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AN ERTS-1 STUDY OF COASTAL FEATURES ON THE NORTH CAROLINA COAST

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Abstract

Unenhanced imagery recorded by the multi-spectral scanner (MSS) of the NASA Earth Resources Technology Satellite (ERTS-1) was analyzed to determine how satellite imagery may be applied to specific coastal engineering problems. The study area of interest is a segment of the North Carolina coast comprising Wrightsville Beach, Masonboro Inlet, Masonboro Beach, Carolina Beach Inlet and Carolina Beach, which are areas of on-going research by CERC. Analysis was supplemented by underflight imagery supplied by NASA and ground truth data.

A number of significant coastal features are visible in the ERTS-1 imagery. Among these are plumes of suspended sediment emerging from inlets, changes in water coloration possibly due to effects of temperature change, and inlet bars and cape bars. In addition, morphological changes in selected coastal land features were determined by direct comparison of ERTS-1 films obtained about one year apart.

Limited water depth penetration is afforded by examining the lower MSS spectral bands. Maximum penetration can be expected to measure in tens of feet, depending on the physical characteristics of ocean water. Although not adequate if deeper penetration is desired, this capability is adequate for exposure of backshore and nearshore underwater features.

Image resolution capability is sufficient for observation of gross coastal features and processes but may not be adequate for viewing smaller features such as wave patterns, morphological features on beaches, and many engineering structures.

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Figures and Tables

Introduction

Imagery obtained by the Earth Resources Technology Satellite (ERTS-1) has been shown to be highly useful in many varied scientific and engineering applications. Evidence of this has been demonstrated by the numerous technical conferences and symposiums sponsored specifically to exploit ERTS-1 imagery and the increasing number of publications appearing in periodicals and newspapers.

Most publications describing the usefulness of satellite imagery have depended on the use of highly sophisticated and expensive equipment and complex computer analysis to derive the "significant" results published. One of the intentions of the original CERC proposal to NASA was to determine the possible use of satellite imagery in coastal engineering applications only with the aid of conventional photographic processes and equipment. It is anticipated that results of this report will be beneficial to individuals and small organizations lacking the expertise and/or financial capability to utilize sophisticated equipment and analysis techniques in order to derive useful information from ERTS-1 imagery.

The results described in this report have been documented through the use of ordinary photographic processes and access to libraries and information available to the general public. The basic data was the ERTS-1 imagery furnished by the NASA Goddard Space Flight Center. This imagery was supplemented by underflight imagery furnished by the NASA Ames Research Center and the NASA facility at Wallops Island, Virginia.

Primarily, the objective of this study is to determine if the status of the littoral regime for a portion of a coastline may be established through the use of remote sensing imagery. Secondarily, can variations of the coastal features, i.e., barrier islands and tidal inlets, be detected and measured by use of remote sensing imagery. It is also of interest to investigate the exchange of waters between the ocean and tidal areas with the ultimate goal of measuring this exchange and its contribution to the littoral budget.

Study Area

In order to have faith in the results of the imagery analysis, it was decided to choose a study area having plentiful ground truth data, preferably a coastal segment along which are sites of on-going research projects of CERC. Accordingly, a segment of the North Carolina coast including the following sites was chosen:

1. Wrightsville Beach
2. Masonboro Inlet
3. Masonboro Beach
4. Carolina Beach Inlet and
5. Carolina Beach

These sites are shown on the location map, figure 1.

In addition to being sites of active research projects of CERC, sites 1, 2, and 5 are either federally sponsored beach erosion control and hurricane protection projects or federally maintained navigation projects.

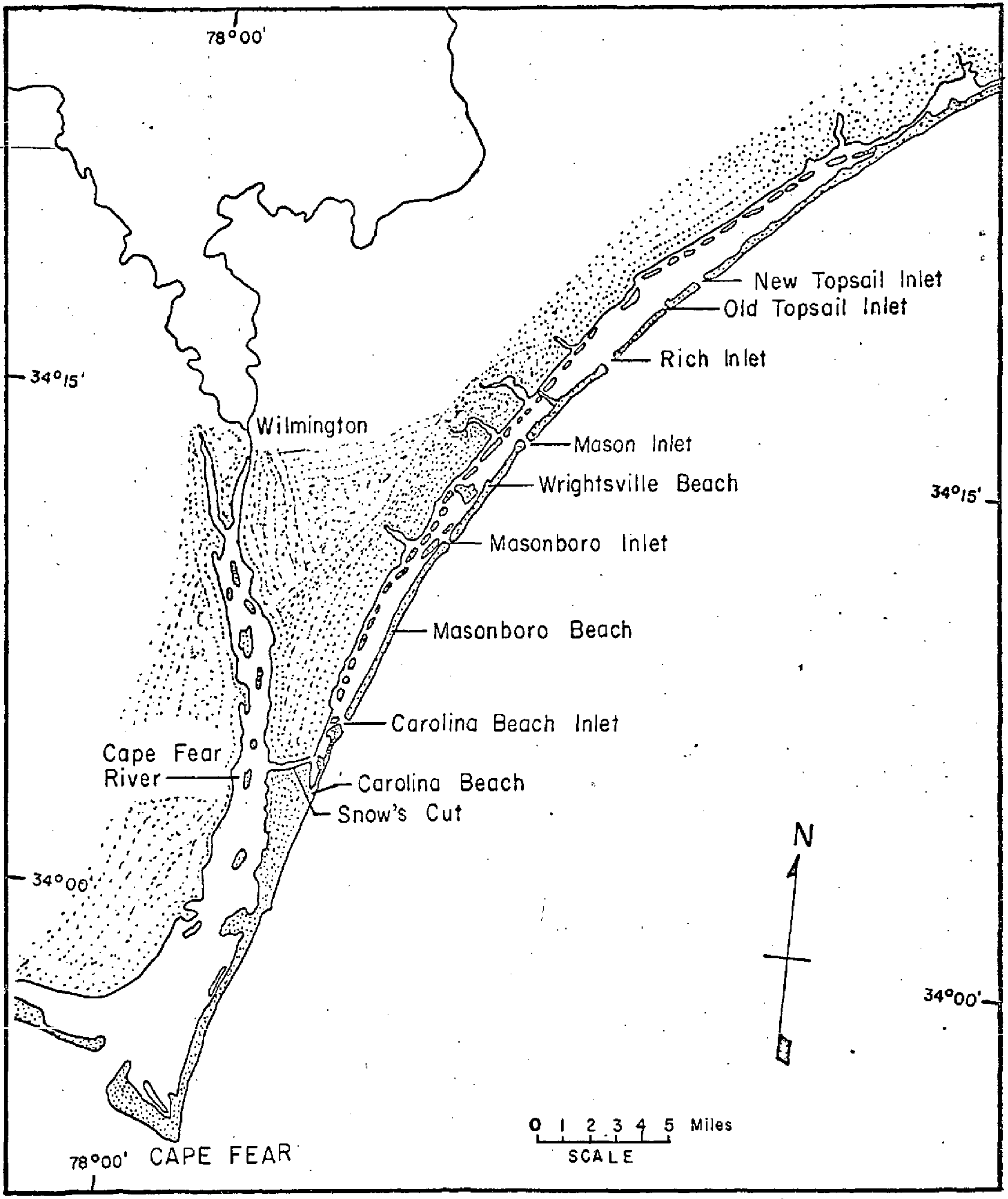

fig. 1 - Location map of study area. Traced from ERTS 1314-15210.

Studies presently underway at Carolina Beach Inlet are being pursued to establish the feasibility of controlling a navigation channel through an inlet by dredging a deposition basin in the throat of the inlet without constructing permanent navigation structures such as breakwaters or jetties. The study of Masonboro Inlet seeks to substantiate the feasibility of a new concept in jetty design, the weir jetty, involving the provision of a deposition area in the lee of the jetty for the storage of naturally moved littoral materials and periodic bypassing of these materials by ordinary dredging equipment while providing protection for navigation. Both Wrightsville and Carolina Beaches are federally sponsored hurricane and shore protection projects constructed by the U. S. Army Corps of Engineers. Data collected on these beaches are being analyzed to determine the budget of the littoral materials of these areas and to monitor the condition of the Corps-built projects. Masonboro Beach, at present an undeveloped barrier island between the two inlets, is being studied because of its integral relationship to the barrier island/tidal inlet complex and its contribution to the littoral budget.

