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Use of Satellite Data in Coastal Zone Programmes

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ABSTRACT

Application of data monitored from spacecraft altitudes in coastal zone programmes are summarized. Special emphasis was given to the data obtained during the Landsat missions. The use of satellite images in natural marine resources, management, mapping of coastal areas, water quality, and upwelling and currents is described. The economic benefits of remote sensing from satellite altitudes are evaluated for the marine sector.

INTRODUCTION

The development of sensors flown on satellites for reconnaissance of natural resources has progressed rapidly during the last few years and results gathered by orbiting satellites have reached an increasingly large community of users. Early experimental flights of instruments, such as those carried on the Nimbus satellites, demonstrated the high potential of remotely/sensed data from spacecraft. For example, specific applications were demonstrated for the detection of cold upwelled waters in regions where a potential for the development of fisheries exists.

Due to the low ground resolution of previous satellite data, only large-scale phenomena such as flooding, areas of vegetation and ice conditions could be investigated. This changed, however, as soon as the ground resolution increased. The Nimbus satellites, for instance, had a ground resolution of about 500 m for the Advanced Vidicon Camera System (AVCS), while the High Resolution Infrared Radiometer could only detect objects greater than 8 km. The more recent Earth Resources Technology Satellites (ERTS)

* The views expressed by the author are put forth in a personal capacity and do not necessarily reflect those of the United Nations.

(now called LANDSAT) are able to detect targets on the ground with a size of about 100 m.

Colour pictures taken during manned space flight missions and infrared recordings taken from orbiting unmanned satellites showed the high potential for detecting the presence of biomass concentrations and upwelling areas in the ocean as well as features in the near-coastal regions such as vegetation, beaches, erosion and suspended sediment. The detection of chlorophyll, as a representative pigment in phytoplankton, has been used to estimate the standing stock of fish.

In the field of pollution monitoring, the importance of the air—sea interface has been recognized as a concentration plane for pollutants and as a contributing medium for transport of such agents across this layer.

Surface anomalies, such as slicks, fronts and foam, are amenable to remote sensing and can be recognized in satellite imageries obtained over oceanic regions.

The most successful spacecraft mission for monitoring the near-coastal areas was conducted under the ERTS programme, the technical background of which will be briefly described in the following paragraphs.

CLOUD DISTRIBUTION

The major advantages of spacecraft observations are the coverage of a wide area and the possibility of having repeated coverage of a region. However, these advantages are limited in many regions by a characteristic pattern in the cloud distribution which is the result of persistent wind systems. The imagery in Fig. 1 is based on recordings by the Application Technology Satellite over the Pacific Ocean. The horse latitudes (or the subtropical calms of descending air) between the equator and about 30° N and 30° S, respectively,

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Fig. 1. Recordings by the Application Technology Satellite (ATS) over the Pacific Ocean.

have low cloud coverage as a result of the trade winds which are constantly transporting air masses.

Examples of areas with dry, nearly cloudless atmospheres are shown in Fig. 2. These include parts of the northeast African continent, the Arabian peninsula and parts of Iran. Although the ground resolution of this recording (by ESSA-9) was not sufficient for use in the reconnaissance of marine resources, it is an important input in selecting the proper conditions for further detailed studies. As shown in the time frequency of satellite images in Fig. 2, arid regions can be monitored very frequently without significant cloud contamination of the field of view.

ERTS PROGRAMME

Originally designed as a feasibility project to demonstrate that information monitored from space can be an important approach to efficient man-

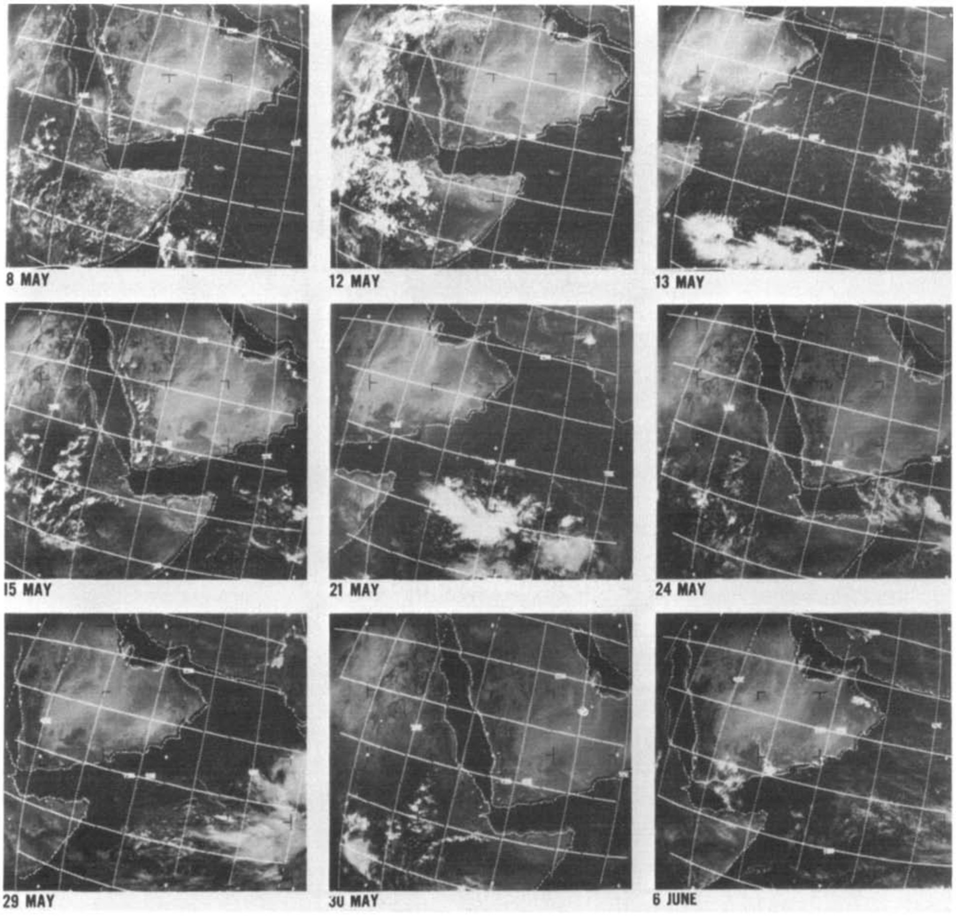

Fig. 2. Analysis of satellite imageries as obtained by ESSA-9 in 1970. According to the cloud distribution, the beginning of the NW Monson can be determined for 15 May.

agement of natural resources, the ERTS programme was integrated into several management and research programmes as an effective operational tool.

ERTS had as its main payload a high-resolution Multispectral[1] Scanner Subsystem (MSS) and a three-camera Return Beam Vidicon Camera System (RBV) which provided for the repetitive acquisition of multispectral data from surface characteristics of the Earth. The overall observatory configuration is illustrated in Fig. 3, which shows ERTS with its payload (RBV and

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[1] The word multispectral indicates that recordings were done in discrete steps of the electromagnetic spectrum.

