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Remote Sensing of the Oceans from Space with Special Reference to Marine Resources

By

N. JASENTULIYANA*

I. Introduction

The world's oceans, covering 75 per cent of the earth's surface, play a fundamental role in the dynamics of the earth's atmosphere and thus potentially affect the weather and climate of the entire earth. The seas provide resources such as food and other materials and are essential to world commerce. However, they also pose hazards such as tidal waves, they cause coastal erosion, and they originate hurricanes and other devastating tropical storms.

It is therefore essential that the dynamics of oceans and their resources are monitored continuously. In order to monitor them effectively, information must be gathered on ocean currents and circulation, sea-surface temperature, salinity, coastal dynamics, sediment transport, erosion, shoaling, surface winds, waves and wave diffraction, and sea ice and its dynamics. Much of this information may be gathered most conveniently by "remote sensing".

Remote sensing of the oceans has been undertaken from fixed towers on the ocean floor, vehicles floating on the sea surface such as ships and buoys, and vehicles above the ocean such as balloons and aircraft. The most used platform for this purpose, of course, has been aircraft. Ships and aircraft operations, however, were too limited and prohibitively costly to provide the needed information on a continuous and real-time basis.

With the advent of manned space flights in the 1960s, there became available a wealth of colour photographs of oceans and their coastal boundaries obtained by astronauts using hand-held cameras. There followed the launching of meteorological and remote sensing satellites which, though not specifically ocean-oriented, provided a large amount of information on ocean processes.

Remote sensing from manned and unmanned earth-orbiting spacecrafts provide the advantage of obtaining synoptic coverage of vast areas rapidly and on a real-time basis. Thus, it has now become quite evident that only satellites can effectively perform the formidable task of monitoring the world's oceans and their resources. Nevertheless, remote sensing of the oceans from space progressed slowly because only the surface can be monitored, although surprising inferences have already been made from data obtained from satellites about conditions well below the surface.

A number of ocean science fields have profited, either directly or indirectly, from satellite remote sensing, including physical, biological and geological oceanography. A number of user oriented applications such as fishing, shipping, offshore drilling and mining, coastal engineering and coastal hydrology have also benefited from satellite remote sensing.

* Chief of Section Outer Space Affairs Division United Nations,

II. The technology

The meteorological satellite series—TIROS and Nimbus—launched in the early 1960s, carrying television cameras and thermal infrared and microwave radiometers which measured sea-surface temperature, were the first unmanned satellites to be used for gathering data for oceanographic purposes. The Coastal Zone Colour Scanner flown on Nimbus-6 and Nimbus-7 are still contributing to studies of chlorophyl content. Data from earth resources satellites, the LANDSAT series, were used extensively to study ocean dynamics and the marine environment. In the latter half of the 1970s, the MARISAT series of satellites were used for maritime communication and navigation purposes.

The first satellite dedicated to oceanography, however, was SEASAT, launched in 1978. It was used to determine if microwave instruments scanning the oceans from space can provide useful scientific data to oceanographers, meteorologists and commercial users of the sea. It sent back information on surface winds and temperatures, currents, wave heights, ice conditions, ocean topography and coastal storm activity. It circled the earth 14 times a day and its instruments swept across 95 per cent of the oceans' surface evry 36 hours, seeing day and night under all weather conditions, providing the oceanographers with their first synoptic or world-wide observations of the oceans.

SEASAT carried five ocean sensing instruments: an altimeter to determine ocean topography and significant wave heights; a scatterometer to determine surface wind speed and direction; a scanning multi-channel microwave radiometer for measuring sea surface temperature in all weather conditions; a visible and infrared radiometer to determine ocean colour patterns and temperature; and a synthetic aperture radar to provide images of the oceans in order to determine wave and current patterns, ice field, and coastal/ocean interaction. Data from the satellite was transmitted to over 12 ground stations throughout the world on a real-time basis at 25 kilobits per second or from the onboard tape recorder at 800 kbps.

A Marine Observation Satellite (MOS-1) currently under development in Japan is scheduled to be launched in 1984. As Japan is surrounded by the sea, marine resources and sea state are of great concern to Japan, and the objective of MOS-1 is to develop the fundamental technologies for marine observations and to observe the state of the sea surface and atmosphere using visible infra-red and microwave radiometers. For this purpose it will carry a visible and near infra-red radiometer, a visible and thermal infra-red radiometer and a microwave scanning radiometer. The shuttle flights in 1981 and 1982 will also carry several sensitive instruments that will assist in the study of the marine environment.