The results of this report will provide additional information for CERC's larger effort in applying remote sensing techniques to understanding coastal engineering problems. Moreover, it is anticipated that the results presented here will provide significant input to the concurrent CERC projects listed above.

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Characteristics of Imagery

Imagery used in this study consisted of ERTS-1 multi-spectral scanner (MSS) imagery in four discrete spectral bands ranging in wavelength from 0.5 microns (green) to 1.1 microns (infrared) and conventional aerial photography taken on black and white, color and infrared color film.

Specific information concerning the ERTS-1 satellite and details of collection, processing and dissemination of imagery are contained in the Data Users Handbook (7); however for the purpose of this paper it is important to list the radiation wavelengths in order to understand what is actually portrayed in the imagery of the MSS and of the conventional photography. Table 1 presents wave length ranges for each MSS spectral band (band numbers fixed by NASA) and for the conventional photography used in this study. Optical filters were used in the conventional photography in order to match the spectral bands of the MSS.

Table 1

ERTS-1 MSS AND AERIAL PHOTOGRAPHY SPECTRAL RELATIONSHIPS

SENSOR		WAVE LENGTH RANGE IN MICRONS
ERTS Band	4	0.5-0.6
	5	0.6-0.7
	6	0.7-0.8
	7	0.8-1.1
Ames Research Center Camera	1	.475-.575
	2	.58-.68
	3	.69-.76
	4	.51-.70
	5	.51-.90*

*Color IR film roughly comparable to a composite photo of MSS bands 4, 5, and 7.

Of particular importance in this study is the water penetration capability of MSS imagery. Because light attenuation by water is related to light wavelength, each spectral band provides a different degree of water penetration. Table 2 shows total light attenuation coefficients in clear water for wavelength of peak sensitivity of each MSS spectral band (8).

Table 2

LIGHT ATTENUATION COEFFICIENTS IN CLEAR WATER

MSS BAND	WAVELENGTH OF PEAK SENSITIVITY (MICRONS)	ATTENUATION COEFFICIENT
4	0.54	0.04/m
5	0.64	0.20/m
6	0.73	1.00/m
7	0.82	2.00/m

Thus for clear water, penetration increases as band numbers decrease.

Using this data, examination of imagery can proceed by making use of the fact that underwater features can be detected and properly identified. Magoon et al (6) have pointed out the utility of examining all four MSS bands, simultaneously and individually, and in conjunction with other existing data.

Imagery Available For Study

Table 3 presents imagery identification, dates and times of obtention for both ERTS-1 and underflight coverage.

TABLE 3

DATES AND TIMES OF ERTS AND UNDERFLIGHT OBSERVATIONS OF STUDY AREA

A. ERTS-1

FRAME NO.	DATE	TIME (EST)
E-1007-15142	30 July 72	1014
E-1080-15203	11 October 72	1021
E-1115-15152	15 November 72	1015
E-1134-15211	4 December 72	1021
E-1170-15205	9 January 73	1021
E-1188-15210	27 January 73	1021
E-1205-15153	13 February 73	1016
E-1242-15213	22 March 73	1022
E-1314-15210	2 June 73	1021

B. UNDERFLIGHTS

FLIGHT NO.	DATE	APPROXIMATE TIME (EST)
72-116	19 July 72	0842
72-144	19 August 72	1044
72-167	22 September 72	1226
W-179-FLT1	2 November 72	1025
73-013A	30 January 73	0945
W-187-FLT1	13 February 73	1025
73-062	28 April 73	1200
W-195	11 May 73	1140
W-222	15 June 73	1220

General Comments Concerning Imagery

In examining the ERTS-1 imagery, a number of basic observations were made and conclusions reached that should be stated. These statements are referenced to those images noted in table 3. However it is felt that the broad range of conditions encountered are representative of ERTS-1 imagery in general and that the statements have applicability to other studies and investigations using this imagery.

Nominal resolving power of the multi-spectral scanner is approximately

250 feet on the ground (7). As a result, smaller man-made structures such as roads and buildings are not visible. This resolving capability however is suitable for observation of gross coastal features and processes.

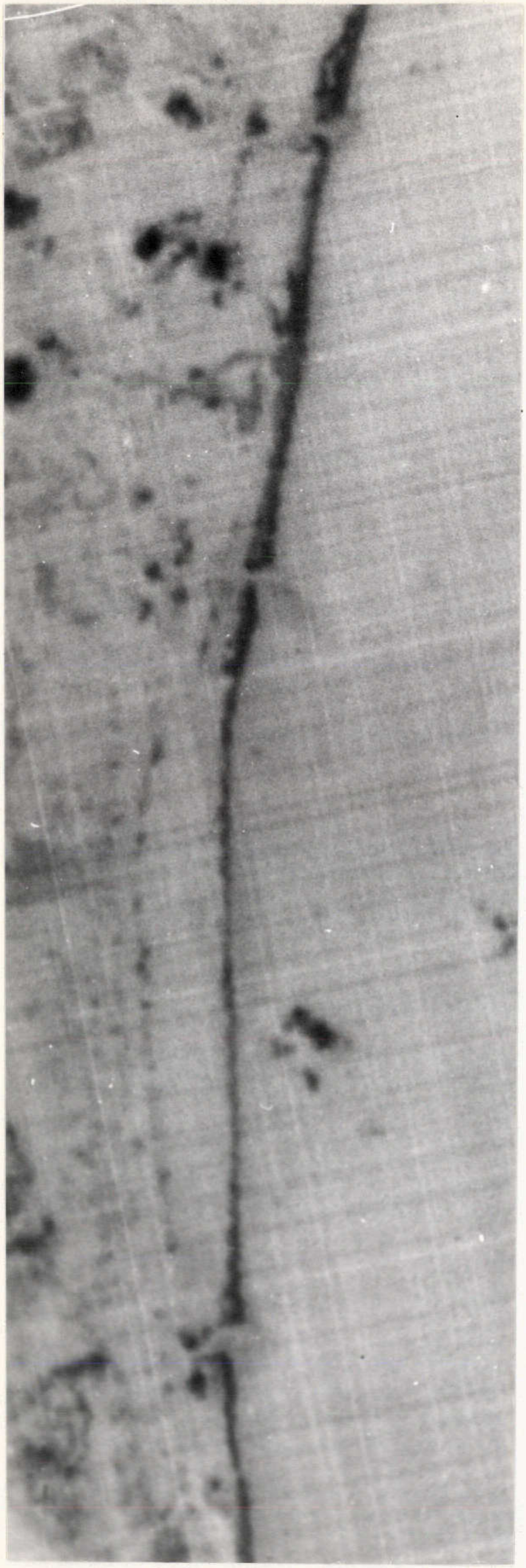
In selected cases distortion of the shoreline was apparent where image scan lines intersect at nearly right angles to the shoreline, imparting a serrated appearance to the shore. This appearance could be interpreted erroneously as a natural cuspate shore by those unfamiliar with the detailed procedure used to obtain and record the imagery.

Band 7 shows the greatest tonal contrast between land and water owing to the fact that water penetration is least in this band (comparable to black and white infrared photography). Contrast, in general, decreases in moving from band 7 to band 4. In some band 4 images it was difficult to distinguish land from water in backshore areas. Additionally, even though water depth penetration is greatest in band 4, poor contrast made it difficult to distinguish shoal areas from land masses. In most of the images analyzed, shoal areas were most apparent in band 5.

Clouds, where present, caused problems in distinguishing features on the ground and in the water. In most of the images cloud cover was light. Only one filmset was so heavily covered that analysis was impossible (27 January, 1973, ERTS 1188-15210). In a few isolated cases, care had to be exercised in distinguishing between shoals and cloud shadows.

Figure 2 presents contact prints* of the four spectral bands showing the study area (11 October 1972, ERTS 1080-15203). Approximate scale

*It should be noted that in this report all ERTS-1 images presented are either contact or enlargement photographs of positive imagery and are therefore negative prints. As a result land areas appear dark and water areas lighter.