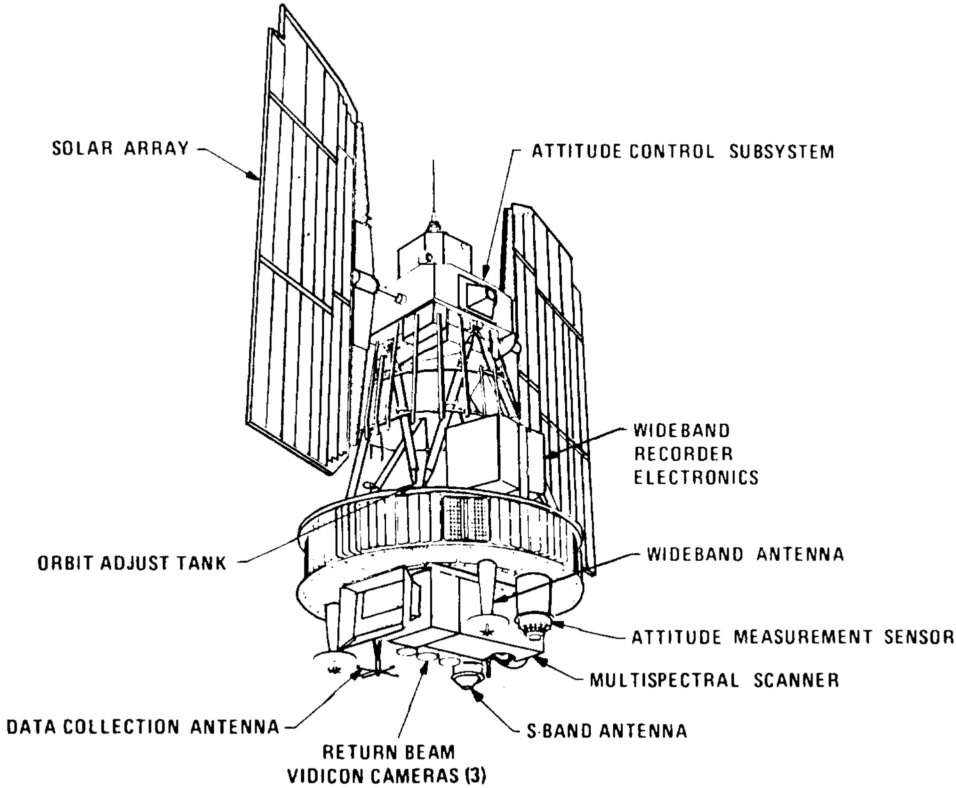
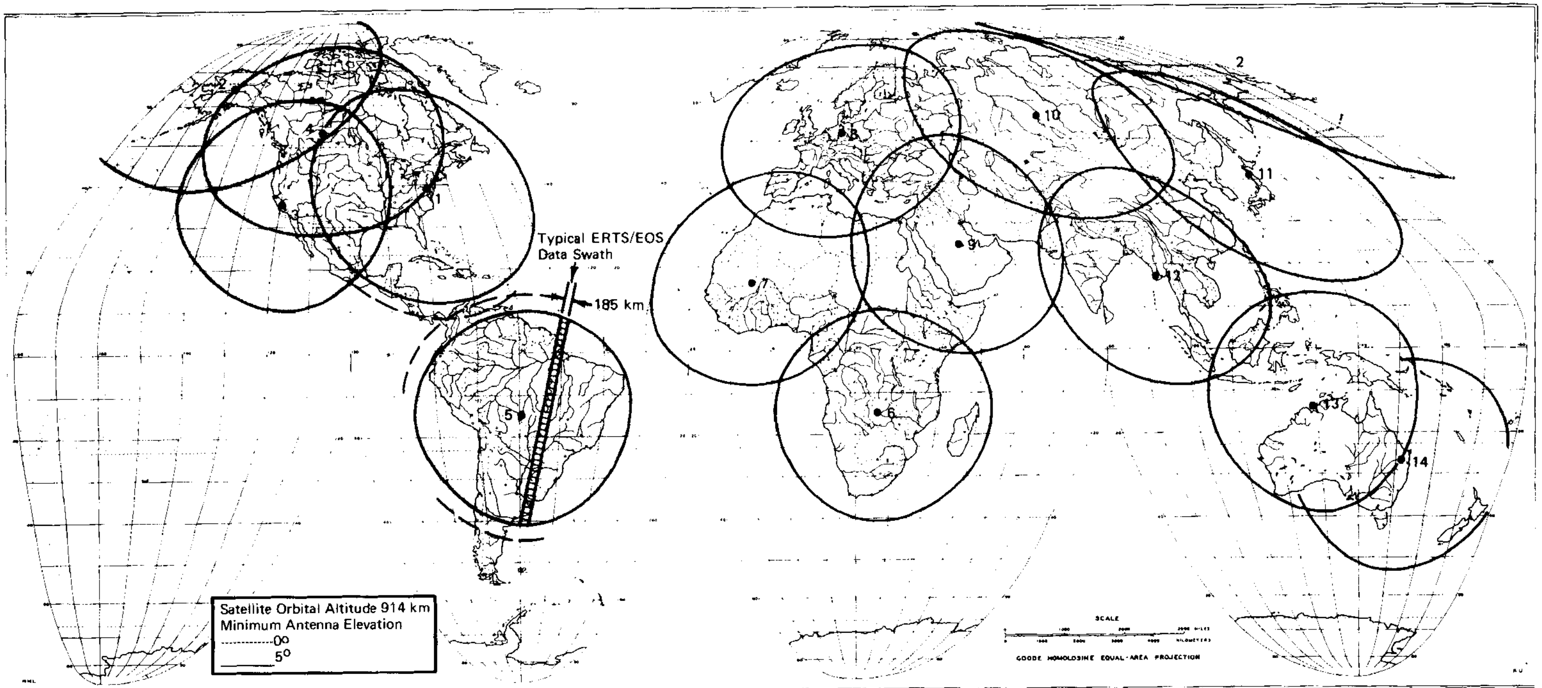


Fig. 3. Overall configuration of the ERTS observatory.

MSS) and also demonstrates its capability to store data from earth-based sensing platforms, as well as the various support subsystems comprising the spacecraft vehicle.

During the ERTS-1 mission, only a few RBV camera images were obtained because of electronic interference between the MSS and the RBV. This meant that most of the material was monitored by the MSS. The MSS used an oscillating mirror to scan continuously the field spectral bands (0.5—0.6 μm, 0.6—0.7 μm, 0.7—0.8 μm and 0.8—1.1 μm) while spacecraft motion provided the long-track progression. Data were transmitted as they were acquired (in real time) if the spacecraft was in the vicinity of a ground-receiving station. Out of the range of a ground station, the data were recorded alternately on two wideband video tape recorders with a recording capacity of 30 min each and played back to a ground-receiving station at a later time.

ERTS was placed into a near-polar orbit at an altitude of about 490 nautical miles and completed 14 orbits per day with a coverage of the total earth surface every 18 days.



Existing Stations				New Stations					
Sta No.	Host Nation	Approx. Location		Sta No.	Approx. Location		Sta No.	Approx. Location	
		Longitude	Latitude		Longitude	Latitude		Longitude	Latitude
1	U.S.A.	77W	39N	6	27E	15S	11	142E	42N
2	U.S.A.	149W	64N	7	4W	16N	12	98E	16N
3	U.S.A.	117W	35N	8	13E	52N	13	130E	13S
4	Canada	106W	53N	9	48E	25N	14	154E	27S
5	Brazil	57N	15S	10	84E	56N			

Fig. 4. Global coverage provided by five existing and nine new data acquisition stations for ERTS and EOS resource-survey satellites. (Source: Beilock, 1973)

Typical data results are in the form of imageries, which make up a composite of the original scanlines, and also computer-compatible tapes for machine processing. The capability of five operational receiving stations in the U.S.A., Canada and Brazil showed that the whole North American continent and about 90% of South America can be covered. Additionally, nine stations located in regions, as indicated in Fig. 4, would provide coverage of all coastal areas, excluding Antarctica. With a single antenna, an area of 23 $\cdot 10^6$ km^2 could be repeatedly covered by ERTS or a similar monitoring system.

