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APPLICATION OF NASA ERTS-1 SATELLITE IMAGERY IN COASTAL STUDIES

by

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ABSTRACT

The NASA Earth Resources Technology Satellite (ERTS) program has been developed to help provide for efficient management of the earth's resources. To achieve this objective, the first satellite, ERTS-1, was launched into orbit in late July 1972, and furnishes repetitive, high resolution, multispectral imagery of the earth's surface on a global basis. Review of the imagery indicates that it contains information of great value in coastal engineering studies. This paper gives a brief introduction to the methods by which imagery is generated, and examples of its application to coastal engineering. Specific applications discussed include study of the movement of coastal and nearshore sediment-laden water masses and information for planning or construction in remote areas of the world.

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INTRODUCTION

The ERTS-1 observatory satellite, figure 1, utilizes two primary sensor systems, a multi-spectral scanner (MSS) with four channels and a return beam vidicon system (RBV) with three channels. Additionally, the satellite carries a data relay system. The RBV and the MSS furnish independent views of the earth directly below the satellite to data acquisition stations on the ground. Two wide-band video tape recorders will store up to 30 minutes of imagery gathered outside the range of these ground stations for delayed readout.

The overall ERTS mission requirements were established to give synoptic, repetitive coverage, and also a reasonable resolution capability. These requirements, together with consideration of space-to-ground communication, led to the selection of a sun-synchronous orbit at an altitude of about 500 nautical miles. Orbit track over the ground is shown in figures 2 and 3.

The MSS collects data by continually scanning the ground along a line directly beneath the satellite, and transverse to the orbit, figure 4. The width of the strip is identical to the coverage by the RBV, 100 nautical miles. Optical energy is sensed by an array of detectors simultaneously in the four spectral bands shown on figure 5. During processing, frames 100 nautical miles square are constructed from the continuous strip to correspond with the RBV information. The image sidelap is approximately 14 miles at the equator, at 45 degrees north or south latitude, 50 miles. The nominal scan width resolution is 88 microradians, equal to 250 feet on the ground.

The three RBV cameras view the same ground scene from the observatory, figure 6, but are sensitive to different spectral bands within the total region from 0.48 to 0.83 micrometers, figure 5. The cameras are shuttered, and images are stored on photosensitive surfaces within each vidicon camera tube, then scanned to produce video outputs. The cameras are scanned in a sequence requiring about 3.5 seconds to read out each of the three images. The shutters of the RBV cameras have been timed to take pictures every 25 seconds which results in approximately a 12 nautical mile overlap in the direction of flight.

RBV and MSS data are transmitted via dual wide-band (20 MHz) data links to the tracking stations where they are recorded on magnetic tape. These tapes are then shipped daily to the NASA/Goddard space flight facility in Washington, D.C. The U.S. Geological Survey, EROS Data Center, Sioux Falls, South Dakota, 57198, makes available copies of all imagery in the form of high quality film or prints for inspection and sale.

Prior to the availability of ERTS imagery it was practically impossible to compile aerial mosaics over large reaches, especially over water. This was because of differential lighting as recorded from typical aircraft platforms. Further, it should be stressed that it is possible to extract a great deal of relevant information from ERTS imagery without laborious and expensive photographic and computer enhancements and processing. The available bands of ERTS imagery should be examined separately, in combination, and in conjunction with other existing data such as navigation charts noting differences and similarities in order to draw rational conclusions concerning the recorded scenes.

ERTS-1 data provides synoptic, multispectral images which can be used in a wide variety of applications. Of particular importance in oceanographic applications is the water penetration capability in the seven sensor channels. A simple quantity related to water penetration capability is the total light attenuation coefficient; data on this coefficient in clear water at the wavelength of maximum sensitivity for each of the seven sensor channels is given in table 1 (after Polcyn & Rollin[2]).

ERTS systems and uses are described in detail in references 3 and 4. General coastal engineering applications are described in references 5, 6, and 7.