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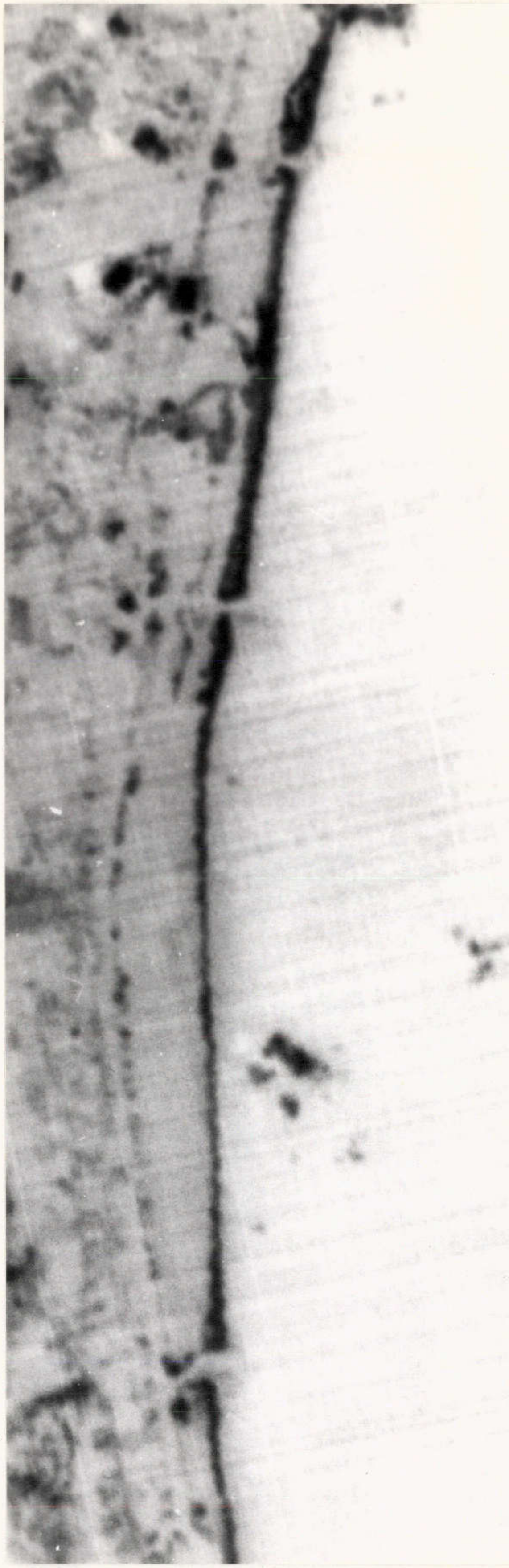
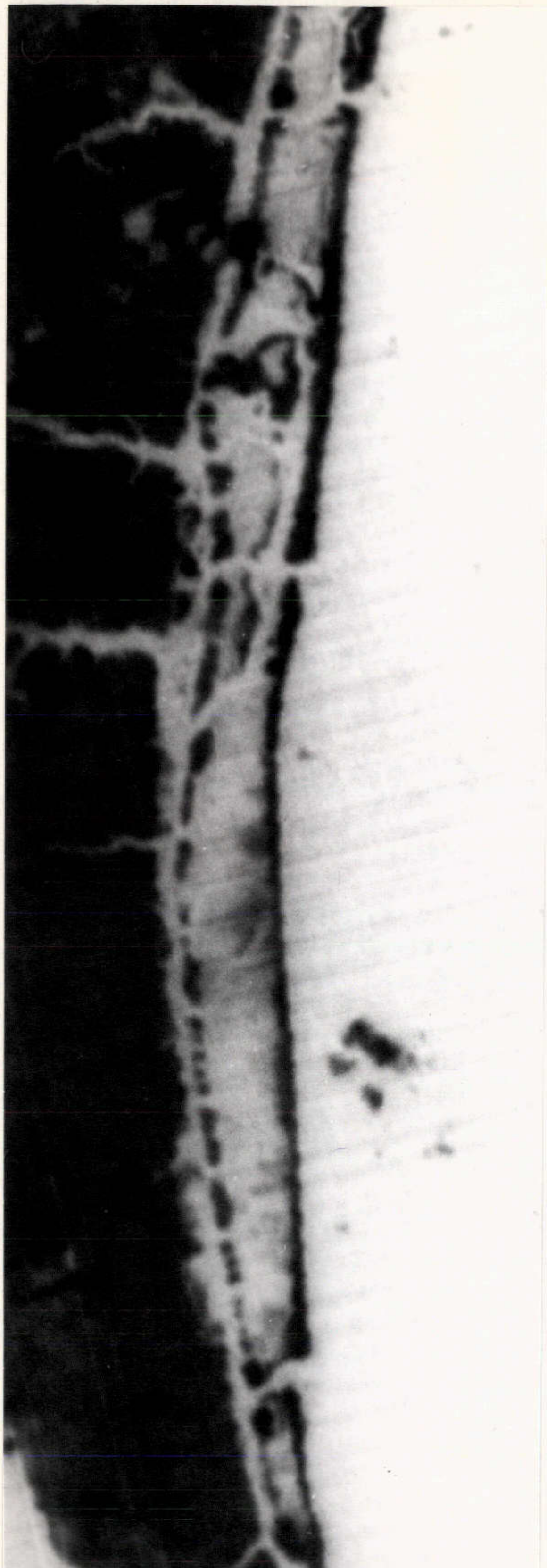
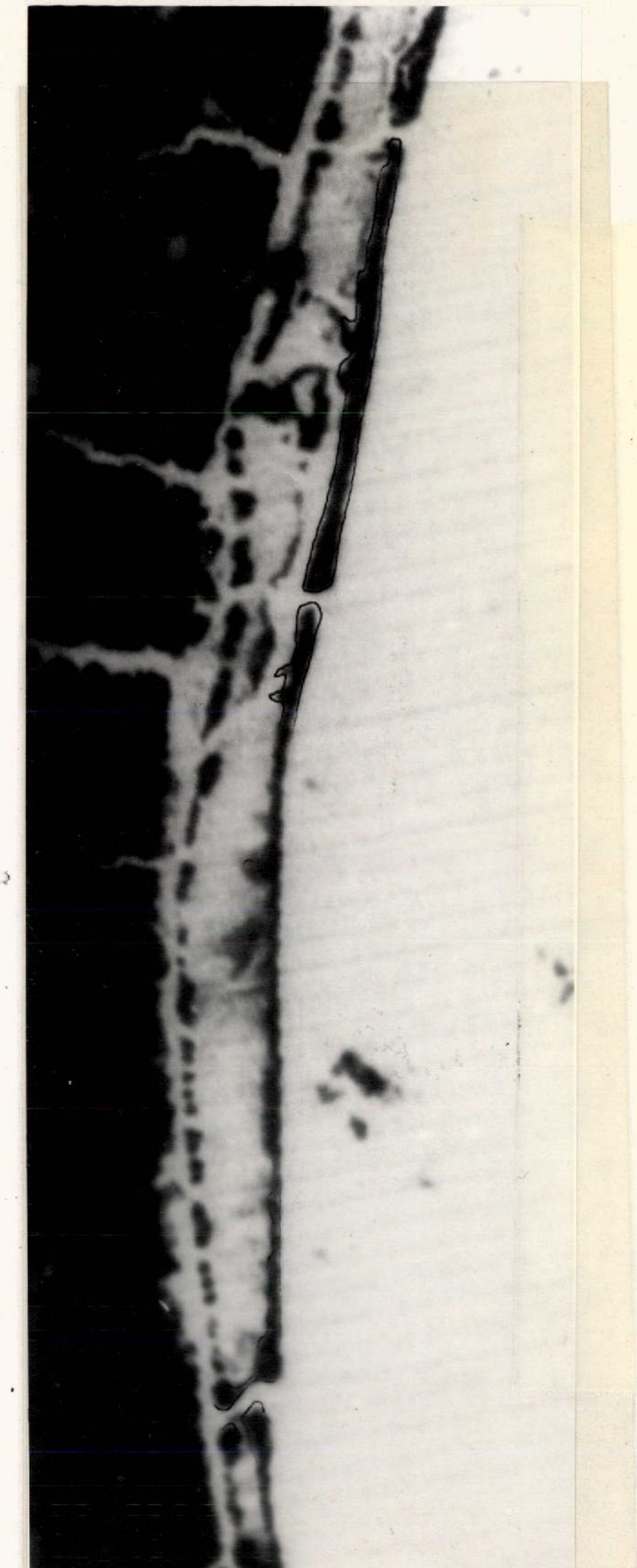