NATURAL MARINE RESOURCES

The fast acquisition of multidisciplinary data from an orbiting platform facilitates especially the monitoring of time-dependent features, such as near coastal erosion, changes in vegetation, current patterns, plankton blooms, etc., and also has the advantage of being useful in the exploration of natural resources.

The application of remote sensing technology to environmental problems and coastal resources was studied by Thompson et al. (1973). Coastal resources, such as productive salt marshes, shell and sand deposits, timber and water were evaluated using remote sensing techniques, photography and infrared scanning imagery). Impact problems related to highway location, dredge spoil placement, industrial and recreational development were considered in the light of data acquired at various seasons. Austen et al. (1973) studied the application of remote-sensing systems in earth-resource exploration. The information thus obtained makes possible more efficient planning and decision-making.

A synopsis of marine resources and ocean surveys from the ERTS-1 programme was made by Greaves (1973). It was demonstrated that sediments are the most visible features and can be used to differentiate water masses. In clear water, bathymetry can be estimated by using contrast enhancement as well as a technique called optical and digital density slicing.

A sample of an aerial photograph taken over Key West, Florida (U.S.A.) during a manned spacecraft mission is shown in Fig. 5 which mainly portrays the topography of the area. Much more detail can be recognized in separated spectral bands, such as in ERTS images, as shown in Fig. 6 using the four different channel imageries over the Little Bahama Bank. Channel 4, with the highest penetration of light in water, shows that the bank has its shallowest part in the north. Although the northern section is partly cloud-covered, it is easy to differentiate between those structures which are created by clouds. With increasing wavelengths, the water penetration depth of light decreases and only near-surface features and coastlines can be identified, as is apparent

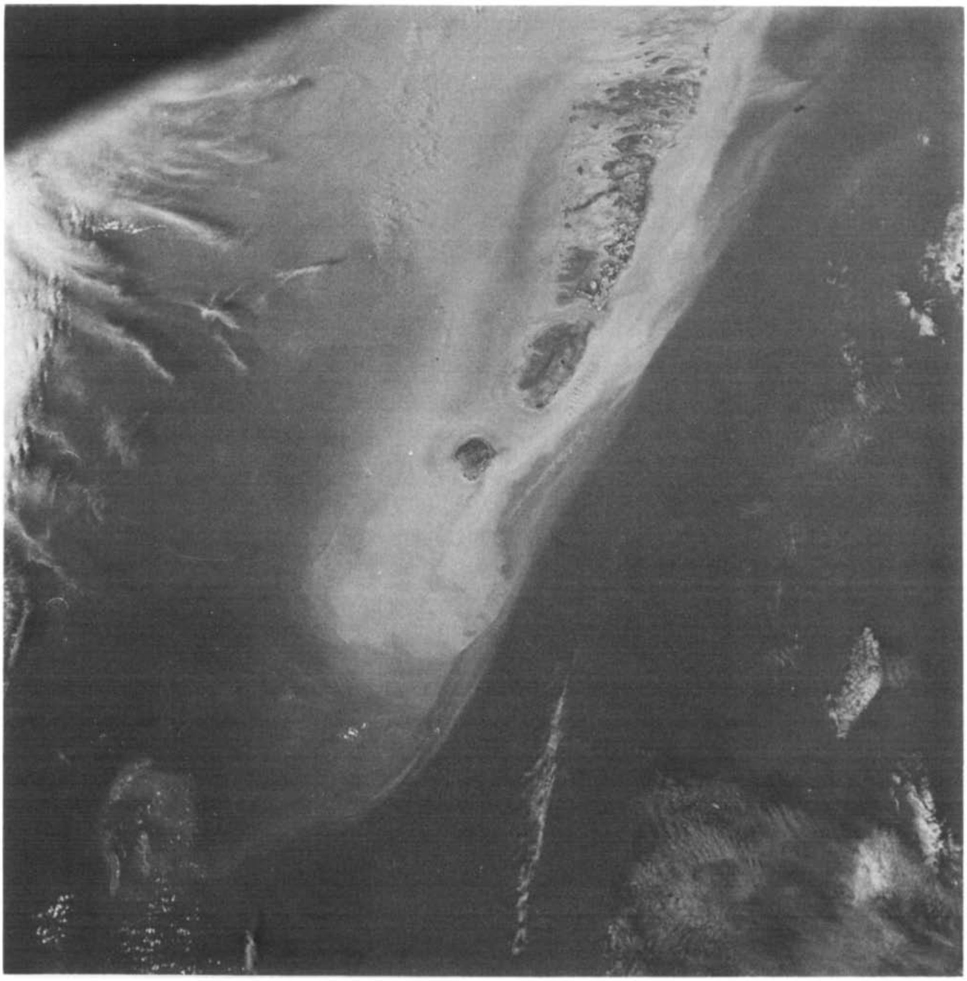


Fig. 5. Topography of the ocean floor as indicated in imagery obtained over Key West, Florida.

by comparing channel 4 with channel 7.

A typical example of river discharge as viewed by ERTS-1 is shown in Fig. 7. During the time of overpass, the predicted tidal currents had an ingoing component (Klemas et al., 1973) which is reflected in the small tongue of ocean water with low particle load entering the centre of the bay.

With the increasing demand for fresh water, remote sensing will be an important tool for water inventory and water-resource investigations. Land uses related to water-resources management can easily be identified and mapped using ERTS-1 data at a scale of 1 : 250,000 (Salomonson, 1973). Areas inun-

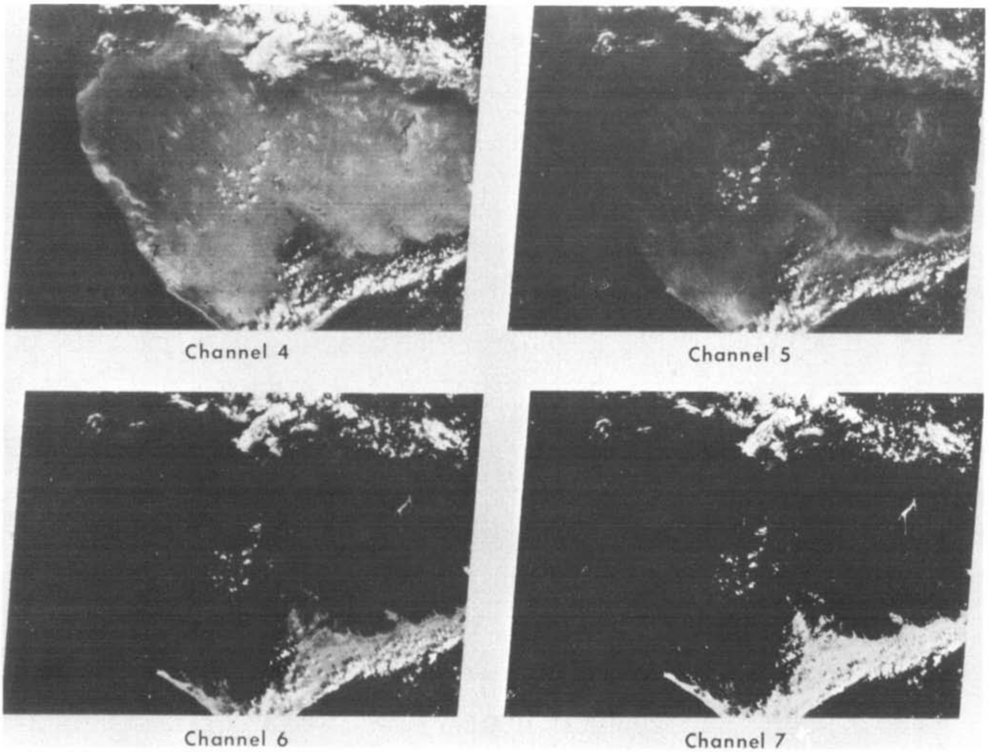


Fig. 6. MSS ERTS data as obtained on 10 October 1972 over the Little Bahama Bank, Goddard Space Flight Center identification number G-73-7701.

