecraft configuration of Table 5-2 for this major area will weigh in the range of 760 to 1350 Kg with 4.5 to 9 0 square meters of array projected area required.

Coverage on a daily basis for a limited number of areas has led to the consideration of a 72° orbit and a 49° retrograde orbit.

The area coverage for the 72° orbit (see Figure 5-4) is fairly good for hazard observation on the west coast and east coast but the Gulf of Mexico and Great Lakes areas are somewhat lacking. Contact with the Fairbanks ground station is good.

The 49°R orbit (see Figure 5-5) will present fairly limited east and west coast coverage but it does provide good Gulf of Mexico and Great Lakes observation. No coverage of Alaska is possible. Therefore, ground station contact with Fairbanks is impossible.

Launch for either orbit would have to be from WTR with the booster requirement as shown in Figure 4-13 although the 72° orbit may have range safety restrictions.

The orbit recommended is the 49°R at an altitude of 540 Km even though the ground station contact time is reduced.

5.2.4 Coastal Geography and Cartography

The geography and cartography mission along the coast is very much like the familiar ERTS A and B missions Complete coverage not only puts the wide area imager in first place, but also suggests the sun synchronous orbit. The ranking of the other sensors gives higher resolution next because of desired coastal detail and the possibility of actually achieving continuity along a line (the coastline) instead of an area. The IR imager and the multi-band spectrometer give respectively a thermal mapping capability and some potential for spectral signature identification of materials.

The spacecraft weight will be in the range of 680 to 1350 Kg with 4.5 to 9.0 square meters of solar array projected area required.

A sun synchronous 82° retrograde orbit at an altitude of 670 Km is an obvious choice for this mission. With this orbit, the launch can be made from WTR. The ground coverage will repeat every twenty-one days with a daily track (150 Km wide) to track overlap of approximately 37 Km at 25° north latitude. The sun angle will be relatively constant over the duration of the mission and will be dependent upon the launch time and date.