Band 5

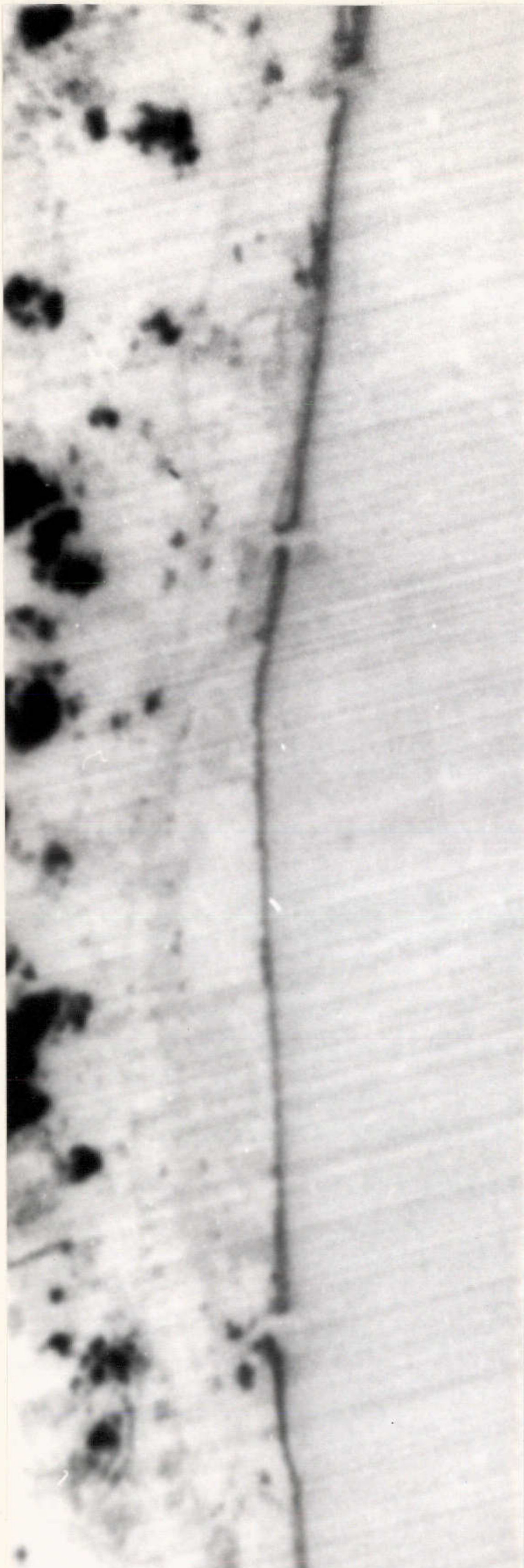


Band 6

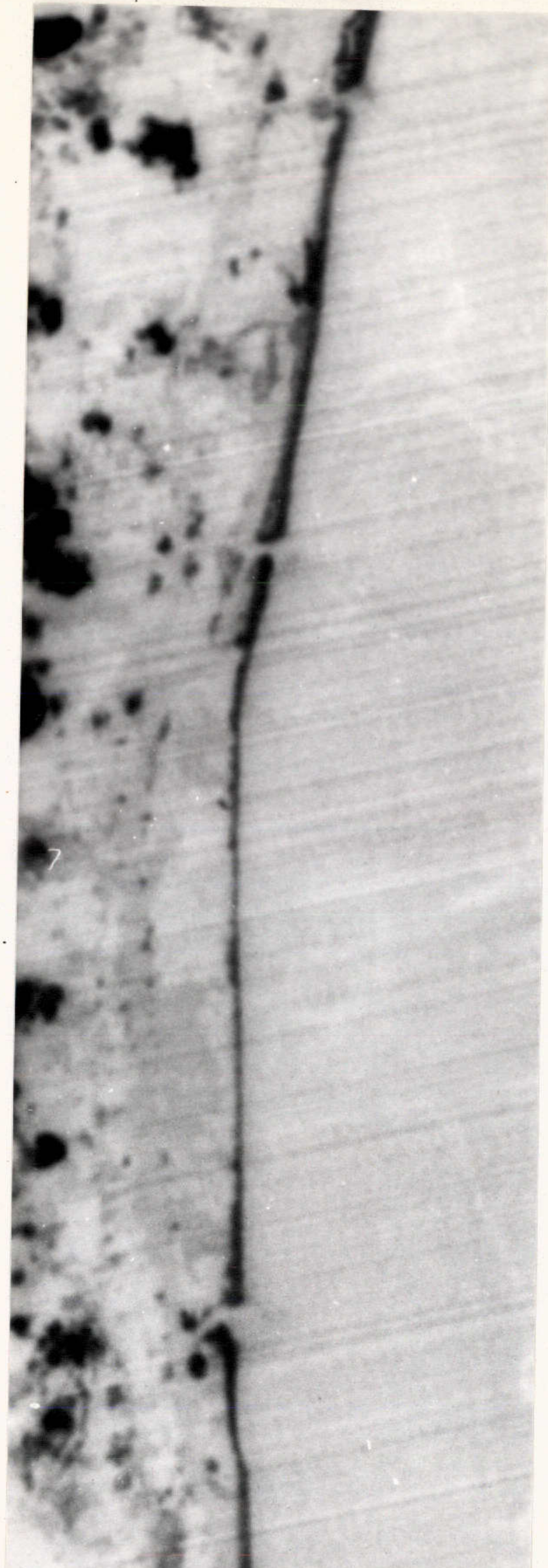


Band 7

fig. 8(b) - ERTS 1314-15210. Enlargement of study area recorded on 2 June 1973.



Band 4



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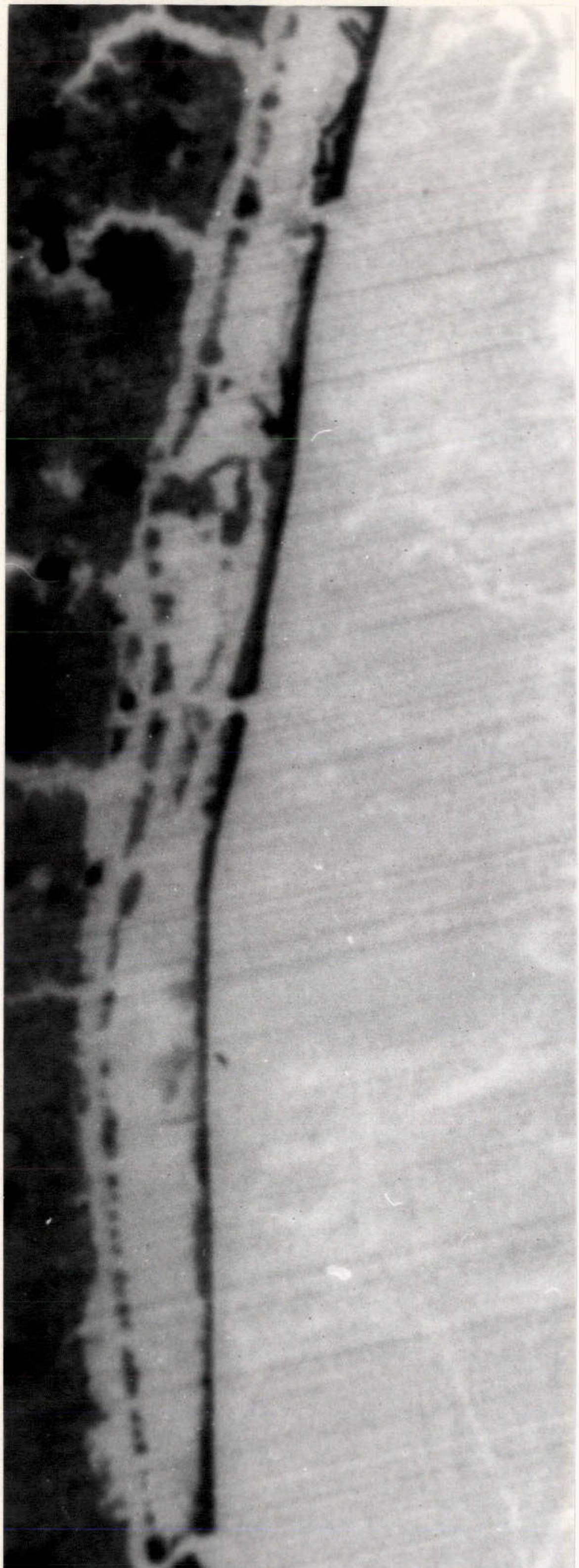