dated by flooding can be mapped at the same scale. The Data Collection System (DCS) on ERTS-1 collected and relayed data rapidly enough to have a significant input in management situations. Size limits for bodies to be detected are in the order of one hectare and rivers as narrow as 70 m in diameter can easily be detected and monitored. Variations in reflection are attributable to variations in depth and concentration differences in suspended matter, such as plankton and suspended sediments.

Many other studies have been undertaken to demonstrate the applicability of satellite data to natural-resource inventory and assessment. Liere (1973), for example, used ERTS imageries for water-resource planning in the Lower Mekong basin and demonstrated that spacecraft are providing data from areas which have been inaccessible in the past. Included is information on the mechanism of flooding and drainage of the delta, changes in siltation and salinity in the lower delta and fisheries in the estuarine areas. The repetitive coverage by satellites makes the data particularly valuable in studying the gradula transformation of changing regional features.

Fig. 7. Near coastal view of Delaware and Delaware Bay, Goddard Space Flight Center identification number 73-9250, as obtained with ERTS-1 in band 5 on 10 October 1972.

Paulson (1974) used the Data Collection System (DCS) aboard ERTS-1 and telemetred data from ground based data-collection platforms in the Delaware River Basin and included stream-gauging stations, ground-water observation wells and monitors to survey the water quality. Salomonson and Greaves (1974) demonstrated that earth-orbiting satellites are able to monitor the effects of man's activity on water and marine resources, because of their repetitive survey capability. In addition, the DCS was proved to be a reliable tool for gathering hydrological data from remote regions. On-site information is also being collected and relayed via satellite to water-resources management agencies (Salomonson and Rango, 1974).

Use of ERTS images in the field of geology and water resources was tested by Akhavi and Ebtehadj (1973) for the purpose of mapping natural resources. A number of geological and hydrological features, such as unknown faults, streams and lakes, were mapped. More detailed information can be detected from the original computer-compatible tapes as recorded by the multispectral scanner on ERTS-1. Yarger and McCauley (1974) used passes over Kansas reservoirs and demonstrated that sun angle and atmospheric conditions have to be considered if ERTS data are to be used for water-quality evaluation.

Geological evaluation of ERTS-1 imagery over diverse geological terrains can also be applied in coastal regions. For instance, geological mapping of terraces of New York State revealed bedrocks and surficial geological information (Isachsen et al., 1973). Such information can also be used in the exploration of minerals and petroleum (Saunders et al., 1973).

Due to the ground resolution of recent satellite technology, living resources such as fish shoals cannot be directly detected. However, environmental factors, which can be correlated with the appearance of marine resources and which can be monitored from space, provide reliable sources of indirect information. Sharma et al. (1973), for instance, investigated water and sediment movements and factors controlling sea mammal distribution.

Kemmerer and Benigo (1973) attempted to relate satellite-acquired imageries to selected oceanographic parameters. Initial results demonstrated that information monitored from space might have important implications for fisheries-resource assessment in the Mississippi Sound and adjacent offshore waters. In the same analysis, relationships were established between water transparency, as established from ERTS-1 data, and fish availability.

An investigation to establish the feasibility of using data acquired from orbiting satellites to determine the distribution and abundance of oceanic gamefish has been undertaken by Savastano et al. (1974). Stevenson and Pastula (1973) used data from ERTS-1 to examine factors affecting living marine resources in the Mississippi Sound. Preliminary results indicated a correlation between back-scattered light and water transparency, changed by chlorophyll and other materials. This allowed eight empirical menhaden distribution models to be constructed, taking into consideration parameters such as water depth, transparency, colour and salinity at the surface, thus demonstrating the potential for the management of natural marine resources. Maughan and Marmelstein (1974) in relating ERTS-1 data to transparency and depth of the water also concluded that remotely acquired data can play a role in commercial fisheries.

Besides the interest in monitoring ice conditions for marine traffic, sea-ice conditions are of special scientific interest because they can act as carriers of