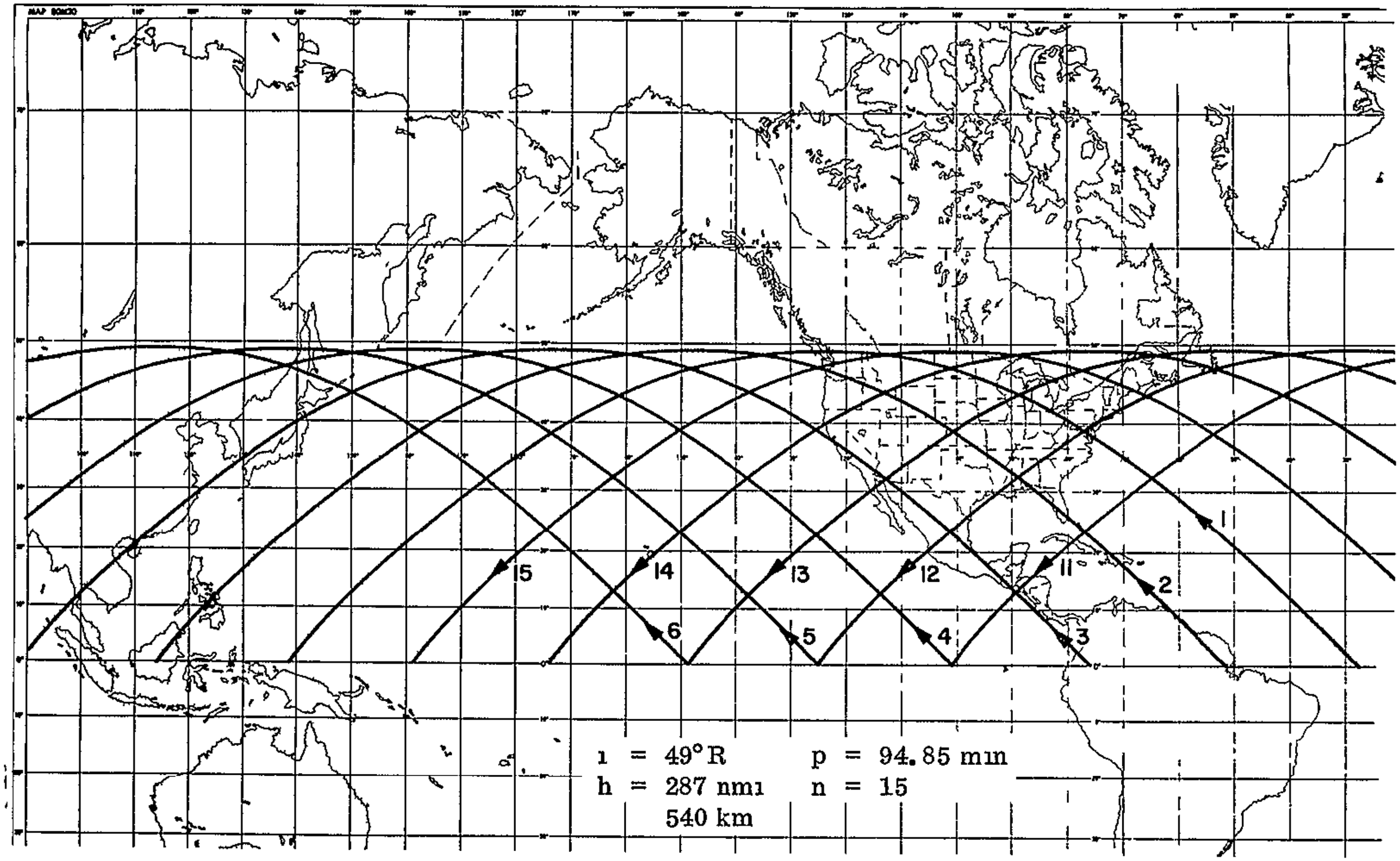

Figure 5-5. 49° Retrograde Orbit With Daily Repeats

5.3 Conclusions and Recommendations

It is apparent from the previous discussion that there is considerable similarity between the configurations suggested for each application. Indeed, three of the sensors - the pointable high resolution multispectral imager and the lower resolution visible and thermal IR imagers are used in the configurations for each of the coastal zone applications. The high resolution pointable imager would appear to be the most useful sensor for all applications although it would require a wide area picture with landmarks (using a low resolution imager) or a very good spacecraft attitude control system in order to be certain of the coordinates of the pictures it takes. It is expected that types of materials, or at least general classes (e.g., classes of pollutants, plankton, particulates, currents, etc.) can be identified and their extent measured using the spectral bands of this device. This would be facilitated if it can be used in conjunction with some thermal IR device. Better success in identifying detailed types of material would require the use of spectrometers, but the existence and use of unique spectral signatures is still in the research stage. Likewise, the use of spectrometers from space with only small area sampling capability should be compared with the technique of using detailed sensing in situ or from aircraft after areas of interest are identified.

Concerning the other sensors, both the thermal IR imager and the multispectral visible/near IR imager are useful for all missions. It would be most desirable to combine them into a single device - currently a NASA goal but still a significant R and D problem. The microwave sensors, both active and passive, would appear generally to be of more use in global oceanography rather than in the coastal zone because of the large areas seen by their antennas. Likewise, the many theories for interpreting their data make present use somewhat confusing. More research, confirmed with field measurements, is required.

From a spacecraft and orbit point of view, it is clear that the configurations can be satisfied. ERTS E/F or EOS can carry the suggested coastal zone payloads plus other sensors for other missions within the assumed total spacecraft size (680 to 1350 Kg). In addition, the prime sensors suggested should be useful for other earth resources and oceanographic missions. The orbits recommended for the coastal zone missions are specifically optimized for the CZ with the exception of the sun-synchronous orbit for coastal geography and cartography. In particular, the frequent repeats over the same areas of interest are important to test how useful satellite remote sensing can be for the CZ. Some variations in orbits are possible, perhaps to combine CZ missions at the expense of amount of area given repeat coverage. However, it is desirable to have some missions flown with the orbits optimized for the coastal zone.

Based on these considerations, a configuration for a universal coastal zone mission could be selected utilizing the weighting factors shown in Table 5-2. However, as mentioned previously, no priority rating of the application areas has been attempted

As pointed out above, three of the sensors have been recommended for all application areas and these are the logical initial selection for a universal mission. The most useful sensor for the universal mission will be the high resolution multispectral imager. Next in value is the IR imager, particularly if it can be combined with the next most useful sensor, the low resolution multispectral imager. Finally, a spectrometer, in the visible and near IR (and IR too, if possible) will complete the selection. In order to provide maximum usefulness the sensors should be mounted on a separate sensor platform to permit pointing off track as necessary for added coverage.

An orbit inclination of 72° provides complete coverage of the U.S. although, if portions of Alaska can be eliminated for consideration, a 64° inclination would be advantageous. In addition, the 72° orbit permits maximum utilization of the Fairbanks ground station for data retrieval and ground command.

An altitude of 700 Km provides ground track repetition each fourth day. Provision of pointing capability for the high resolution imager and other sensors will permit viewing many areas on three out of four days, thus providing good coverage for all four application areas. Although no observation of the ground will be possible during poor weather, hazards can be evaluated with a "before and after" concept. The changing scene illumination angle can have some benefit in aiding in image interpretation.

In summary, the major recommendations for development of the sensors and satellite configurations for a coastal zone oriented observation satellite are:

(1) A high resolution, pointable, multispectral (visible, near IR) imager should be developed with 10-20 M ground resolution and 30 Km ground field of view.