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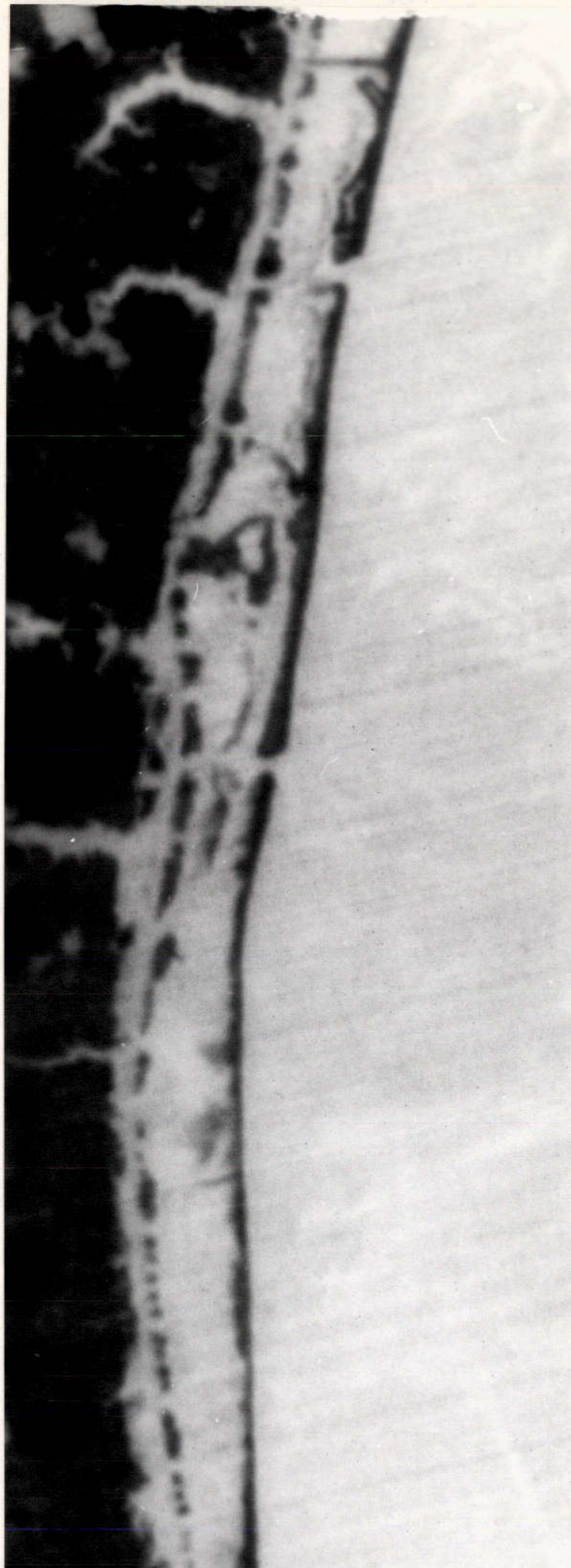


Band 7

fig. 9(a) - NASA/ARC Flight 72-116. Underflight mosaic of study area photographed on 19 July 1972. Altitude: 65,000 ft. MSL.

fig. 9(b) - NASA/Wallops Flight W-222. Underflight mosaic of study area photographed on 15 June 1973. Altitude: 9,500 ft. MSL.

Band 4

Band 5

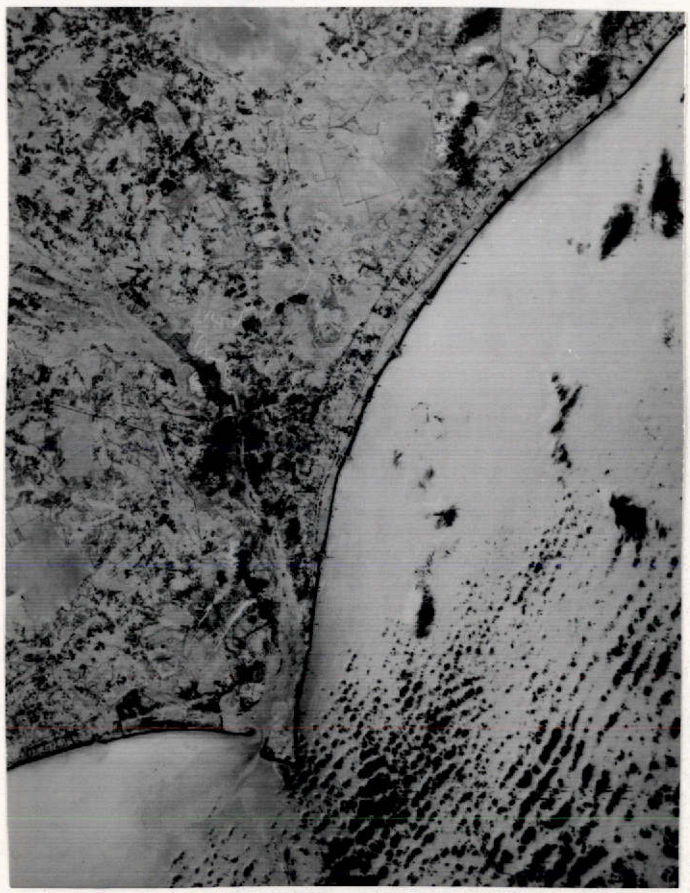
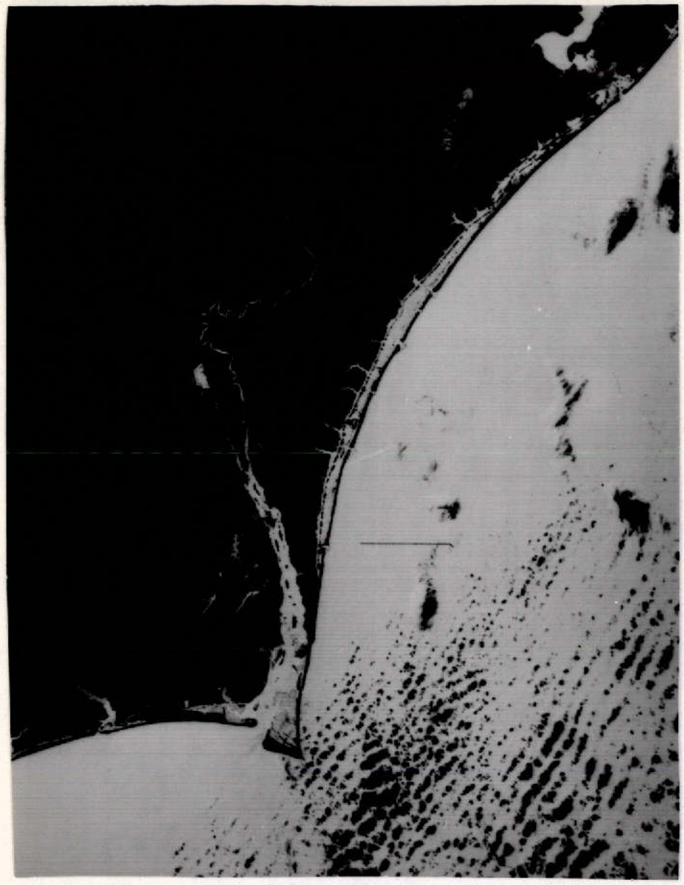


fig. 2 - ERTS 1080-15203. Study area.



Band 6

Band 7

fig. 2 (cont'd)

is 1:1,000,000. The prominent cape is Cape Fear. Photographic coverage of the shoreline extends from just south of Little River Inlet in South Carolina north to Bear Inlet, North Carolina. Spectral bands 6 and 7 clearly show the Cape Fear River and its tributaries, one tributary extending all the way to the northwest corner of the photograph. Also clearly delineated in these bands are the barrier islands extending north and south of Cape Fear. Inlets separating the barrier islands are seen as well.

Scan line distortion along the barrier islands is apparent in all four spectral bands (note for example Masonboro Beach).

In bands 4 and 5, contrast between land and water decreases and shoaling areas at the mouths of inlets become more apparent. These two bands illustrate the problem of contrast versus depth penetration covered above. The result was that shoals were studied primarily by using band 5. Sediment plumes also are visible in bands 4 and 5 and are seen at the mouth of the Cape Fear River and migrating along the seaward edges of the barrier islands both north and south of Cape Fear.

Figure 2 illustrates the problem of cloud cover. Cape Fear is known to have a southeast-trending shoal off its tip visible in the lower spectral bands (shown later). Cloud cover in the southeast corner of figure 2 effectively obscures any evidence of shoaling off Cape Fear.