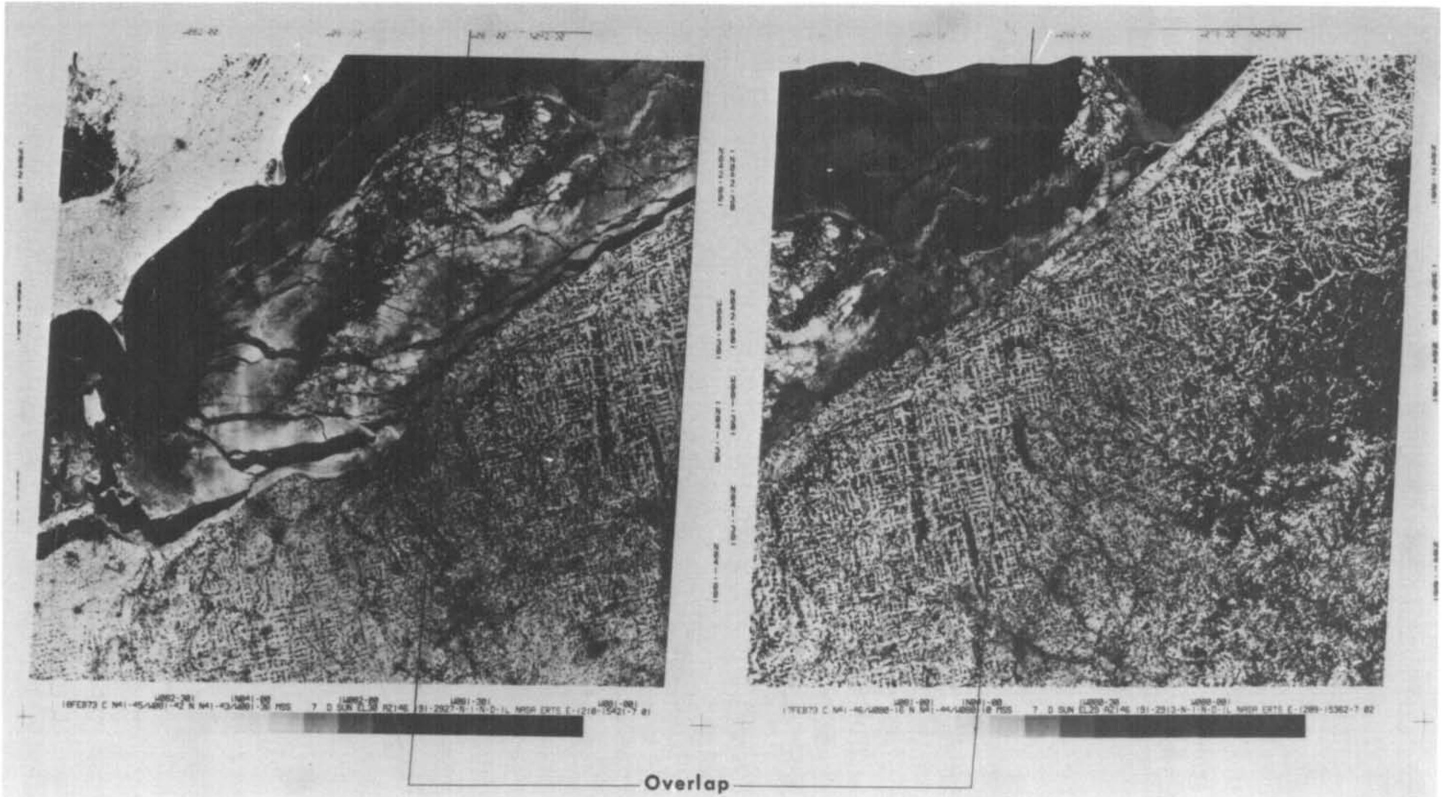


Fig. 8. Twenty-four-hour breakup of ice on Lake Erie as imaged by ERTS on 18 February 1973 (left) and 17 February 1973 (right).

sediments and may influence the water circulation as well as changing the hydrography (Barnes and Reimnitz, 1973). Patterns as detected in ERTS-1 imagery showed a close relationship between geomorphic processes and the influence of sea ice along Alaska's northern coast. Sea ice is detectable in all the MSS channels but the near-infrared measurements provide the most detail. Barnes and Bowley (1973) identified ice flows, pack ice, ice belts, brash ice, fast ice, leads, fractured, cracks, puddles, thawholes and flooded ice. Classification of the ice types is based upon the multispectral component in the ERTS data. Fig. 8 gives in example of how the ice patterns can be viewed from space. During the break-up, the pattern of ice distribution changed considerably during a 24-h period.

Hult and Ostrander (1973) investigated the applicability of ERTS to Antarctic iceberg resources and the possibility of determining environmental conditions which might influence the harvesting of icebergs.

Additional investigations have applied ERTS data to polar-region studies. Graves (1972) used ERTS data for ice detection and map correction. MacDonald (1973) examined the cartographic application of ERTS' RBV imagery in polar regions, and demonstrated that detected changes in the northern limits of the ice shelves as well as the discovery of unmapped geographic features in Antarctica were possible with the use of satellite imagery. Features such as glaciers, ice tongues and ice shelves were monitored for changes in sice, shape and position.

MANAGEMENT

ERTS data were applied to the protection and management of the New Jersey (U.S.A.) coastal environment (Yunghans et al., 1974). It was demonstrated that rapid access to ERTS data resulted in the application of computer-compatible tapes within 60 h following the overpass. This operational demonstration of the rapid availability of satellite data and subsequent data processing illustrated the application of spacecraft data to environmental protection and management programmes. Within these programmes, computerized analysis techniques have been used for the recognition and monitoring of offshore waste disposal, drift direction and speed and the dispersion rates in the New York Bight area. For example, the density slicing from ERTS data was used to identify the intensity level of waste.

Verger and Demathieu (1973) used ERTS data to study the ocean front of France between Cap Gris-Nez and south of Arcachon. An assessment of ERTS-1 imagery, as an aid in land-resource planning, was reported by Keech et al. (1974). Land-use maps were prepared at a medium scale and some vegetation complexes could be defined with the spacecraft data.

ERTS imageries were used for the cartographic mapping of land, at a scale of 1 : 500,000 by Mooneyhan (1973). The map was used to complement existing line maps and to support the revision of existing maps. Objects as small as 100 m in diameter, and linear features as narrow as 15 m, were detected. In conjunction with automatic pattern recognition, schematic land-use categories could be established. For instance, in urban areas three to four different categories were mapped.

For producing classification of imageries and thematic maps, digital data from ERTS are processed using ground-truth observations during the overpass (Conrod, 1973). The procedure can be handled by contracting the processing, which means that the results may be obtained by personnel who are data users and not data-processing specialists. Klemas (1973) applied the classification imagery for ecological, geographical and oceanographic investigation in the Delaware coastal resource planning. The results obtained by analysis of digital ERTS data are:

(1) Statistical outputs indicating the reliability of discriminating eight coastal vegetation and land-use classes on a given group of training sets which included:

(a) mean and standard deviation of response in each class chosen,

(b) contribution tables indicating importance of each channel in discriminating each thematic class from the background,

(c) Scatter diagrammes showing relationships of thematic spectral signatures in spectral space, and

(d) classification table showing reliability (in per cent) of identification of each thematic class;

(2) Thematic colour maps at a scale of 1 : 1,000,000, showing vegetation and land-use categories for Delaware's entire coastal zone; and

(3) Thematic computer plots at specified smaller scales (i.e., 1 : 24,000) for comparison with existing map data such as U.S. Geological Survey topographic maps.

A thematic map obtained from ERTS data is shown in Fig. 9 and demonstrates that the main features can be recognized as in high-altitude aircraft photographs.

Kritokos et al. (1974) used the magnetic digital tapes of the imagery obtained by ERTS for an analysis of resuspended solids in the Potomac River. Channel 6 was used to determine the water-to-land interface while in channel 5 the existence of three distinct water masses could be detected. Greater reflectivity correlated with high concentrations of suspended solids and regions of low-reflectivity could be identified as having lower concentration of particulate material. In another study using ERTS imagery, recognition of beach

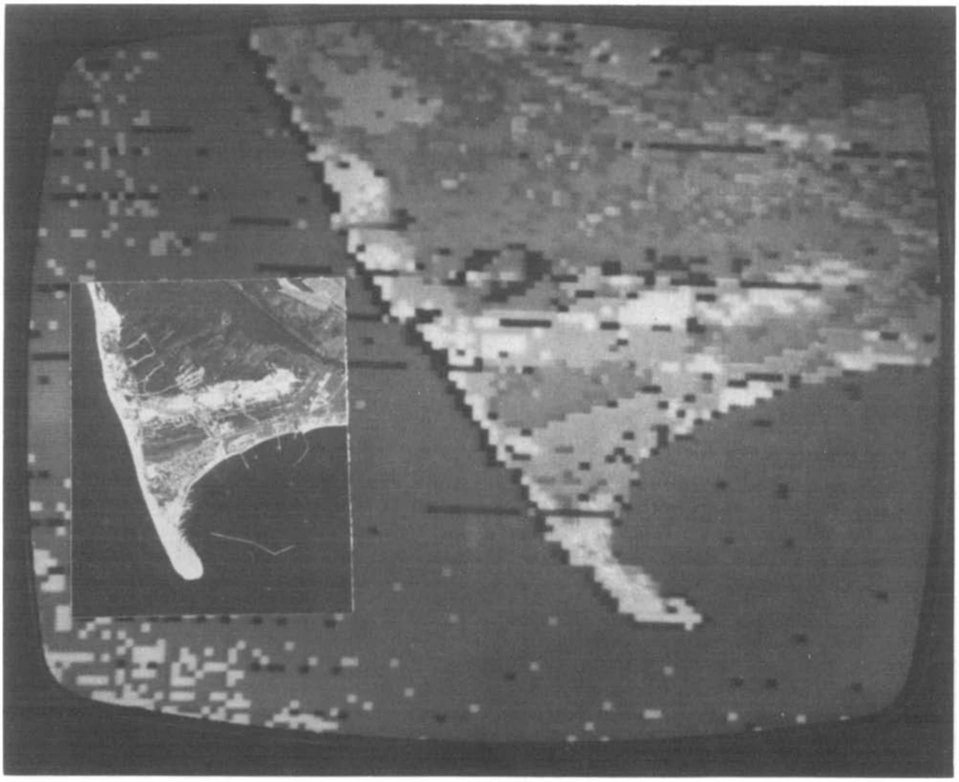


Fig. 9. Thematic map of near coastal areas in the vicinity of Delaware Bay. The insert shows the same area as mapped from a high flying aircraft.

and nearshore deposition features of Chesapeak Bay (U.S.A.) was reported (Kerhin, 1973).