Among other satellite systems in the design or planning stages is a coastal ocean monitoring satellite system (COMSS) to be launched by the European Space Agency (ESA) to moniotor coastal regions of Europe and the world. It is intended to support forecasting of sea state, storms and currents, assistance to oil exploration, optimization of coastal construction and construction at sea, forecasting and location of surface fish and surveillance of oil and chenical pollution. For these purposes, it is expected to carry an ocean colour monitor, a synthetic apperture radar and an imaging microwave radiometer.

Also under development is a series of satellites which will assist in maritime weather forcasting, communication, navigation, and search and rescue purposes. The satellite series which will serve all these purposes is the MARECS system being developed also by ESA to be launched in late 1981 or early 1982. The United States, Canada and France are jointly developing the SARSAT system to provide a satellite-aided search and rescue system. The Soviet Union is planning a similar system under the COSPAS programme with a view to establishing a system compatible with the SARSAT system. If successful, these two projects could lead to the establishment of an operational international satellite-aided search and rescue system to save lives at sea and minimize the cost of marine emergencies.

These and other satellites under development or being planned will provide in the next decade operational data on the dynamics of ocean processes and will also provide support for economically important marine operations, in particular the estimation and development of the potential of resources of the oceans.

III. Oceanography

(a) Sea-surface temperature

Sea-surface temperature is one of the important parameters of oceanography. Knowledge of surface temperature leads to identification of currents and provides an index of energy exchange across the sea-air interface and an indication of biological activity. The early infra-red observations from meteorological satellites showed that patterns of temperature variations could be detailed quite readily, especially near the great current systems where there are strong temperature gradients.

The Gulf stream was monitored on a daily basis in the north Atlantic, and satellite imagery showed large gyres or eddies which were formed as the gulf stream interacted with the surrounding waters. As they move on to other waters these eddies influence the temperature of surrounding waters and the atmosphere above. They are believed to influence the transport of heat from the equator to the poles, and also horizontally across the ocean basins. Satellites offer the most effective means of studying these eddies which were unknown to oceanographers and meteorologists a few decades ago.

By providing the capability to measure ocean temperatures accurately, remote sensing satellites will make it possible to predict and perhaps eventually control the migration of marine life as discussed below in greater detail.

b) Sea-surface circulation

The surface circulation of the world oceans is primarily a result of prevailing wind patterns over the sea. The transfer of atmospheric kinetic energy to the sea surface sets up water transport mechanisms, which range from small scale eddies to major ocean current systems. The large amounts of energy transported by these currents influence weather and climate, and the enormous quantities of energy involved are dramatically illustrated by hurricans and typhoons. the source of which is the heat stored in the oceans. It is unlikely that oceanographers and meteorologists will even be able to make reliable predictions of weather, climate and ocean currents without large-scale numerical models of sea surface circulation on the basis of data that are possible only with satellite observations.

A radar altimeter carried on SEASAT has provided some revealing information on how the average sea surface is affected by dynamic forces moving water and by irregularities of the earth's gravitational field.

The best studied example of surface currents is the Gulf stream which is the largest surface current in the ocean.—Weather satellites have also looked at other major currents, such as the Agulhas current, the Brazilian current and the Kuroshio current.

A study was carried out successfully under the 1979 World Weather Experiment using a satellite to monitor slow-moving buoys which provided a new source of information on the circulation of southern oceans. Plans are being made for additional buoy experiments to study oceanic motion elsewhere, to obtain information on the year to year variability of currents. Satellite tracked drifting buoys will also aid in reasearch on the origin and movement of fish stocks.

(c) **Sea waves**

Better understanding of the dynamics of wave fields on the sea surface will lead to more precise predictions in regard to waves and marine weather, which are of major importance to commercial shipping. Satellite observations have proven more reliable and accurate than conventional measurements made from special buoys, or estimations made from ships in measuring wave heights. The GOES-3 satellite began to provide wave data from space, and SEASAT, using the short pulse altimeter, continued on a more accurate and systematic basis covering the oceans completely.