(2) A single imaging sensor should be developed which adequately provides four visible and near IR channel and one IR channel for large area (150 Km) and 50-75 M resolution.

(3) Spectral signature experiments should be conducted over the coastal zone to test their validity and to determine useful spectrometer bands.

(4) Analysis and field experiments of microwave radiometry and radar scatterometry should be pursued to determine their feasibility for sea surface measurements.

(5) Special orbits for providing frequent coverage of particular coastal areas (viz, the East Coast and Southern Pacific Coast) should be used for at least some ERTS E/F missions, and the use of these orbits for non-coastal zone missions should be examined.

(6) Consideration should be given to an attitude determination system that can relate the principal axis of one sensor to locations in an image from another sensor taken earlier within a two-three minute period.

APPENDIX A

ASSESSMENT OF EARLIER STUDIES OF SPACECRAFT APPLICATIONS IN OCEANOGRAPHY

Woods Hole Oceanographic Institution convened a conference on oceanography from space in 1964. Over 150 oceanographers at the conference suggested numerous ways in which spacecraft measurements might advance marine science and technology. Physical oceanographers noted the ideal vantage point of a satellite for measurements of sea level, waves, sea ice, currents, and sea surface temperature to·

-- strengthen understanding of oceanic circulation and transport;

-- recognize and classify the surface exposure of water masses and their interfacial boundaries or "fronts";

-- completely describe the directional and energy spectrum of ocean waves; and

-- maintain a survey of sea ice.

Marine biologists called for measurements of chlorophyll concentration and the location of areas of discolored water with which to prepare maps for assessing the photosynthetic rate in the upper sunlit layers of the sea. Geographers, geologists, and coastal engineers noted the appeal of a satellite in monitoring large-scale features and events whereever they occur. These include inaccessible coastlines and their modification by storms, floods, surges, tsunamis, and wave attack. It was widely agreed by several panels, also, that a most important use of satellites in oceanography might be in gathering and retransmitting information telemetered from surface sensors.

The Woods Hole conference, sponsored by NASA's Office of Space Science and Application, was significant, not so much for providing a definitive guideline for future ocean-oriented satellite development, but rather for the first time marshalling ideas of the oceanographic community as to what the future needs and opportunities for spacecraft oceanography might be. It broadened consideration of satellite initiatives, accelerated investigation of remote-sensing applications in marine science, and strengthened the information base for subsequent analysis.

Three significant studies related to spacecraft oceanography have been conducted since 1964. Although they were not identical in objective, were more discipline than goal-oriented, and were separated in time, they represent a substantial investment in analysis which is relevant, and should be understood as an initial step in the present study. Moreover, each represents a certain degree of institutional as well as individual involvement in defining goals for satellite applications in oceanography[1] The main conclusions and recommendations of the studies, particularly in regard to specific proposals for satellite oceanographic measurements, are summarized below.

The Potential of Observations of the Oceans From Spacecraft, General Electric Company, December, 1967.

This study was conducted for the National Counsil on Marine Resources and Engineering Development. Its objective was to evaluate the application of space technology to the collection of oceanographic data required to meet needs identified in the Marine Resources and Engineering Development Act of 1966.

The study opens with an assessment of space/ocean achievements and technology and the determination of user requirements; postulates three evolutionary systems for 1970-1974 (Table A-1); and recommends:

- -- continued investigation related to the technology of remote sensing and its specific applications to oceanographic phenomena,
- -- initiating detailed design and trade-off studies for an oceanographic satellite as early as 1970;
- -- promoting sensor development for the 1971-1975 time period so that increased capabilities in oceanographic sensing may be realized; and
- -- assessing significant advances in space data handling and data reduction so that maximum advantage can be taken of increased sensing capabilities.

[1] The relevant literature on activities in spacecraft oceanography and ocean-oriented, remote-sensing research is expanding. See, for example· United States Activities in Spacecraft Oceanography, National Council on Marine Resources and Engineering Development, October 1967; Man's Geophysical Environment, Its Study from Space. A Report to the Administrator of ESSA, Environmental Science Services Administration, March 1968; and Proceedings, AIAA Earth Resources Observations and Information Systems Meeting, Annapolis, Md., March 2-4, 1970.