Littoral drift and the recognition of sedimentation patterns have led to the evalution of beach and nearshore features in areas of little or no data. ERTS multispectral scanner data were used by Flores et al. (1973) for the classification and determination of the areal extent of coastal features on the Texas (U.S.A.) coast. Features such as water masses, salt marshes, beaches, forest and vegetation and exposed soil or construction material could be analyzed. The accuracy of the measurements of the percentage of wetland along a salt-marsh boundary ranged from 89 to 99%.

WATER QUALITY

From the distribution pattern of particulate matter in water, conclusions have been drawn concerning the circulation of water masses in near-coastal areas. Magoon et al. (1973) concluded that the data from different spectral bands, when used in conjunction with other available data, are very useful for studying coastal processes and for coastal-engineering planning in the Indian River inlet (Delaware, U.S.A.)

Similar analysis was done in near-coastal waters in Alaska where water flow was inferred from the plume shape of suspended material. Differentiation between water masses was also detected in channel 4. Suspended sediment plumes which were generated by the Welland Canal and the Genesee River were identified by Pluhowski (1973). Although the Niagara River discharge could not be detected in any of the ERTS-1 frames, the river discharges from the Oswego River was identified after storms but was not visible during low flow periods, showing that high turbidity levels are created by storm runoff.

Sediment distribution and coastal processes in Cook Inlet, Alaska, were investigated by Anderson et al. (1973). The coastline configuration was well defined in the red band while in the near-infrared band, current patterns were visible which were attributed to different concentrations of suspended sediment.

Oceanic turbidity and chlorophyll, as inferred from ERTS-1 observations, were reported by Curran (1973). Curran compared surface ship measurements of chlorophyll concentration with the ratios of channels 4 and 5, as obtained from the ERTS-1 multispectral scanner. It was concluded that the plankton distribution found with ERTS-1 was comparable to the ship measurements.

Bowker et al. (1973) correlated ERTS multispectral imageries with suspended matter and chlorophyll in lower Chesapeake Bay. While greater detail in the distribution pattern of suspended material was revealed by the multispectal scanner in channel 5, near-surface suspended material associated with chlorophyll was observed in bands 6 and 7. The discharge of sediment-loaded water from the James River entering the Chesapeake Bay could be traced as a plume along the shore extending seaward of Cape Henry and variation in turbidity in the lower bay could be related to a strong tidal current. The author pointed out that the MSS imagery could be used in monitoring the character 8 estuarine water for the assessment of siltation, productively and water types. Similar conclusions were drawn by Klemas et al. (1973), by using satellite imagery of Delaware Bay during different tidal cycles.

Sea surface circulation, as indicated by the sediment distribution and as monitored from ERTS, was investigated by Wright et al. (1973) in Cook Inlet, Alaska. A high turbidity stream entering the upper inlet provided a tracer for the circulation in the inlet and channels 4 and 5 were used to plot sediment and pollution trajectories. In another study, the distribution of suspended sediment in the Gulf of Mexico, off the coast of Texas, was examined (Hunter, 1973). A general decrease in turbidity in the offshore direction was noted, while more complex concentrations of sediment could be classified as plumes of bands. Separate plumes from river outlets were caused by tidal action especially at the end of a tidal cycle when the plumes became detached from the river outlets. Data from the Return Beam Vidicon Camera (RBV) were analyzed while a shell-dredging barge was operating in Tampa Bay, Florida (U.S.A.). The pathway of the dredged material could be recognized at each RBV band.

UPWELLING AND CURRENTS

Nearly 90% of the world's fisheries are in near-coastal waters and in connection with upwelling ecosystems (Ryther, 1969). Although only a small percentage of the world's oceans are considered as upwelling regions, they are the major fishing grounds in the world, e.g. off the coasts of Peru, north-west Africa, Somalia and south-west Africa.

For better management of fishing resources, the monitoring of the upwelling areas with chlorophyll-sensing and measurements of additional parameters, such as temperature, to understand the fluctuations in biomass as a function of time and space, are a very promising approach. Estimation of biomass in upwelling areas, including the dynamics of environmental factors, and the determination of the time required for changes to affect the biomass, are criteria for evaluating the potential use of an oceanic region.

An example of sea-surface temperature change in the upwelling area of the Somali coast is shown in Fig. 10. By periodic comparisons, data could be developed on the response time of chlorophyll and biomass production to change in environmental factors, including pollutants. Such information is very difficult to obtain from sporadic and scattered ship observations.

Düing and Szekielda (1971) used infrared data to demonstrate that the response time of current systems and upwelling to the wind field can be monitored from orbiting platforms (see also Warnecke et al., 1971; Szekielda, 1972). This plays an important part in monitoring fishery potential as well as the management of near-coastal processes. Although individual temperature measurements from space are still less accurate than the conventional measurements (Szekielda, 1973), repeated coverage of a test site with multispectral sensors or the application of statistical methods leads to more precise data (Smith et al., 1970; Shenk and Salomonson, 1972; Szekielda et al., 1974).

Fig. 11 is a typical example of a synoptic view of the temperature patterns viewed from spacecraft altitudes over the cloud-free regions of the Gulf Stream. It must be stressed that the position of sharp temperature gradients over a large area cannot generally be determined by classical ship measure-