TABLE 1

LIGHT ATTENUATION COEFFICIENT IN CLEAR WATER

Sensor Channel (NPDF)	Wavelength of Peak Sensitivity, μm	Attenuation Coefficient, m^{-1}
RBV 1	0.56	0.06
RBV 2	0.59	0.08
RBV 3	0.70	0.5
MSS 4	0.54	0.04
MSS 5	0.64	0.2
MSS 6	0.73	1.0
MSS 7	0.82	2.0

Ref: After Polcyn & Rollin, 1969.

COASTAL WATER MOVEMENT

One of the applications of ERTS imagery is in the study of coastal water movement. Figures 7 and 8 show the location of Admiralty Inlet, Alaska. Note that the inlet consists of a deep gorge and connecting channels, the location of Brady Glacier just inland and to the north of Admiralty Inlet, and the location of Bernes Bay. Figures 9, 10, 11, and 12 show MSS channels 4 through 7, respectively, of this same scene. It can be seen that the turbid water from Brady Glacier and other sources is shown to the greatest extent in MSS 4; is decreased in MSS 5; is barely noticeable in MSS 6; and has essentially disappeared in MSS 7. The reason is that the higher MSS numbered bands are in the infrared region and have relatively little water penetration. MSS 7 being the farthest in the infrared has practically no water penetration. This image then provides an ideal way to delineate the "triple line" which is defined as the projection of the land-sea-air interface in the horizontal plane. Note also that in the Bernes Bay area where sediment is shown as being derived from a discrete source such as the narrow channel at the right center margin of figure 9 (MSS 4) and flowing into Lynn Canal, the direction of water movement carrying this sediment away from the source may be easily inferred. Repeated coverage of a given location compared with a study of other environmental variables could give a reasonable model of sediment movement and water circulation in the vicinity of known sources of natural pollution.

A second example of sediment plumes in the water is noted along the Alaskan coast adjacent to Admiralty Inlet in the vicinity of Lituya Bay, shown on vicinity map, figure 7. The general ERTS view (MSS 5) shows a long finger-like plume extending some 40 miles seaward of the coast just south of Lituya Bay, figure 13. The Brady Glacier plume is clearly traced some 10 miles seaward of the inlet. An enlargement in the vicinity of Lituya Bay is shown on figure 14. The coastal sediments entering the water can be traced to areas relatively close to the shore. A well defined plume of turbid water associated with the Alsek River is clearly inferred to be moving to the northwest. It is particularly interesting to note that the water masses south of Lituya Bay abruptly turn seaward and extend in a jet-like plume. It is conjectured that the sediment laden jet of water may indicate circulation patterns or currents extending great distances seaward from a coast and may have application to the "home stream" concept of anadramous fish migration (8,9,10); which simply stated is "that the species (i.e. salmon) each consist of a large number of independent local populations or races and that the adults return from the ocean predominately to the streams of their nativity".[10] The north-south trending streaks are clouds. The thin straight cloud is probably a condensation trail left from an aircraft. In the black & white image the clouds are inseparable from the sediment, but in the multiband composite of figure 18, the clouds and sediment are clearly separable by color differences.

Coastal sediment plumes that are relatively short and well-defined along the Pacific coast of Mexico between Punta San Telmo and Punta Mangiove, figure 7, are shown on figure 15 with an enlargement on figure 16, from MSS 5. Enhanced views processed by Steller[11] (North American Rockwell Corporation) are shown in figure 17 (Mexico) and in figure 18 (Alaska).

NEARSHORE MEASUREMENT PROGRAMS

Inspection of ERTS-1 multispectral scanner output has confirmed the value of this imagery for synoptic monitoring of various nearshore oceangraphic processes. Two examples of large-scale fluid mixing phenomena in shallow waters are discussed. In each, sharply defined gyres of suspended sediment delineate the boundary between waters with evidently quite different characteristics. The occurrence of such features can be of great importance in designing and interpreting nearshore oceanographic measurement programs.