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TABLE A-1

PROPOSED SPACECRAFT OCEANOGRAPHIC SYSTEMS, 1967

POSTU-LATED SYSTEM	TIME PERIOD	SENSORS	PRINCIPAL FUNCTION
1	1970	Infrared Radiometer Television Microwave Radiometer Interrogation and Recording	Surface Temperature (Cont) Medium Resolution Imagery (Cont) Low Resolution Surface Temperature and Imagery (Cont) Buoy Readout (Point)
2	1971-1972	Infrared Radiometer Television Microwave Radiometer Microwave Scatterometer Multispectral Camera Interrogation and Recording	Surface Temperature (Cont) Medium Resolution Imagery (Cont) Low Resolution Surface Temperature and Imagery (Cont) Sea State (Cont) High Res. Multispectral Imagery (Point) Buoy Readout (Point)
3	1973-1974	Infrared Radiometer Television Microwave Radiometer Microwave Scatterometer Synthetic Aperture Radar Absorption Spectrometer Interrogation and Recording	Surface Temperature (Cont) Medium Resolution Imagery (Cont and Point) Medium Resolution Surface Temperature and Imagery (Cont) Sea State (Cont) High Resolution Imagery (Point) Surface Spectral Analysis (Cont) Buoy Readout (Point)

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A major element of the study was the derivation of spacecraft measurement requirements related to national goals for marine science, including protection of health and property; enhancement of commerce, transportation, and national security; rehabilitation of commercial fisheries; and increased utilization of marine resources. Objectives and sub-objectives were selected for each goal; knowledge requirements were related to each sub-objective; and finally, potential users were consulted to refine a list of specific measurement requirements -- those that might be met by observation from spacecraft. The specific requirements, on which the postulated 1970-1974 spacecraft systems were based, are identified in Table A-2. Both requirements and systems were proposed from the viewpoint of implementing marine science policy rather than identifying research needs in oceanography and meteorology as in the next study considered.

TABLE A-2

PROPOSED SPACECRAFT OCEANOGRAPHIC MEASUREMENTS, 1967

Sensing Requirements

Temperature	Sea Color
Sea State	Fish Sighting
Wind Speed	Current Direction
Wind Direction	Current Speed
Surface Oil Slicks	Cloud Cover
Ice	

Oceanography and Meteorology, A Systems Analysis to Identify Orbital Research Requirements, Douglas Missile and Space Systems Division, McDonnell Douglas Corporation, April 1968.

This study was performed for NASA's Manned Spacecraft Center, to identify elements of an evolutionary, long-range research plan which could be accomplished effectively with manned space platforms. The study includes the definition of orbital measurement requirements which would most directly serve the needs of the scientific community and potential using agencies.

The study first assesses the current status and requirements for oceanographic research programs and observation and forecasting systems. From this base, relevance research trees are structured relating broad questions related to uses of the ocean, knowledge of the ocean, and effects of the ocean to selected knowledge requirements. The latter were screened to select candidates for space observation and these were translated to specific measurement requirements. The requirements are identified with selected supplemental data in Table A-3.

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TABLE A-3

PROPOSED SPACECRAFT OCEANOGRAPHIC MEASUREMENTS, 1968

1 Sea Color

Use of sea color characteristics to determine biological and chemical state of the ocean. The intensity and spectral distribution of the light reflected or scattered from the surface and a volume under the ocean surface are indicators of the types of suspended matter, chemical composition and boundary characteristics. In particular the color characteristics are thought to be related closely to the productivity of the ocean volume, especially to chlorophyll amount.

2. Turbidity

Use of the transparency of the water to light to determine the physical state of the ocean. The turbidity of the ocean is an indicator of the transparency of the ocean to light The transparency is considered to be a measure of the amount of suspended matter in the volume under consideration. The turbidity could be caused by stirring up the bottom, unusual plankton bloom, pollution, or river discharge.

3. Bioluminescence

Use of bioluminescence to determine the biota characteristics. Determine the usefulness of bioluminescence as an indicator of the population dynamics and indirectly as an indicator of pollution and temperature structure.

4. Cloud Pattern

Use of the characteristics of cloud patterns and their changes to infer physical dynamical-biological state of atmospheric/ocean boundary layer. Low level cloud pattern characteristics and their changes are influenced by low level stability, turbulence, and humidity. These, in turn, are influenced by the sea surface temperature, character, and roughness through the heat, water vapor, and momentum flux at the air-sea interface.

5. Coastline Patterns

Determine detailed characteristics of coastlines for engineering and scientific use. Time changes in coastline patterns can be used not only for engineering purposes but particularly to extend knowledge of coastal geology and physical, dynamic, and biological processes.

TABLE A-3 (Cont'd)

6. Storm Tracking

Locate storm areas and tracks to determine large-scale atmospheric effects on the oceans. Storm tracks are an indicator of the general wind direction and its variability. The wind character is important in determining the general current and temperature structure of the upper layer of the ocean.

7 Heat Flow

Sea surface vertical temperature gradient near sea surface for heat flow studies. Measurement of vertical temperature gradient in the top 0.3 mm of the sea surface layer by means of measured radiation intensities emitted in specific wavelength regions (microwave). Knowledge of the heat flow at the air-sea interface is fundamental for developing principles of air-sea interaction and improving forecasts of ocean and atmospheric states.

8. Sea Surface Temperature

Mapping of sea surface temperature distribution to determine physical and biological states. Sea surface temperature distribution characteristics and time variability are fundamental to determining the physical and biological states of the ocean as well as dynamic processes at the air-sea interface, in particular fish population, motions, and heat flow at the surface.