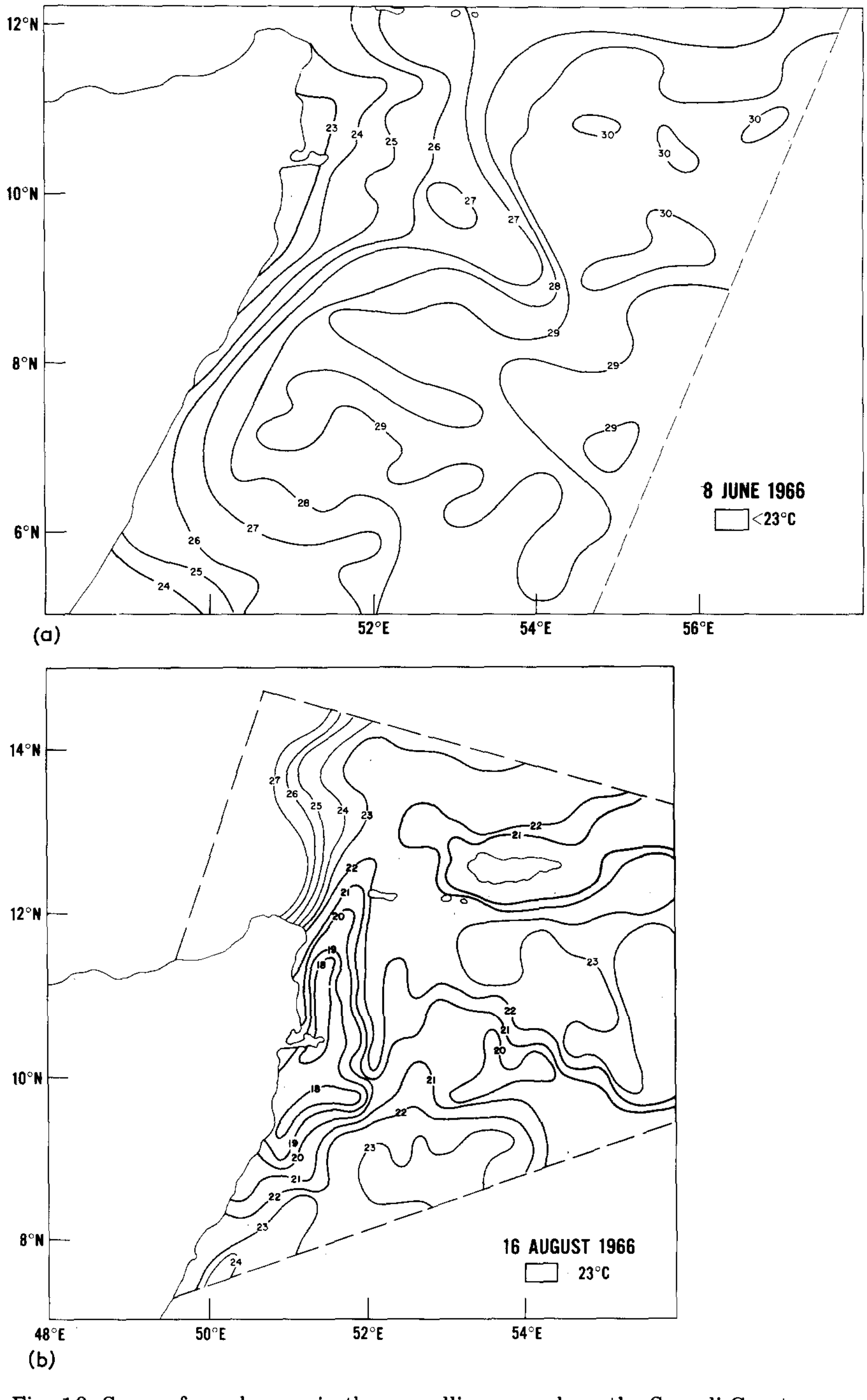


Fig. 10. Sea surface changes in the upwelling area along the Somali Coast as monitored by Nimbus II, 1966. (a) June 8, 1966; (b) August 16, 1966.

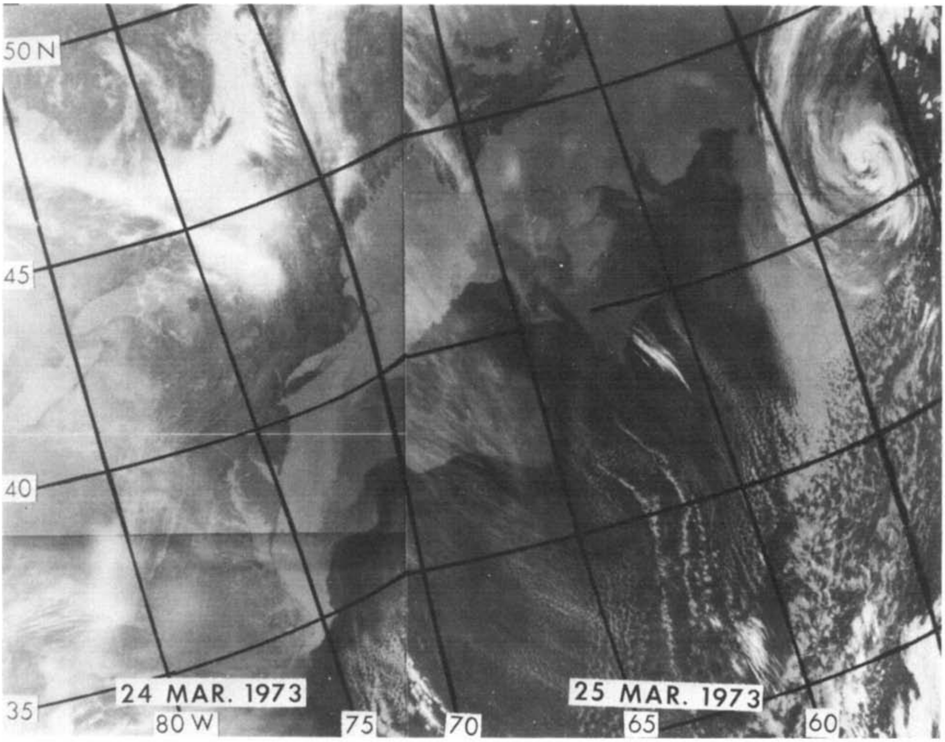


Fig. 11. Synoptic coverage of the Gulf Stream near the east coast of the United States as viewed from NOAA-2. The distinct gradient between the dark and the light areas represent the north wall of the Gulf Stream. Note the strong meandering and the patchiness in temperature distribution. Analysis done by Dr A. Strong (NOAA).

ments. Certain other phenomena can be used indirectly to examine oceanographic conditions. Cloud distribution, for instance, depends on the wind field, water temperature and near-coastal features. The Somali coast is a good example, where the presence of upwelling is reflected in the distribution patterns of clouds. Fig. 2 shows the cloud coverage for the Northern Arabian Sea. The time between May and June is known as the transition time, when the NE monsoon changes to the SW monsoon. Since the response time of the upwelling to the SE monsoon is only a matter of days, we can derive from the synoptic cloud distribution the onset of the SE monsoon and the presence of upwelling. The importance of such obserbations is the fact that with the start of upwelling more biomass is available to grazing organisms.

Repeated coverage by ERTS-1 in the upwelling area along the NW coast of Africa demonstrated the possibility of using spacecraft data to locate plankton blooms and the changes in position of patches (Szekielda, 1974). An

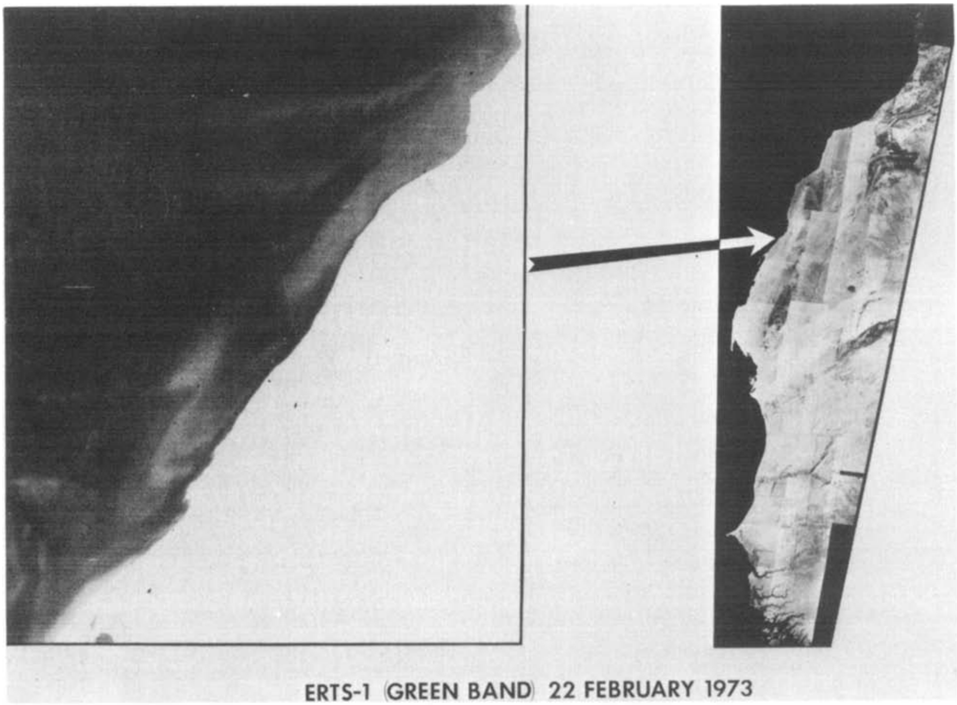


Fig. 12. Upwelling and plankton patterns, north-west Africa.

example of the patterns observed in the upwelling area is shown in Fig. 12.

