

CHAPTER 3

Active Microwave Remote Sensing of Oceans

Active Microwave Working Group

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A rationale is developed in this chapter for the use of active microwave sensing in future aerospace applications programs for the remote sensing of the world's oceans, lakes, and polar regions. This chapter is divided into five major parts: (1) Applications, (2) Technical Background, (3) Local Phenomena, (4) Large-Scale Phenomena, and (5) Technical Approaches. Summaries pertaining to applications, local phenomena, and large-scale phenomena are given in chapter 1. A discussion of orbital errors is presented in appendix 3A.

The technical background section is a detailed account of the general physical interaction of an electromagnetic wave with the ocean surface. Large ocean waves (gravity waves) behave like an ensemble of specular reflectors so that the strength of the scatterer is proportional to the slope of the gravity

waves. However, ocean waves comparable to the wavelengths of the microwave systems used show resonant (Bragg) scattering effects for angles of incidence larger than 20°. This type of scattering is controlled by the capillary waves, which in turn depend on the local short-term surface wind field and the ocean water surface tension. The latter changes when an oil film covers the water surface, resulting in a modification of the character of the capillary waves (smoother because of the greater surface tension of oil), and the presence of oil is thus detectable with active microwave systems.

The section concerning technical approaches is a discussion of specific instruments and their needed characteristics. Radar altimeters, scatterometers, and imaging radars are the major instruments needed to accomplish the many applications outlined.

For the detection and determination of sea-surface topographic features, which relate to many important phenomena, the altimeter (corrected for orbital perturbations) is the only instrument able to economically supply the needed information on a global scale. This ability was demonstrated by the recent, very successful Skylab altimeter experiment in which height variations of the sea surface were detected with a precision of 1 to 2 m on a local scale (as large as 200 km). In the future, the broadening effect on the radar-return pulse will also provide accurate information about significant wave height as well as the surface height probability density function.

The scatterometer viewing the oceans at 0° to 10° incident angles provides sea-state information through the detection of the slope statistics of the ocean waves. For higher incident angles, local wind fields can be determined. The Skylab experience demonstrated that wind velocities as high as 20 m/sec are detectable by such methods.

Imaging radars may be the most versatile instruments for ocean-surface observations. These instruments can provide information on global wave climatology, coastal wave refraction, and buildup of waves in large storm areas. In addition, radar images of sea ice, polar ice, open water areas, and Great Lakes ice conditions will provide important practical application for weather forecasting, coastal structure design, fishing, and shipping.

In conclusion, airborne and, particularly, spaceborne active microwave systems are essential for almost all previously mentioned applications.

No actual attempt was made to reduce the applications and requirements outlined herein to specific operational flight hardware and missions. Further, active tracking systems such as radar, lasers, range and range-rate systems, and satellite-to-satellite tracking systems are not discussed; these systems are very important for some of the oceanographic measurements to be made but are adequately covered in the literature. Also, documentation already exists (and is cited in the section entitled "Current User Needs") that outlines in some detail the requirements for oceanographic data using aerospace technology. These requirement reports are being coordinated by the Interagency Coordination Committee, Earth Resources Survey Program, and some coordination was accomplished at the recent National Academy of Engineering Study, July 1 to 13, 1974, at Snowmass, Colo. System performance parameters, such as measurement accuracies and intervals, spatial and time resolution, coverage, etc., are addressed in those documents and have been used with modification in this report. Therefore, a restatement of those requirements is not included in this document. However, it is recommended that some of the requirements be updated in view of the evolving knowledge and technology discussed in this document.

PART A

APPLICATIONS

CURRENT USER NEEDS

User needs for a large portion of the ocean community have been compiled and integrated in documents by the National Oceanic and Atmospheric Administration (NOAA) (ref. 3-1) and the U.S. Coast Guard (USCG)

(ref. 3-2). Other information concerning the use of oceanographic observations has been documented by the National Academy of Sciences and the National Academy of Engineering. Also, a SEASAT User Working Group within the NASA Earth and Ocean

Physics Application Program (EOPAP) has defined the ocean communities' physical oceanographic data needs.