9 Atmospheric Color

Mapping of color of the atmosphere to determine aerosol particle distribution. Atmospheric color mapping can be used to determine aerosol particles resulting from sea surface roughness, breakers, surf, or pollution sources.

10. Surf Patterns

Mapping of surf patterns to investigate erosion/sedimentation processes and for recreation activities. Surf patterns reflect generally the swell characteristics of the offshore area which in turn result from low level wind fields. The surf patterns influence the character of the beaches and headlands as well as surfing, bathing, boating, and construction design and activities at the shoreline.

11. Precipitation Patterns

Mapping of precipitation areas for air/sea energy ex-

TABLE A-3 (Cont'd)

change determination as well as ocean physical and biological processes. Knowledge of precipitation variability is important for heat budget considerations and for interpreting sea surface temperature and salinity patterns.

12. Surface Wind

Determination of sea surface wind for wave spectrum studies and ship and recreation activities. Knowledge of surface wind variations is needed for surface wave spectrum studies. It is also important for determining tidal anomalies, surf and current characteristics, and sea temperature patterns.

13. Wave Height

Determining spectrum of wave heights for ship operations and air/sea energy exchange. The determination of wave height distributions as a function of wind distributions and low level atmospheric stability will aid in improving forecasts

14. Wave Period

Determination of wave period for ship operations The wave spectrum needed for improved ship design and operations is related to atmospheric parameters.

15. Wave Direction

Determination of wave direction for ship operations. There is need to relate the wave spectrum to atmospheric parameters for application to ship design and operations to improve forecasts.

16. Sea Level

Determination of mean sea height to estimate currents. The relative changes of mean sea height over the ocean should give an estimate of the slowly changing large and medium scale currents as well as tidal effects. This knowledge could also be used to estimate the convergence/divergence of the ocean surface layer.

17. Wave Patterns

Mapping of surface wave patterns to determine wave statistics. Wave patterns and their changes can be used to determine wave statistics for design and operation; they can also be used to forecast swell and surf changes, wind intensity,

TABLE A-3 (Cont'd)

momentum transfer at the air-sea interface, slick patterns, current character, etc.

18. Glitter Patterns

Mapping of glitter patterns for determining sea surface roughness, wind, and slick character. Glitter patterns are related to the sea surface roughness which in turn is related to the swell, local wind speed, near surface atmospheric stability, slick patterns, and sea ice character

19. Slick Patterns

Map slick patterns and analyze composition as an indicator of the character of biological, geological, and physical processes Slick patterns are partially controlled by surface currents which are in turn caused by wind stress and subsurface ocean motion. Visible slicks are the result of changing reflectance of the ocean surface caused generally by a concentration of micron-thin oil residue on the ocean surface.

20. Depth Profile

Mapping of the depth profile of the ocean bottom. Variations in the depth of the ocean affect swell and surf characteristics in shallow water and the propagation characteristics of tsunamis in the open ocean as well as near shore. Depth profiles are also important in determining tidal effects.

21. Locate and Track Surface/Subsurface Objects

Mapping of the location of ocean vessels, icebergs, fish, and other objects. Continuous monitoring of objects on and under the sea surface is important for improving safety at sea and for search and rescue in case of mishaps.

22. Salinity

Mapping of salinity variations to determine physical and biological state. Knowledge of the salinity is important in its relation to population dynamics of the ocean. With the temperature field it can be used to infer the ocean motion and current characteristics along coastlines.

23. Mixed Layer Depth

Mapping the variations in depth of the isothermal (mixed)

TABLE A-3 (Cont'd)

surface layer to relate to physical and biological processes. The mixed layer depth is related to the distribution of ocean biota, especially to certain species of fish. It is also important in determining surface sound channels in the ocean.

24. Currents

Mapping of currents to determine the physical, biological, chemical, and geological state The currents determine the transport of nutrients, suspended matter, dissolved chemical constituents, and heat. Time changes of the currents can be used to infer dynamic processes in the ocean and at the boundaries

25. Barometric Pressure

Mapping of sea level atmospheric pressure to relate to mean sea height and surface winds. The distribution of sea level pressure can be used to estimate the sea surface wind field, and storm tracks, hence currents, sea surface roughness, etc. The pressure distribution and time variations are also important in determining mean sea level and internal oscillations.

26. Magnetic Anomalies

Measurement of magnetic variations to estimate sea level magnetic anomalies. Measurements of magnetic field space variations can be used to estimate earth composition. Time variations can be used to locate objects under the ocean surface and to investigate magnetic disturbances in the atmosphere.