Figure 19 presents a mosaic of two MSS 4 images of an area on the north coast of Siberia, located on figure 7 and shown on the vicinity map of the Laptev Sea, figure 20. The interface between waters of markedly different turbidity shows large-scale undulations, and a narrow surface streak (probably ice) extends from the center of the strait at the right (between the Laptev Sea to the west and the east Siberian Sea). Figure 21 presents an enlargement of MSS 4 along the interface. Figure 22 presents a color enhancement compiled by NASA/Houston[12] using MSS 4,5, and 6. The corrugations at the edge of the turbid water mass have a scale of about 5 miles while the strait approximately is 15 miles wide. These figures suggest that sediment-laden water has flowed westwardly through the Strait Dmitriya Lapteva to the Laptev Sea.

Figure 23 reproduces a composite of two MSS 4 images of the Colorado River flowing into the Gulf of California and figure 24 reproduces a composite of two images slightly further south in the Gulf of California (29 September 1972) ; each area shown is located on figure 7. Note that the structure of the suspended sediment pattern in the overlap area is quite different on the two days. It is interesting that such well-defined mixing structure was not detectable in conventional color and color infrared photographs taken by astronauts of the same area,[13,14] although large-scale fluid mixing phenomena have been recorded, e.g., in the well-known Gemini photographs of the surface gyre on the Salton Sea[15] and in the flow patterns of clouds around islands.[16]

Such flow patterns, recorded with suspended sediment as a tracer, have implications in planning nearshore measurement programs using point sensors of oceanographic variables. It is interesting to note that Stewart[17] indicated that oceanographic data collection programs using widely spaced buoys may have difficulty in describing the ocean environment due to the relatively fine structure of some oceanic processes. The use of ERTS imagery can aid in the design of such programs and can assist in interpreting the significance of the measurements obtained.

CONSTRUCTION & NAVIGATION INFORMATION

As reported in Engineering News Record, Magoon[18] has suggested that ERTS imagery will be helpful to the construction industry in preparing bids because of the timeliness of the data recorded. It should be added that the synoptic coverage of this imagery and its repetitive nature will also be of great value. Another useable aspect will be in correcting and updating navigation charts of coastal areas not normally visited by oceanographic or hydrographic survey ships, where construction, trading or research projects are contemplated.

An example of such use was observed in imagery of an area of the tropical Pacific near latitude 2° N, longitude 126° E shown on figure 7.

The archipelago in this area is known as the Sangi (or Sanghie) Islands and is shown on U.S. Navy Hydrographic Office (H.O.) charts 1727 and 3056. The Sangi Islands are roughly oriented in a north-south azimuth and lie between Mindanao of the Philippine's Republic and The Celebes. The particular islands selected for detailed examination are three small islands known as Pulau Tahulandang, Pulau Ruang and Pulau Pasige shown on the vicinity map of figure 25. Navigation instructions and general descriptions of the area are contained in U.S. Naval Oceanographic Office Sailing Instructions.[19]

As described, these islands are volcanic in origin with very deep waters close to shore. It should be noted, that the narrative description of the three islands is contained in eight short paragraphs; revealing the lack of detailed information. A portion of the Sangi Islands is shown in figure 26.

Enlargements from the original frame in the four MSS bands with a vicinity map are shown in figures 27-31. In examining these photographs it seems best to start with MSS 7 which shows the strongest contrast between land and water masses and closely resembles available maps. In this enlargement figure 27, the most southerly island of the group,Pulau Ruang, reveals a narrow, incised body of water on its eastern shore that is not indicated on figure 31. Since information shown on the chart is based on data collected on March 1939 and updated in June 1966, a major change in the land mass has occurred which may have been caused by volcanic action or major erosion of the island which destroyed a portion of the mountain or volcanic crater composing the island. Other than this the photograph generally agreed with the chart.