Briefly, the total need may be defined as an increasing requirement for improved marine environmental monitoring. This, in turn, may be subcategorized as monitoring of physical parameters; forecasting of weather, winds, waves, and circulation; hazards warning; ice surveillance; and the detection and monitoring of ocean and near-shore pollution events.

The environmental monitoring requirements may be broadly grouped into three regions: estuarine and coastal (including the Great Lakes), open ocean areas with major current systems, and open oceans. The polar regions could be regarded as a fourth general area, but the requirements are very similar to those of the coastal region. The U.S. territorial waters and proposed coastal economic zones are of immediate importance for monitoring man's activities in the oceans.

BENEFITS

The benefits that may ultimately be derived from an aerospace remote-sensing system are as multifaceted as the impact of the oceans on the affairs of people. These benefits generally fall into the categories of protection of life and property along the coasts and at sea; improvement of commercial fisheries and the management of marine resources, particularly in the coastal environment; safety and navigation of U.S. shipping and maritime interests; enhancement of the quality of the environment; improved ship and oceanic structures design; and improved long-range weather forecasts for the ocean and continental environment.

The general problem of defining coastal circulation in detail is an important feature that affects most coastal-related activities. This need is common to all coastal studies; for example, in fisheries, the prevailing current system moves larval forms from the spawning grounds to other regions where they either grow or perish; water quality is subject to change at any point as a function of the tidal system and prevailing currents;

and, for protection of life and property, the focusing of wave energy in the coastal region is gradually altered by both the methodical action of daily currents and the dramatic effects of storms as they change the bathymetry and shape of the coastline.

Substantial benefits would be derived from active microwave sensing. It must be noted that the development of remote sensors addresses only a part of the entire system necessary to fully achieve the benefits. Thus, not only is it necessary to develop the technology, but the involvement and acceptance of the new technology by the user is also required.

Improved Environmental Forecasting

Because of the large area of ocean compared to land and the coupled complex interactions between ocean and atmosphere, much of the world's weather is created over the water and ice that comprise the surface of the Earth's oceans. The combination of surface measurements and meteorological and oceanographic satellite data would significantly help to achieve the goal of meaningful 1- to 2-week forecasts. An accurate 5-day forecast would immediately improve U.S. shipping operations. These 5-day forecasts should reduce the present international shipping cargo damage losses of approximately \$500 million per year globally by estimates of 5 to 10 percent, and permit reductions in transoceanic transit time of as much as 10 percent.¹

Hazard Warnings

It is difficult to consistently predict the landfall of a major weather disturbance (e.g., tropical cyclones and the resultant storm surge) to within 200 km and 24 hr in advance. With the increase in the number of people living along the coasts, where approximately 80 percent of the U.S. population now reside, and in the number of offshore facilities contemplated for this region, the potential for loss of life and property has been

¹ From 12 to 24 hr in the Atlantic Ocean and 12 to 60 hr in the Pacific Ocean.

increased proportionately. In the world's low-lying areas, particularly in the U.S. Gulf of Mexico region where more than 30 million people dwell, early warning of severe hurricanes is absolutely essential to initiate evacuation of the population. Observations of sea/air interactions, sea-surface temperature, wind, waves, and an increased understanding of the storm surge process will constitute a large step forward in providing the required early warnings.

Not only are forecasts needed but compilation of such data as wave spectra, focusing of wave energy, and storm-induced along-shore currents is also critically needed to improve ship and oceanic structures design. The 2000 to 3000 doubtful shoals presently located on the world's hydrographic charts are potentially confirmable by high spatial resolution instrumentation operating in both the visible and microwave portions of the electromagnetic spectrum. Such shoals, which may or may not even exist, require avoidance by as much as 50 km for the conservative ship navigator.