Several points should be made for perspective in comparing this with the other studies discussed herein. First, this study represents a more comprehensive effort than the others. Second, although it was sponsored by the Manned Spacecraft Center, the role of man was not explicitly considered in formulating the specific orbital measurement requirements. Finally, priorities were considered, but only from the viewpoint of ranking the importance of marine-related activities, such as pollution control, transportation, fisheries, etc. Priority analysis did not extend to the identification of which measurements and geographical areas might be most important to the various research goals.

APPENDIX A

Useful Applications of Earth-Oriented Satellites: Panel 5 - Oceanography. Summer Study on Space Applications, National Academy of Sciences, National Research Council, 1969.

In 1966, NASA asked the National Academy of Sciences to conduct a study on "the probable future usefullness of satellites in practical earth-oriented applications." The study was intended to obtain the recommendations of highly qualified scientists and engineers on the nature and scope of the research and development program needed to provide the technology required to exploit these applications. NASA subsequently asked that the study include a consideration of economic factors.

Thirteen technical panels were convened The panel on oceanography met during the summer of 1967 and reported its work in an interim report. That report was reviewed and made current under the direction of Dr. Gifford Ewing, Panel Chairman, during the summer of 1968.

The study considers briefly the special needs of industry and the public for information and services in several application areas, namely, fisheries and resource management; industrial and public use of the coastal and shallow water environment, including coastal engineering, water quality surveillance, and recreation; and shipping and ocean transportation. It identifies the most promising measurable physical parameters on the basis of feasibility, as shown by past accomplishments of manned and unmanned satellites or aircraft reconnaissance or by established state of the arts; possible direct economic benefit; and indirect benefit as the result of scientific programs. The measurements discussed include·

- -- Sea surface temperature (infrared, microwave, and telemetry)
- -- Imagery* (photography, imaging radar, infrared)
- -- Sea state (by radar roughness scatterometry)
- -- Spectrograms (chlorophyll detection, sea color, bioluminescence, fluorescence)

*Directed toward the shape, pattern, or position of such targets as shorelines, shoals, underwater bars, trash lines at the edge of currents, and patches of discolored water from rivers, estuaries, or the discharge from sewers. Discussion also includes ship and fish sighting.

-- Dynamic topography of sea surface (by radar or laser altimeter)

-- Drift rate of floating objects (interrogation, recording and location of systems, buoys, drifting ice, etc.)

-- Sea ice and icebergs (by radar imagery).

This list is narrowed in a concluding summary statement of the study (pg. 77): "The six oceanographic parameters that appear to have the most significance for satellite applications are: sea surface temperature; imagery, including sea ice; drift rate; spectrograms of color and chlorophyll; sea state by radar roughness; and dynamic topography."

The NAS/NRC study thus does not broaden the list of candidate oceanographic measurements, so much as it tends to validate the conclusions of earlier studies in regard to the technological readiness for selected measurements and unmet needs. Table A-4 summarizes the measurements for oceanography proposed in the three studies.

As far as coastal needs are concerned, greater emphasis should be given to pollution surveillance. While thermal and biological pollution surveillance can be aided by measurements of sea surface temperature and sea color, respectively, provisions should be made for the direct observation of surface oil concentration and movement. High frequency, high resolution imagery is also important for the detection and survey of ice in its various forms and for monitoring coastline patterns and prominent features such as ships and schools of fish over the continental shelf. The earlier studies thus suggest that the most useful coastal oceanographic measurements would be:

1. Sea surface temperature
2. Imagery, sea ice and icebergs
3. Imagery, coastline patterns
4. Imagery, ships
5. Imagery, schools of fish
6. Sea color, turbidity
7. Sea color, index of biological activity (plankton blooms)
8. Sea color, depth profiles
9. Spectrograms, chlorophyll
10. Spectrograms, natural petroleum and products
11. Sea state; wave height and direction
12. Communications; data relay.

APPENDIX A

TABLE A-4

SUMMARY OF CANDIDATE SPACECRAFT MEASUREMENTS FOR OCEANOGRAPHY

Candidate Measurements	GE Study	McDonnell Douglas Study	NAS/NRC Study
1. Sea Color	X	X	X
2. Turbidity		X	
3. Bioluminescence		X	X
4. Cloud Patterns	X	X	
5 Coastline Patterns	X	X	X
6. Storm Tracking		X	
7. Heat Flow		X	X[1]
8. Sea Surface Temperature	X	X	X
9. Atmospheric Color		X	
10. Surf Patterns		X	
11. Precipitation Patterns		X	
12. Surface Wind Speed	X	X	X
13. Surface Wind Direction	X		X
14. Current Speed	X	X	
15. Current Direction	X		
16. Wave Height	X	X	X
17. Wave Period	X	X	X
18. Wave Direction	X	X	X
19. Wave Patterns		X	
20. Glitter Patterns		X	
21. Slick Patterns	X	X	
22. Sea Level		X	X
23. Depth Profile	X	X	X
24. Locate and Track Surface/Sub-surface Objects (Drift Rate)		X	X
25. Salinity		X	
26. Mixed Layer Depth		X	
27. Barometric Pressure		X	
28. Sea Ice & Icebergs	X		X
29. Fish Sighting	X		X
30. Chlorophyll			X
31. Magnetic Anomalies		X	
32. Ship Sighting			X

[1]Mentioned as a possibility. Not singled out for discussion.