Comparison of MSS 6 to MSS 7 shows some subdued but striking differences. Since these islands are located in the tropical Pacific, it should be expected that coral reefs would be present, and this is confirmed by the information shown on the chart and in The Sailing Directions. Faint white lines, indicating coral reefs or waves breaking on such reefs are shown completely around Pulau Pasige and on the northwest and south coast of Pulau Tahulandang. The bay previously discussed on Pulau Ruang now appears to have a different tone indicating either recent coral growth or deposition of eroded sediments in the nearshore area. The shape of this area is slightly triangular, which indicates a deltaic formation probably confirming the latter supposition.

The limits of the fringing coral reefs and impounded lagoons is clearly defined in MSS 5. The bay on Pulau Ruang now exhibits more strongly the deltaic formation indicated on MSS 6. Also, the north and easterly shores of Pulau Tahulandang, the largest of the islands, shows no indication of coral reef development. This may be interpreted that these portions of the island undergo somewhat constant wave action of relatively high energy. A subjective conclusion indicating the direction of predominant wave action.

The full extent of the fringing coral reefs is clearly shown in MSS 4.

BREAKING WAVES

Preliminary review of ERTS imagery indicates that coastal waves are not positively identified. Areas of breaking waves, however, which extend along reef areas or shoals appear to be visible under appropriate conditions. Figure 32 presents an MSS 5 image of the coast of Mozambique. This area is located on figure 7 and shown on vicinity map figure 33. Note the shoal areas extending at an angle to the coast in the lower left-hand portion of the image. Similar examples of breaking waves are seen on fringing reefs in the Sangi Island images previously shown.

REGIONAL VIEWS

An obvious application of the ERTS-1 imagery is in obtaining regional views of extended coastal areas. An example of this is an area shown on figure 7 and figure 34. This mosiac is made of a color composite (formed from MSS 4,6, and 7) of a portion of the United States east coast. Note that a linear demarcation landward of the New Jersey coast is seen. It is thought that this represents an ancient shoreline feature. Additionally, in an area seaward of New York City there appears an unusually shaped pattern. Detailed examination of the four MSS images (figures 35-38) have indicated that this pattern is the result of waste disposal.[20,21]

BARRIER ISLANDS

Of the major types of natural protection to the shore and thus of great interest to the coastal planner and coastal engineer are the barrier islands. Due to the large extent of these islands it is relatively difficult to obtain good synoptic coverage of major portions of these islands after severe storms. One important use of ERTS will be in studying the changes of barrier islands after severe storms and hurricanes. Some idea of the capability of ERTS to resolve small features is shown on a series of scenes taken at Indian River Inlet on the Maryland Atlantic Ocean coastline, figure 7. Figure 39 is a view of Indian River Inlet taken from high ground on the north side of the inlet and looking toward the south. Figure 40 is a low level aerial oblique photographic view of the inlet as viewed from the south. Note that the beach is offset on the south side and extends considerably more seaward than that on the north. Also the landward portion of the inlet is generally arrow-shaped with the narrow end of the inlet to seaward. A NASA U-2 color infrared image, figure 41, taken at 65,000 feet shows the coast with Indian River Inlet on the north. Both the inlet shape and offset of the beach are clearly defined. Figure 42 is an ERTS image of the same general area. The inlet shape and the offset between the north and south sides of Indian River are clearly discernible. This configuration gives an indication of south to north gross littoral movement at the inlet.

One of the important parameters that must be considered in coastal planning and design studies is the movement of littoral sediments at the reach of coast under consideration. A number of investigators have identified techniques that correlate gross littoral sediment movement with shoreline configuration. For example Galvin[22] has related gross littoral transport to four types of barrier island offset at inlets. Additionally, Silvester[23] has shown the relation of crenulate shaped bays to net sediment movement, and on this basis, suggested a model of coastal sediment movement along the coastlines of the world. Silvester's estimate was based on examination of 250 Admiralty charts. Inasmuch as ERTS imagery of coastal areas provides several orders of magnitude more information on a world wide basis than navigation charts, a set of ERTS images of the world coastlines will provide a basis for a vastly improved estimate of the net sediment movement along the world's coastlines. The NASA is obtaining such a set of images, based on availability of satellite time and weather conditions. These images will be available in the EROS data center as they are released.

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