(d) **Maritime weather**

Maritime weather has two major influences on man's use of the oceans. In coastal areas where the highest population densities are located, the effects of wind and sea associated with storms can create catastrophic damage and considerable modification of the coastline. On the high seas storms can delay and damage shipping resulting in staggering annual losses.

Although it is not yet possible to control maritime weather, it is possible to develop forecasts with the use of satellite data that reduce hazards in both coastal areas and on the high seas to the absolute minimum. Good forecasting requires continuous monitoring of the world's oceans to locate and track major weather systems, as well as the wind and wave fields generated by them, and this could only be done effectively by satellites. SEASAT surface wind data, for instance, were equivalent to 20,000 ship reports each day, roughly an order of magnitude larger than that presently provided by surface vehicles.

The Global Atmospheric Research Programme (GARP) and the United States Weather Service are experimenting with the possibilities of weather modification, both to reduce the intensity of storms and to steer them away from heavily populated areas. Although these efforts are still in the very early stages, some preliminary results indicate that these goals could be reached. Without the use of satellites, these efforts could not have been undertaken.

(e) **Navigation**

Since 1960 several dozen navigational satellites have been put into orbit. These satellites provide mariners with navigational data more accurate than any used previously. More recently an international organization—the International Maritime Satellite Organization (INMARSAT)—has been established to conduct an operational satellite system for maritime navigation.

(f) **Coastal zone management**

Coastal management involves the protection of coastline against the modifying forces of nature, as well as man's efforts to develop it for his purposes. Wind, sea, and run-off from land all continully work to change the configuration of the coastline, while man modifies it to suit his requirements.

Satellite data have already been used to detect most of the influences that result in coastal changes From the detection and tracking of marine weather systems to changes in near-shore bathymetry due to river sediment deposition, satellite data can provide the continuous monitoring required to preserve the coastline.

A major concern in coastal zones is the effects of pollution. Much of the pollution is introduced into the coastal waters by the discharge of wastes into harbours and rivers. Offshore sewer outfalls are also a source of pollution where sewage treatment is lacking. Remote sensing techniques are ideal for routine monitoring of pollution and for the study of effects on the coastal zone as a whole. Since most pollutants have both thermal and colour signatures, monitoring of coastal zones is easily done by remote sensors. The distinctive spectral reflectance of crude oil enables satellites to estimate the extent of oil spills and track and forecast their probable direction and speed. For instance, LANDSAT imagery has been used to monitor the massive oil spill from the oil platform blow-out in the Gulf of Mexico.

Information about sea ice is important for several reasons. The weather and climate studies in the polar regions where much of the world's weather is spawned will be greatly enhanced by the study of sea ice. Drifting ice poses threats to shipping in heavily used lanes, particularly in view of the interest in developing the resources of the arctic slopes for which ice is a major obstacle. Because darkness and cloud cover prevail over the polar regions a great deal of the time, only satellites carrying large microwave antennas can effectively montitor sea ice in these regions on a continual basis. Such work has been carried out by Nimbus and SEASAT satellites, and new satellites are being planned with very large antennas that will improve the ability to observe sea ice.

(h) Other applications

Remote sensing of the oceans from space is also important in many other areas of physical and geological oceanography such as the study of deep ocean circulation, estuarian circulation, surface of the geofd, salinity, hydrography and coastal hydrology, where already satellite data from the Nimbus series, SEASAT, LANDSAT and other satellites have provided much valuable data and information.

IV.—Marine resources

Fishing is man's oldest enterprises involving the sea, but yet it has always been a marginal enterprise. Approximately 70 million metric tons of fish, shellfish and sea weed are harvested annually from the sea while the full potential is estimated to be as high as about 640 million metric tons. On the basis of the use of time, it is a poorly organized enterprise. The fishermen spend 65 per cent of their time searching, 10 per cent catching, and the balance travelling to and from the fishing grounds. As marine resources are an important source in meeting the global food probleme it is essential that we realize the full potential of these resources.

In order to accomplish this, there is a need to evaluate the resources of the sea and to develop methods to harvest them. At the same time there is a need to understand the effect of man and of the environment on the presently exploited stocks of marine resources and to provide management information or advice based upon this understanding to government and industry. Hither to these needs have not been fully met because of the limitations in collecting and examining synoptic data on the fish populations and on the large scale features of ocean processes. With the advent of space, technology, a new tool is now available to collect such synoptic data on a real-time basis.—Moreover, remote sensing from space has made it possible to monitor parameters which are directly or indirectly correlated with the presence of marine living resources.