Features Noted in the Study Area

A number of selected coastal features within the study area were noted during analysis of the ERTS-1 images. Interpretation of these features is important to coastal engineering because they provide vital clues to the littoral budget and behavior of shorelines and inlets. This section treats each feature separately with accompanying ERTS-1 photographs and pertinent ground truth data.

Sediment Plumes. Because they act as tracers, bodies of suspended sediment as seen in aerial and space photographs have long been used by coastal engineers in interpreting current structures and estuarine flushing patterns. These sediment bodies, or plumes, are seen readily in spectral bands 4 and 5. With ERTS-1 imagery it is possible to observe sediment plumes of areal extent measuring in thousands of square miles.

Figure 3 shows bands 5, 6 and 7 (band 4 not available) of the study area observed on 4 December 1972 (ERTS 1134-15211). Band 5 reveals sediment plumes at the mouths of Carolina Beach and Masonboro Inlets (refer to figure 1 for precise location). The visible portion of the plume at Carolina Beach Inlet is almost semicircular with its longest diameter against the shoreline and measuring approximately 2.8 nautical miles. Maximum seaward extent of the plume is approximately 2.1 nautical miles. Masonboro Inlet has a smaller, more linear plume extending seaward about 1.5 nautical miles and trending toward the southeast.

Tide data (table 4), obtained from a station at Masonboro Inlet, indicate ebb tide occurred at the time the ERTS-1 observation was made. Tide level was 1.9 feet above mean low water (slackwaters were 4.3 and 0.3 feet above MLW respectively). Daily weather data obtained from the National Weather Service Office, Wilmington, North Carolina (5), for 4 December 1972 and the preceding three days show zero precipitation. The sediment plumes then do not reflect abnormal quantities of runoff due to heavy precipitation but most likely are normal discharges associated with ebb tide.

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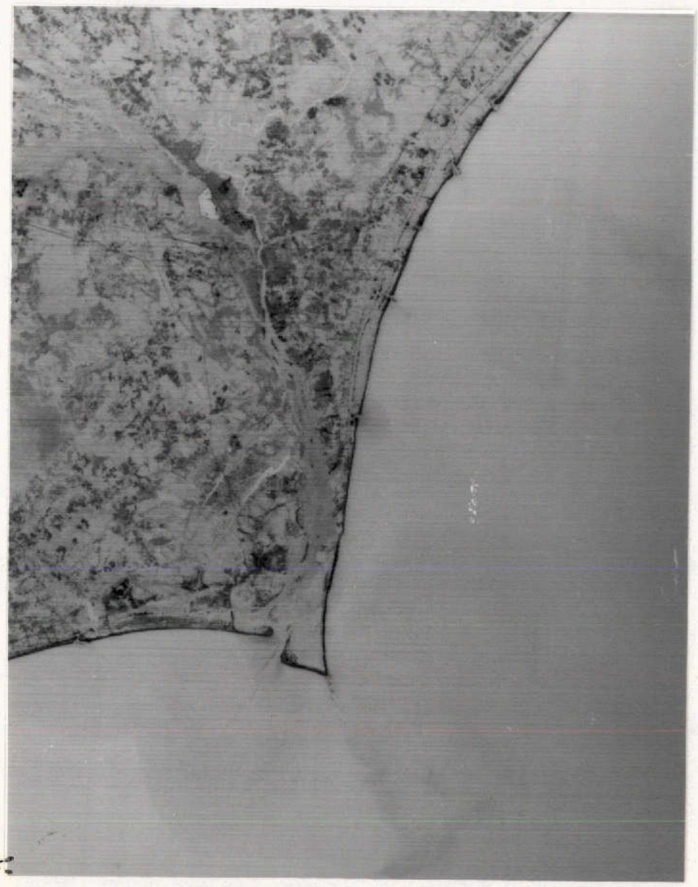
Band 4 (not available)

Band 5

fig. 3 - ERTS 1134-15211. Sediment plumes and Cape Fear bar.



band 6

Band 7

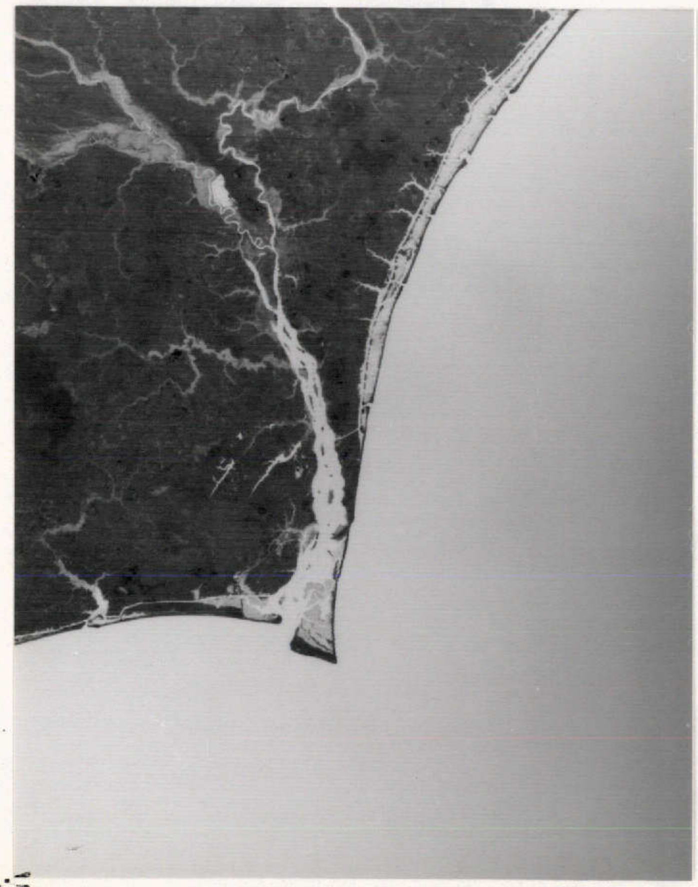


fig. 3 (cont'd)

TABLE 4

TIDE DATA - MASONBORO INLET
(from *Tide Tables*)

A. ERTS-I

DATE	TIME (EST)	TIDE (FT)	RANGE (FT)*	CYCLE
30 July 72	1014	4.1	(-)0.4-4.1	flood
11 Oct 72	1021	4.1	4.2-1.0	ebb
15 Nov 72	1015	1.5	0.9-3.7	flood
4 Dec 72	1021	1.9	4.3-0.3	ebb
9 Jan 73	1021	3.6	(-)0.1-3.6	flood
27 Jan 73	1021	1.1	0.7-2.4	flood
13 Feb 73	1016	0.0	4.0-0.0	ebb
22 Mar 73	1022	3.1	3.2-(-)0.1	ebb
2 Jun 73	1021	2.7	3.6-(-)1.0	ebb

B. UNDERFLIGHTS

DATE	TIME (EST)	TIDE (FT)	RANGE (FT)*	CYCLE
19 Jul 72	0842	0.6	0.5-3.4	flood
19 Aug 72	1044	1.2	0.8-3.7	flood
22 Sept 72	1226	0.0	4.7-(-)0.1	ebb
2 Nov 72	1025	0.7	4.3-0.5	ebb
30 Jan 73	0945	0.8	3.4-0.4	ebb
13 Feb 73	1025	0.0	4.0-0.0	ebb
28 Apr 73	1200	1.1	0.2-3.6	flood
11 May 73	1140	1.1	0.0-3.9	flood
15 Jun 73	1220	0.1	2.9-(-)0.1	ebb

* Ranges denote maximum or minimum tidal height preceding and following tide levels given.

The plume off Carolina Beach Inlet is displaced slightly toward the south indicating the presence of a southbound current. The near-semicircular configuration suggests that this current, though present, was relatively weak in the vicinity of the inlet. There is no ground truth data available to substantiate the existence of a predominant southward littoral drift at the time of observation that may be a contributing factor to this movement. Wave gage data (table 5) obtained at Wrightsville Beach for 0100, 0700, 1300 and 1900 hours (EST) on 4 December 1972 show lower significant wave heights and longer wave periods than the average for the month of December 1972. Wave energy therefore was lower than average for those times. Wave observation data obtained by volunteer observers at Wrightsville Beach under the Beach Evaluation Program (4) managed by CERC show that wave crests for the most part approached parallel to shore during that day. The data from the wave gage and observers combine to support the view that any longshore current generated off Wrightsville Beach or nearby vicinity must have been relatively weak.