From the ERTS programme, flow patterns and the direction of sediment-loaded surface water could be correlated with the major current systems. Maul (1974) used computers and enhanced images to observe the loop current by colour or sea-state effects which are associated with the cyclonic boundary. The observations were in agreement with experimental measurement. In another study, Maul (1973) located the cyclonic edge of the current by surface chlorophyll concentration which contributed to the shift in colour from blue to green in the open ocean. He observed that sea state in the current is frequently higher than in the surrounding waters which have different reflecting properties.

Upwelling and cold-water eddies were investigated by Strong et al. (1972) with the NOAA environmental satellite. Upwelling off Mexico's Pacific coast has been detected and cold eddies off Cape Hatteras have been tracked as they move soutwest in the Sargasso Sea.

Satellite imagery was also used by Teleki et al. (1973) in the Gulf of Carpentaria (Australia) to study the nearshore circulation and demonstrate that sediment disposal can be studied and mapped on a seasonal basis. The author identified the transport direction for coastal sediment and confirmed a hypothesis about the bidirectional nature of non-tidal currents along the east coast of the Gulf.

Richardson et al. (1973) observed Gulf Stream eddies in the western Sargasso Sea. A cyclonic Gulf Stream eddy was tracked by infrared data and the observations over a time period of 14 months indicated that the eddy moved southwestward at an average speed of one mile per day. Strong and DeRycke (1974) employed the visible channel on the NOAA-II satellite to observe the shoreward edge of the Gulf Stream from Florida to Cape Hatteras. The visible pattern was due to an abrupt change in sea surface roughness as a result of the opposition of waves propagating against the flow of the Gulf Stream.

ECONOMIC EVALUATION OF REMOTE SENSING DATA

Studies relating to cost were done on the ERTS-1 programme but those conducted prior to the launching are not very relevant because of broad generalizations and of the speculative nature of the studies. Studies conducted after the launching are more realistic and are summarized in a report by the United Nations (1975). Specific coasts were given in this report which, however, cannot be applied to all regions. For instance, the reconnaissance of ice conditions by satellite is of importance specifically for countries in the high latitudes, having marine transportation problems, like Canada, U.S.A. and the U.S.S.R.

For developing countries, Summers et al. (1974) reported preliminary results of a study which was conducted under the sponsorship of the US Agency for International Development (AID) to assess the benefits and costs of the utilization of ERTS data. The study focussed mainly on rice crop forecasts, range-land management, watershed management and cartographic mapping. For range-land management in Kenya, for instance, the benefits over a 20-year period were estimated to be about $8—26 million.

Price estimates of aircraft and satellites for operational earth resources systems were reported by Cheseman (1973). Data pertaining to satellite costs are given below.

	Cost (million $)		
Satellite:	low-altitude	geostationary	data-relay
Recurring procurement costs plus launch vehicle	14.5	.50	15
Command and control operations costs per year	1	1	0.5

Although many countries are not able to invest the capital necessary for the development and the operations of satellites and launch vehicles, they may nevertheless benefit from spacecraft remote-sensing programmes, i.e., by collecting data from ground stations. Imageries produced from satellites are also available at a low price. Morley (1972), for instance, reported that the Canadian Air Photo Library markets 9-square inch black and white prints for U.S. $1 each, a black and white transparency for $2, and a colour transparency for $3. Imagery materials may be obtained from other sources, such as the National Space Data Bank which guarantees the supply of spacecraft data at a low price.

Hindrances, based mainly on lack of information, can be overcome by broader application of spacecraft data. The customer profile for data request in Fig. 13, established by the United States Department of the Interior (EROS Data Center, Sioux Falls, South Dakota), shows that a total of 129,288 frames for the period July 1973 to December 1973 were acquired. The main user community can be identified as private industry which is closely followed by the U.S. Federal Government. Foreign participation in

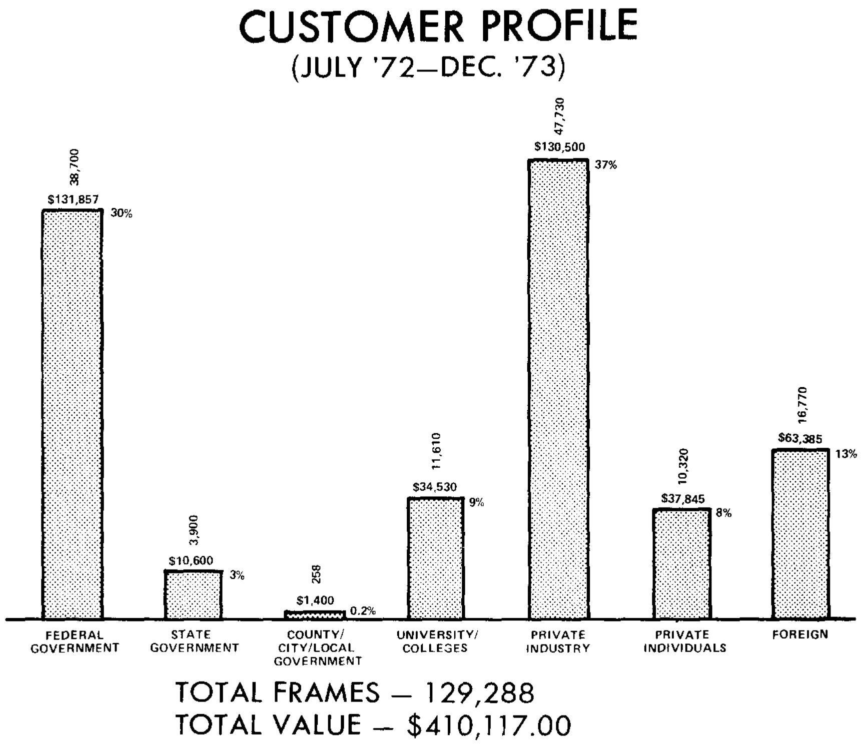


Fig. 13. Customer profile of the EROS Data Center.

the use of spacecraft data is only 13%. No further breakdown is indicated in the graph in Fig. 13, but it is known that Canada, Europe, Japan and Australia were the main foreign customers for the 16,770 frames during the investigated period of time. Therefore, developing countries represent only a very small fraction in the customer profile. Measures to be undertaken to increase the participation of developing countries are of interest for the countries launching spacecraft and processing the obtained data, as well as for the developing countries themselves. In order to transfer knowledge of applied spacecraft data in management programmes for coastal areas, it is more desirable to establish concrete demonstration projects where developing countries can integrate satellite information into their planning.

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