(a) Monitoring of upwelling areas

The ocean's highest productivity is normally located in near-coastal areas and is associated with upwelling, a process by which cold water, normally from depths of 150–200 meters, is transported either by current systems or by wind conditions to the surface layer. Because of the high nutrient concentration of the deeper water layers, the surface waters become enriched by these nutrients which stimulate and enhance primary productivity at the surface. Upwelling regions thus provide excellent feeding grounds for secondary producers (zooplankton), and finally, the next step in the food chain, fish. Some fish of great commercial importance, for example the tuna family, feed on small fish. These small fish in turn feed on smaller life which is abundant only in regions of strong upwelling.

Since high productivity is associated with upwelling areas, two important parameters which can be monitored from space become significant: (1) temperature anomalies which are important in indicating places of upwelling; and (2) the change in sea surface colour. Although most of the fish catches come from upwelling regions which can be located by temperature measurements, several species can also be correlated directly with certain temperatures because some species of fish prefer a particular temperature range and avoid waters that are either too warm or too cold. Thus, by knowing the temperature of a given area, one can predict and locate the regions with highest possibility of catching particular species. Temperature, however, is only one of the parameters, and other parameters are necessary for a complete understanding of the pattern of fish distribution. High productivity regions are also characterized by a change in sea colour related to the abundance of plankton. In upwelling regions without river discharge, patchiness as observed from spacecraft can be interpreted in terms of plankton or biomass. A relationship exists which can be used to estimate the standing stock of fish. For instance, the Coastal Zone Colour Scanner on Nimbus-7 provides a quantititaitve way of determining ocean colour as the data received shows the amount of green (water with high chlorophyl content, which is a basic index of productivity and thus of areas where life is abundant), blue (regions where there is little microscopic life) and red (where there are sediments from continental run-off). These promising results are being improved upon to show more details of marine productivity, as is expected from the better sensors which will be used in future spacecraft.

Thus, the monitoring from space of upwelling areas with temperature and successful colour measurement is a promising tool for better management of fishing resources.

(b) Monitoring of coastal zone/wet land regions

The abundance of nutrients in coastal zones, which, though comprising 10 to 20 per cent of the surface area of the world's oceans, produce approximately 90 per cent of the marine resources, is due to transport of biomass across coastal land/water boundaries, particularly in areas of complex coastal geometry with wetland type vegetation as the primary land cover. These areas are sensitive ecological regimes that are affected by such processes as salinity intrusion and deterioration, and which are influenced to a degree by man's activities such as dredging, building of levees, and extraction of mineral resources.

Characterization and monitoring of changes in wetlands can be determined largely through correlations with vegetation. Both monitoring of the vegetation types and extent, and measurements of land and water area and shoreline length provide information important to marine resources. Changes in vegetation can be used as an aid in the analysis of changes in ecological factors. In addition, some erosion and deterioration processes are occuring with such rapidly that semi-annual surveys of the coastal wetlands would be very useful, and, in some cases necessary, for interpretation of changes.

In contrast to the frequency of changes in the coastal wetlands, the coastal waters represent a very dynamic environment due primarily to the effects of tidal action and wind driven circulation. In some coastal areas, storms also are important and frequent contributors to the shaping of coastal geometries. The dynamics of coastal waters may be divided into two parts; the daily or even hourly changes causes by tides and winds; and the longer term changes characterized for example, by seasonal levels of temperature, turbidity, and salinity, by river flows, by prevailing currents, and by shoreline erosion.

Measurements of these environmental factors which are of major importance to the monitoring, assessment and prediction of marine resources location and availability in coastal zones have been made in the past, on a limited scale, using traditional methods. However, the first attempts to use the technology of space remote sensing show great promise in providing many of these measurements on a synoptic scale and in timely and inexpensive manner. Moreover, for certain parameters affecting coastal fisheries such as annual changes in harsh environments serving as resources nurseries, satellite remote sensing can provide important information on a routine basis for the development of assessment and prediction techniques possible with conventional methods.

(c) Examples of satellite data applications to marine resources

Due to the inadequate ground resolution of camera systems used aboard current satellites, identification of individual fish does not currently appear technically feasible although improved resolution would allow some fish schools to be identifiable. However, environmental factors discussed above which can be monitored from space provide reliable sources of indirect information and have been correlated to the appearance of marine resources.