The plume off Carolina Beach Inlet is much larger in areal extent than the one off Masonboro Inlet. This phenomenon can be explained in terms of the tidal hydraulics of the area. A detailed analysis of the tidal flow through Carolina Beach Inlet was made in connection with a study investigating erosion at Carolina Beach (12). This study revealed that tidal flow through the inlet is controlled not only by the ocean tide fluctuations but also by those of the Cape Fear River through Snow's Cut. High water in the ocean occurs about one hour before high water in the river, and low water occurs about one and one half hours before low water in the river. The result of this combined tidal action is that

TABLE 5

SIGNIFICANT WAVE HEIGHTS AND PERIODS
(obtained from Wave Gage Data, CERC)

DATE	0100 H(ft.)	0100 T(sec.)	0700 H(ft.)	0700 T(sec.)	1300 H(ft.)	1300 T(sec.)	1900 H(ft.)	1900 T(sec.)
*19 Jul 72	2.0	7.4	2.1	8.8	2.2	8.8	2.1	8.0
18 Jul 72	2.0	9.7	1.7	8.8	2.1	8.8	2.0	8.8
17 Jul 72	2.3	9.7	2.0	8.8	2.2	8.0	2.1	8.0
July Avg.	2.4	7.3	2.2	7.8	2.3	7.8	2.3	7.6
*19 Aug 72	1.5	7.4	1.4	8.0	1.7	8.8	1.4	7.4
18 Aug 72	2.1	9.7	---	---	1.8	8.8	1.7	8.0
17 Aug 72	2.4	5.0	1.9	5.0	2.0	10.8	2.0	9.7
August Avg.	2.4	7.3	2.6	6.1	2.6	7.4	2.7	6.8
*2 Nov 72	1.8	7.4	1.8	10.8	1.8	8.8	1.7	10.8
1 Nov 72	2.9	4.0	2.2	4.3	2.2	8.8	1.9	8.8
31 Oct 72	3.0	5.0	2.8	4.0	3.4	4.8	2.6	5.3
October Avg.	2.5	6.4	2.6	5.2	3.2	5.8	2.6	5.9
*15 Nov 72	2.9	8.0	1.9	9.7	2.4	8.8	2.5	8.8
14 Nov 72	3.3	5.0	5.6	6.9	---	---	---	---
13 Nov 72	3.4	4.0	3.0	5.0	3.0	4.8	2.5	4.3
November Avg.	3.2	7.8	3.1	7.7	3.0	7.4	3.1	8.5
*4 Dec 72	1.2	8.8	1.2	8.8	1.4	8.0	1.7	8.8
3 Dec 72	1.4	8.8	1.5	8.8	1.6	8.8	1.7	8.0
2 Dec 72	1.9	6.9	1.7	9.7	1.6	9.7	2.0	3.0
December Avg.	2.7	7.8	2.8	7.6	2.8	7.7	3.0	7.1
*9 Jan 73	3.1	8.0	2.7	8.8	---	---	2.0	9.7
8 Jan 73	4.6	5.0	6.8	7.4	5.3	8.0	4.6	8.0
7 Jan 73	2.0	4.1	3.5	5.6	3.3	5.6	3.8	5.3
January Avg.	2.8	7.6	3.2	7.5	3.0	7.8	2.8	8.1

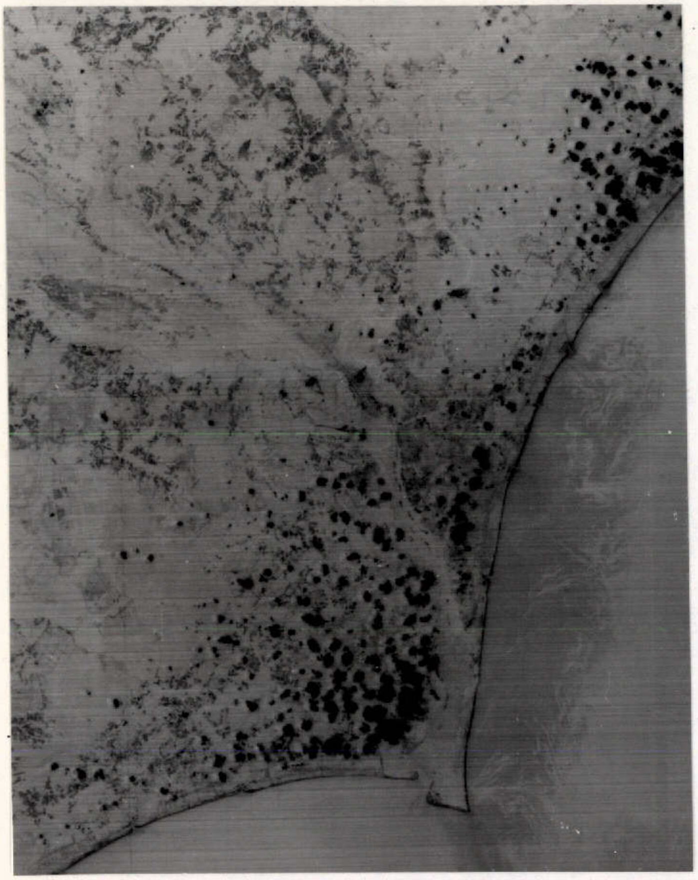
* - Date of Flight, either ERTS or underflight

slack water before ebb at the inlet occurs one hour after low water in the ocean and slack water before flood occurs one and one half hours after ocean high water. Translated in terms of time on 4 December 1972, slack water times (EST) for the ocean, Carolina Beach Inlet, and the Cape Fear River are listed as follows:

	OCEAN	RIVER	INLET
Time of high:	0829	0929	Slack water before flood: 0959
Time of low:	1551	1721	Slack water before ebb: 1651

Based on the information presented above, it is clear that at 1021 EST, the time of the ERTS-1 image shown in figure 3, Carolina Beach Inlet was at the beginning of the flood cycle and not ebb as indicated by table 4 which gives tidal data from Masonboro Inlet. What is observed in the ERTS-1 photograph therefore is the plume at Carolina Beach Inlet that resulted from the preceding ebb cycle and what is seen at Masonboro Inlet is a partially developed plume about two hours after the beginning of the ebb cycle at that inlet.

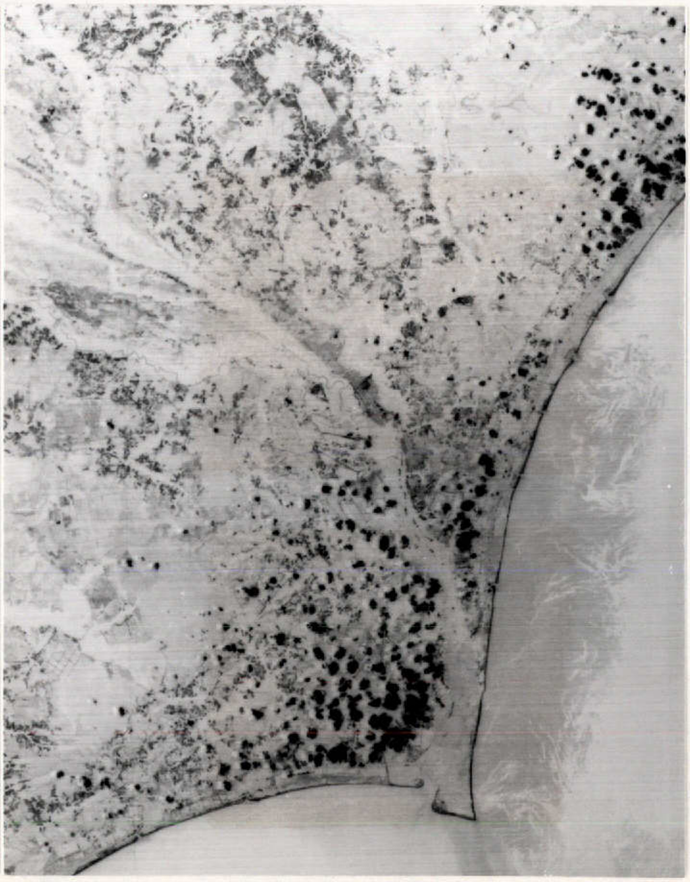
"Density" Mass: A striking color (or gray tone) change in the ocean water off the North Carolina coast is visible in all four bands of the ERTS-1 imagery recorded on 2 June 1973 (ERTS 1314-15210, figure 4). The water adjacent to the coast is of a lighter color (darker in the negative print) and appears to be in the form of a linear mass irregular in outline and running roughly parallel to shore. The mass extends from the southern frame border north approximately to Rich Inlet where it pinches out and picks up again at Old Topsail Inlet. Approximate width of the mass is 7 miles from shore seaward. Examination of the adjacent frame to the south (ERTS 1314-15213, not shown) reveals that the mass is bordered on the south by the shoals off Cape Fear (discussed in a later section). The



Band 4

Band 5

fig. 4 - ERTS 1314-15210. Gray
tone change in ocean water.