Fisheries Improvement

From 1959 to 1969, the deficit in the U.S. balance of payments attributed to fisheries accounted for 19 percent of the total deficit. Since the late 1950's, this deficit has been on the order of hundreds of millions of dollars and currently is about \$1.5 billion per annum, with about 70 percent of its products imported. An increase in fisheries productivity and protection in U.S. coastal waters is needed to reduce the dependency on other nations. Active microwave sensors will benefit the U.S. fishing industry from two standpoints. First, improved forecasting of marine environmental conditions will enhance decisions concerning those regions of the oceans where efficient operations can occur without loss of nets, vessels, or life. Second, the anticipated increase in the "economic coastal region" to 370 km will require monitoring of all vessel operations in a region nearly 20 times larger than historically required. Radar imaging systems could provide initial

detection of localized activity that could be monitored by aircraft or geostationary satellite systems.

One specific fisheries application is the use of spaceborne sensors to make surface salinity and temperature isomaps. These maps can be used as an index of possible density distribution of those game and commercial fish species having definite salinity and/or temperature habitat preferences, with obvious potential for increased yield. Such maps would be of particular use in pinpointing local low-temperature anomalies indicative of coastal upwelling and its attendant high biological productivity.

Ice Surveillance

The Arctic region has a significant impact on global meteorological and climatological conditions. It has been estimated that, at any time in the Arctic region, approximately 10 percent of the ocean surface is open water. The heat flow through the water/air interface is two to three orders of magnitude greater than the heat flow through the water/ice/air interface. The dynamics and forecasting of ice strain in terms of ice type, leads, and polynyas are thus important not only to shipping but also to long-term weather forecasts, which are significantly affected by major points of energy input. The Polar Experiment, as a part of the Global Atmosphere Research Program (GARP), should be a major program during the next decade. This experiment will be supported by microwave sensors. The first benefits will be scientific and are threefold: the synoptic view of ice conditions; the availability of surface truth for instrument calibration and validation; and an area for international cooperation.

In addition to the aforementioned effects of ice and water on weather predictions, marine transportation in various parts of the continental United States and Alaska is subject to hazardous ice conditions. Increasing emphasis is being placed on the Great Lakes, the central river system, and New England. Nearly all iron ore transported in the Great

Lakes region is carried by ship. Significant amounts of wheat, oil products, coal, and finished goods also move across these regions by ship.

Ordinarily, domestic icebreaking is provided for vessels that are not designed to move through ice-covered waters. Therefore, an ability to determine ice coverage, clear water passages, pressure ridges, and ice thickness is material to the successful extension of the navigation season. An interim USCG report on the extension of the St. Lawrence River and Great Lakes navigation season beyond the December 15 closing date estimated the economic gains listed in table 3-I.

These gross estimates are based on a number of factors, some of which are improved ice surveillance, data analysis and prediction, all-season aids to navigation, and increased icebreaking activity. No attempt has been made to assess the economic benefit of each of these contributing programs. Therefore, estimating that portion of the potential benefit to be derived by improved ice surveillance and forecasting is not possible at this time.

Arctic and Antarctic icebreaking have historically been conducted in support of scientific investigations and, to a limited degree, military operations. Discovery of oil deposits on Alaska's North Slope and the political and economic ramifications of a dependency on Middle East oil supplies have spurred further activity in the far north. Scientific and geological surveys, commercial oil drilling, ocean transport, and support of icebreaking requirements in the high latitudes will place increasing emphasis on all-

weather monitoring and prediction of ice extent, ice-free passages and polynyas, ice thickness and pressure ridges, and on the discrimination of new ice from multiyear ice. The benefits of more complete data gathering and ice forecasting should be more efficient icebreaking operations, reduced damage to vessels and structures, increased safety of personnel, and more economic or other advantageous vessel transport of petroleum and other resources.