APPENDIX B

DESCRIPTION OF U. S. BIOPHYSICAL REGIONS

North Atlantic

This region extends from Canada around the Gulf of Maine to Cape Cod. Cool, fertile waters with a large tidal range strike a steep, indented coast with deep water close inshore. The coast is rugged on the north, reducing gradually to nearly a plain from Boston south around Cape Code Bay. The estuaries of Maine are narrow with deep, open inlets, steep fringing marshes and flats, and rocky coastal islands. Southward the coastline is more even; its marshes and beaches more gently sloped and extensive.

Commercial fishing for lobsters, clams, and scallops is an important industry in the region, as are tourism and recreation

Uses of the coastal zone which most adversely affect the North Atlantic region are· industry, mining, pest control, urbanization, waste disposal, and water supply. Approximately 50 percent of the coastal zone has been significantly affected by these uses, with severe deterioration in the Boston harbor and its immediate environs.

Middle Atlantic

This zone extends from Cape Cod south to Cape Hatteras, exclusive of Chesapeake Bay. A wide, gently sloping continental shelf with a smooth shoreline is cut by the entrances of several major river systems. The same cool, fertile waters as in the North Atlantic zone wash this coastline but with smaller tidal range. Small, marsh-lined estuaries occur at intervals along the glaciated part of the coast. Along the coastal plain segment, estuaries and marshes are nearly continuous behind outer banks, and marshes fringe Delaware Bay. The outer bank reaches are wide and sandy with gently deepening offshore waters.

This coastal region is one of the most densely polulated in the country, constituting a virtually continuous metropolitan belt along its entire length. The same uses of the coastal zone mentioned as having the principal adverse effect in the North Atlantic are found in the Middle Atlantic: industry, mining, pest control, urbanization, waste disposal, and river impoundment and flow control for water supplies. Of these, pollution and land occupation for port cities and industry are the causes of greatest coastal degradation. Approximately 95 percent of the coastline has been significantly affected, with some 30 percent being severely degraded.

APPENDIX B

Chesapeake Bay

This region encompasses all of the Chesapeake Bay system from Cape Charles to Cape Henry. It is the estuary of the drowned lower Susquehanna River and tributaries, extends inland nearly 200 miles, and is from 5 to 40 miles wide. Chesapeake Bay is unique among estuaries of the world for its size, complexity, and productivity Its tidal-river reaches and baylets are fringed with marshes, those on the eastern-shore plain being most extensive. Bluffs and narrow beaches edge some of its western shores.

Tides and other natural forces are generally favorable to life of the Bay. It is known for its abundant oysters and blue crabs, and yields a variety of other marine life. The Bay is a key area for migratory waterfowl and shorebirds, and many State and Federal refuges have been established around the Bay to accommodate these birds.

Pollution and land occupation are locally limiting around Baltimore harbor, through the upper reaches of the Potomac River, and throughout the length of the James River. Due to dense urbanization of its metropolitan areas, even pleasure boating results in a moderate adverse impact to the conservation of the tributary rivers. Scenic beauty and life of the Bay has been significantly affected, with more than one-half of the coastline showing a degraded environment. In the immediate areas of Baltimore harbor, Washington, D. C., Richmond, and Norfolk, this degradation is chronic and severe.

South Atlantic

This zone extends from Cape Hatteras south to Fort Lauderdale. It is bordered by a 100 mile plain, terminating in the north in barrier islands and marshes in which large amounts of sediments are being continually deposited by moderate-sized rivers fed by heavy summer rainfall. Tides are moderate and the warm waters of the Gulf Stream favor the multiplication of living resources.

A great variety of fish are abundant. Waterfowl, shorebirds, and marsh birds of many species find a haven in the estuaries and wetlands of the zone.

Pollution and land modification have degraded coastal areas immediately adjoining urban centers such as Wilmington, N.C., Charleston, S. C., Savannah, Ga., Jacksonville and Fort Lauderdale, Fla. Only about one-third of the coastal region does not show appreciable degradation.

APPENDIX B

Carribean

This zone extends from Fort Lauderdale around the tip of Florida inside the Florida Keys to Cape Romano, plus Puerto Rico and the Virgin Islands. High temperatures, heavy rainfall and warm ocean currents along practically non-existent continental shelves result in the only genuinely tropical environment in the United States. Coral reefs and mangrove swamps are typical features of the Florida coast, while the islands are mountainous and are fringed with coral reefs and beaches. Population in the region is increasing rapidly and, together with its adjoining regions, may take on the character of a metropolitan belt within the next decade.