For instance, the recordings made by the thermal channel of the multispectral scanner of Skylab made it possible to determine an intensive area of upwelling along the north-west coast of Africa. Using the data from Nimbus satellites, a very particular upwelling region was found along the Somali Coast in the Indian Ocean where upwelling responds to the monsoon seasons, appearing only during the south-west monsoon. Satellite observations of the temperature field showed the economically important upwelling region which is connected with the Benguela current along the west coast of South Africa.

The data indicate that on a large-scale, the regions of greatest upwelling are seasonal, while in certain smaller regions there exists a more or less permanent upwelling. This affects the abundance of fish which may migrate with temperature fluctuations or are related to the standing stock of plankton. The economic impact of upwelling regions is demonstrated by the catches of the local and foreign fleets in regions such as that associated with the Benguela current.

The feasibility of applying satellite data to marine resources problems in the coastal zones was demonstrated in several experiments. Classification techniques for water colour using LANDSAT data were utilized to predict the commercial harvest potential of manhaden the largest volume fishery in the United States. The dependence of marine resources productivity in coastal areas upon the amount of nutrients in the coastal wetlands crossing the shoreline boundary into the water and becoming available for food in the life cycle of marine resources was used to show that LANDSAT data could be used for fishery resources assessment as was demonstrated in the Mississippi sound and adjacent off-hore water in the United States. An experiment in the state of Louisiana, located along the Gulf of Mexico, showed that shrimp yield is highly correlated to the complexity of the shoreline. It showed the correlation between the availability of shrimp and the load of suspended sediment.

The results from these experiments have been extensively verified in the Gulf of Mexico coastal regions. Since these regions have an abundance of fish resources and characteristically comprise large areas of wetlands, scientists believe that they should be representatives of similar areas in other parts of the world where marine resources are important.

Satellite imagery has also been used on a limited scale to monitor fish oils as an indicator of abundance of marine life. It is known that when one fish stock feeds on another, organic oils are liberated and form a film on the surface. Such an oil film is detectable through remote sensing and is distinguishable from fresh and older slicks. Schools of fish however do not emit oil at all times, nor do they stay in the same area where oil has been released by feeding or other process. Thus while the technology is promising in this a a, much work has yet to be done to make it widely applicable for detection of fish stocks.

(d) Management of marine resources

An important aspect of management of marine rsources is the monitoring of the presently exploited stocks. In order to succesfully monitor such stocks. it is necessary to monitors the position of high seas fishing vessels for purposes of enforcing manageent agreements designed to conserve exploited resources. Curratly there are several such international and bilateral agreements in effect, and as the demand for commercial fishing increases States will enter into many more such agreements. In many cases the conservation regime may apply to a number of species of fish and extend over very large areas, and may even be oceanwide. These agreements often take the form of open and closed areas and seasons. In order to enforce these provisions, it is important to be able to monitor the locations of fishing vessels.

At present such monitoring is done by observers placed aboard vessels, surveillance with aircraft over-fights or patrol vessels. These and other techniques currently used are limited in scope by physical and logistic constraints and are expensive. Satellites, on the other hand, are not limited in the same manner, and by the nature of their syoptic coverage could provide an effcient system of monitoring vessel positions. The United States of America currently has plans for a continuing operational satellite programme concerned with such monitoring systems.

V. An Appraisal

The possible applications of remote sensing from satellites to oceanography and the management of marine resources as discussed above and the success of experiments already carried out provide impetus for the development of operational satellite systems specifically designed to provide information for these purposes. At this time the use of remote sensing data for oceanography and the management of marine resources is yet in its infancy, but as new and more sophisticated sensors and techniques become available, this technology is bound to be used to enable greater understanding of the oceans and their marine resources. This is why several countries are planning to launch satellites in the next decade to provide operational data in this field.

The quality and quantity of data generated by satellites will however create formidable problems in data handling and analysis. Costs have already been minimized through the use of small computers and optimized software for data handling and analysis, but further development in this area will be required before satellite data can be used on a day to day basis around the world. While the technology is developing, it is essential that Third World countries, like Sri Lanka, develop an inter-disciplinary programme of remote sensing on a modest scale which will provide a nucleus of trained personnel in the interpretation and use of satellite data.

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