Ocean Pollution

Oil pollution constitutes a major threat to U.S. water resources, marine life, waterfront property values, and the recreational industry. Oil pollution incidents are generally agreed to be a direct result of the number of transfer operations between vessels and shore facilities, the volume of oil transferred, the number and length of vessel passages within U.S. waters, and the number of offshore oil wells.

The size of the area to be monitored is significant; it includes thousands of kilometers of rivers, lakes, harbors, and coastlines. Remote-sensing techniques that enhance the ability to observe oil discharge will materially assist in the enforcement of applicable laws and tend to ameliorate the environmental damages by more rapid response and cleanup.

The USCG has observed marked decreases of as much as 25 percent in the number of oilspills when continued surveillance of critical areas was used. Although much of this decrease could be attributed to increased attention to handling and transfer methods, the fact that better and more complete surveillance is being conducted would tend to dissuade the intentional polluter.

Cost estimates of USCG daily observation of certain harbors and waterways with existing vessels and aircraft are \$2 to \$4 million annually. Extension to a dedicated surveillance of major U.S. continental lakes and coastlines for pollution may exceed \$18 million. High-resolution radar, imaging micro-

TABLE 3-I.—*Economic Gains Resulting From Extension of Navigation Season of the St. Lawrence River and Great Lakes*

Navigation season extended to—	Economic gains, millions of dollars	
	By 1975	By 1985
Jan. 31	40	85
Feb. 28	58	123
Year round	68	145

wave radiometers, and multispectral low-light-level television are presently being installed on aircraft for low-altitude flight. Sensor systems that could detect a surface oil sheen of 1000 m² or greater from high-altitude aircraft with corresponding increased swath width could decrease yearly costs from \$11 to \$18 million.

Monitoring of Endangered Marine Life

The Marine Mammal Act of 1972 (Public Law 92-522) focused on the need to assess the stock of specific species of marine life to insure their continued existence and on the ultimate goal of restoring and maintaining a viable commerce with certain of these species. The prime current need is to conduct a census of many of these mammals, including, for example, sea otters, and gray

and bowhead whales, walrus, and seals. Three specific forms of space technology appear appropriate for development.

1. Tracking of animals by surface, aircraft, or spacecraft techniques, potentially using radar transponders, to determine the habits of the creature; in particular, the time in and out of the water.

2. Overflights by aircraft to determine the herd sizes and numbers of animals in the herds.

3. Where appropriate, satellite tracking of icefields to assess and forecast the location of ice where these animals are most likely to be found, thus reducing aircraft search time.

Benefits are difficult to establish beyond the preservation and conservation of these marine animals.

PART B

TECHNICAL BACKGROUND

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SUMMARY

This section describes the physics of electromagnetic scattering from the sea and is presented as a guideline to relate an observable (such as the radar cross section) to the hydrodynamics or physical properties of the sea.

At microwave frequencies, the ocean produces two types of scattering processes. The larger ocean waves essentially behave as an ensemble of specular reflectors such that the strength of the scatter is proportional to the tilts (or slopes) of the gravity waves. Because the length of the ocean wave is much greater than the height, quasi-specular scattering occurs only at angles close to the nadir direction (usually within 25°). Therefore, near nadir, the active microwave system is closely linked with the physics that controls the gravity wave slope. For angles beyond 20°, resonant (Bragg) scattering

occurs from those waves that are comparable to the wavelength of the incident electromagnetic wave. At microwave frequencies, this type of scattering is controlled by the capillary wave structure. Because the capillaries have a short time constant for growth and decay, the scattering strength is linked to the local wind fields and the surface tension of the ocean surface.

As specific examples of the interdisciplinary science of electromagnetics and geophysical oceanography, the physics is discussed in connection with data provided by three instruments; namely, the scatterometer, the altimeter, and the imaging radar. These instruments are selected because of the availability of generally consistent data resulting from numerous experiments conducted from stationary platforms, aircraft, and satellites. The data provided by each instrument are discussed in context with