Tides and most other natural conditions favor the growth of fish and wildlife. Diversion of freshwater to urban areas northward has produced the most serious alteration of the ecosystem, aggravating periods of drought. Susceptibility of the region to tropical storms causes occasional local stresses. About one-half of the coastline has been adversely affected by pollution and wetland occupation.

Gulf Coast

This zone extends from Cape Romano to the Mexican border. A wide continental shelf extends around the entire coast, with warm tropical waters moved gently by weak currents and small tidal ranges. Heavy rainfall over most of the area brings sediments from the broad coastal plan. The dominant estuarine features are the Mississippi River Delta, and the intricate network of lakes, bayous, bays, marshes, and barrier islands that extend virtually the entire length of the zone. The Mississippi, carrying drainage from 41 percent of the land mass of the United States, forms one of the major deltas of the world, both in size and in the extent to which it has built out over the continental shelf.

Although natural conditions of tide, runoff, and climate are generally favorable in the region, the western estuaries suffer drought, and the entire zone is subject to storm calamities. Substantial degradation to the coastline has occurred through industrial pollution, land occupation, drainage of wetlands, and diversion of runoff. Only about 15 percent of the coastal area has thus far escaped noticeable affliction.

Pacific Southwest

This zone extends from the border of Mexico north to

Cape Mendocino. The coastline has a typical beach and bluff configuration with only a few shallow embayments and the extensive valley of San Francisco Bay. The continental shelf is narrow and tides are of moderately high range. The southern part of the zone is warm, but is naturally deficient in precipitation and runoff.

About two-thirds of the coastal zone has been significantly affected by man's depredations. In and around urban centers, pollution and land development have severely degraded the zone and extended areas in the south have experienced drought aggravated by diversion of freshwater streamflow.

Pacific Northwest

Extending from Cape Mendocino to the Canadian border, the Pacific Northwest region continental shelf and coastal configuration is similar to that of the Pacific Southwest. Ocean water temperatures are lower, movement of the California current is not as pronounced, and heavier rainfall has resulted in several major rivers cutting through the coastal mountains to form deeply embayed estuarine systems. The southern part of the zone has a resistant-rock coast, but in Washington the coast is reduced to low coastal flats and islands by erosion of sedimentary rocks. The Columbia River mouth is notable for the quantity and force of its outflow; Puget Sound for its intricate spiderweb of channels and islands.

Degradation of the coastal zone is substantial at the river mouths and estuarine systems associated with urban areas, such as the Columbia River mouth and Puget Sound. Less than 15 percent of the coastline has escaped appreciable impact.

Alaska

This zone is composed of the coastline of Alaska, including the Aleutian and Bering Sea Islands. The detailed tidal shoreline is 33,900 miles, or about one-third of the coastal shoreline of the continental United States including the Great Lakes. Dominant factors in the zone are temperature and precipitation. Water temperatures are near freezing, and much of the precipitation falls as snow. The continental shelf is wide throughout, and tidal ranges are very large. The southeast and south coasts have active glaciation; the west and north coasts are much flatter, having been modified by sediments eroded from the interior and by the grinding of pack ice.

Principal hazards of pollution and coastal degradation result from lumbering, fish processing, and oil exploration; the latter certain to increase. At the moment, much of the coastal zone is unaffected by man's activities, with at least 80 percent of the natural environment remaining.

Pacific Islands

This region includes the Hawaiian Islands, American Samoa, and Guam, all tropical islands of volcanic origin. Dominating features are the lack of a continental shelf, full exposure to oceanic conditions, and warm temperatures.

Tropical storms, seismic sea waves, and leeside droughts are the only natural stress factors of the region; all other natural factors of the area are highly favorable to biological life.

Most activities productive of pollution and coastal zone deterioration can be found in the Pacific Island region, characteristically concentrated in densely settled urban areas. Due to the sparsity of such settlements, less than 50 percent of the total coastal region is significantly degraded. Tourism and land development are rapidly increasing, however, and may imperil the environment through the foreseeable future.

Great Lakes

This region includes Lake Michigan and the United States shores of Lakes Superior, Huron, Erie, and Ontario, as well as Lake St. Clair between Lakes Huron and Erie. The lakes occupy basins carved and deepended by glaciers from preglacial erosional basins and valleys of the St. Lawrence River system

Man has degraded many bay and marsh areas by dredging, filling, and pollution. Pollution due to industrial waste disposal, agricultural runoff, and sewage disposal is extensive, and has resulted in advanced eutrophication of the whole of Lake Erie. Efforts to control this degradation have been initiated, but without marked recovery thus far. No more than one-third of the U. S. shoreline of the Great Lakes can be considered ecologically and environmentally wholesome.

APPENDIX C

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