Band 6

Band 7

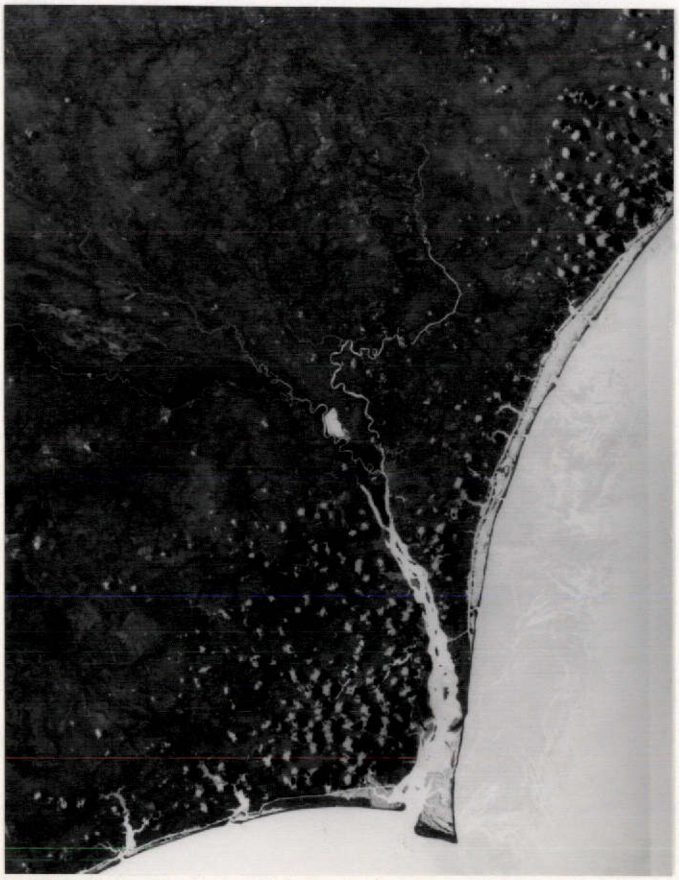


fig. 4 (cont'd)

mass itself does not contain any visible patterns that would suggest a result of tidal outflow. Its irregular outline suggests that mixing with adjacent ocean water is in progress. The fact that the mass is visible in all four MSS bands indicates that the feature has some depth to it.

Local climatological data for Wilmington (5) reveals zero precipitation for the day of the ERTS-1 observation and the preceding two days. Weather observations made at three-hour intervals on 2 June 1973, starting at 0100 EST, show that air temperature rose from 59 degrees F at 0400 EST, the lowest recorded temperature for that month, to 82 degrees F at 1000, the highest recorded temperature for the day. In the interval of six hours, air temperature rose 23 degrees F. Recorded wind speeds for 0100, 0400, and 0700 EST were zero, but the wind picked up to 8 knots by 1000 hours.

The change in color most likely is caused by a difference in density which may result from changes in salinity, quantity and type of suspended matter (as in the sediment plumes covered above), concentrations of marine life and nutrients, or any combination of these. Often changes such as these are observed between water masses of differing temperatures. Figure 5 presents a map of the Carolinas' coast showing sea surface isotherms recorded by an airborne radiation thermometer on 24 and 25 June 1973, the closest days to the ERTS-1 observation for which this data is available (3). Dotted portions along some of the isotherms represent extrapolations made by the investigators. A trough of cooler water is seen to originate off the coast north of Cape Lookout and extend south as far as Cape Fear as evidenced by the linearity of the 25°C isotherm and a small entrapped 24°C isotherm. Just off Cape Fear

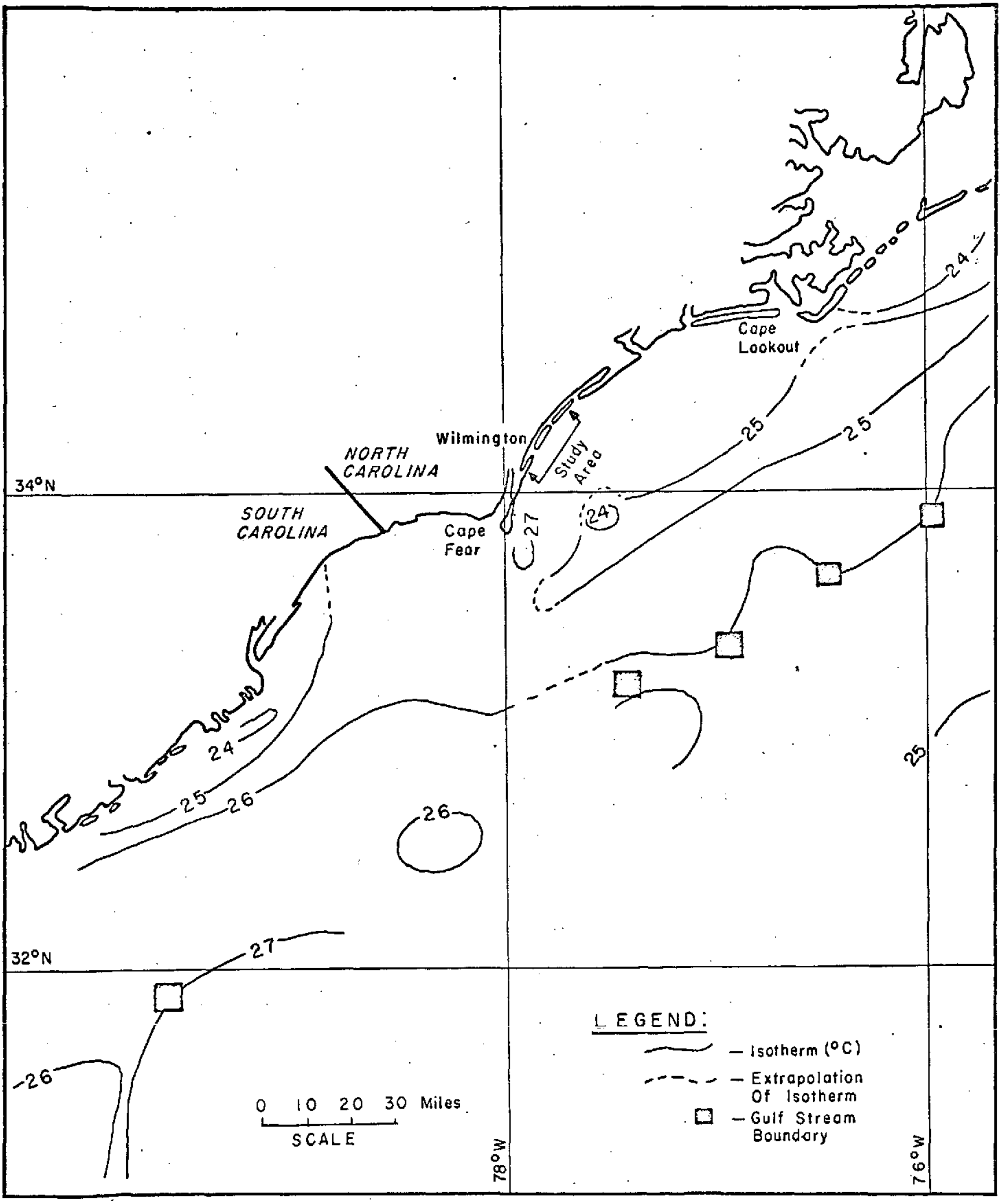


fig. 5 - Sea surface isotherms (3) recorded on 24 June (southern portion) and 25 June (northern portion) 1973.

is a small 27°C isotherm. It is reasonable to infer from the chart that a body of warmer water may be trapped by the 25°C isotherm between Capes Lookout and Fear. As previously noted the change in water temperature may be a factor in causing a tonal change in the photographs. That the darker tone represents warmer water is borne out by examination of the next ERTS-1 frame to the south (ERTS 1314-15213, not shown). The same tonal variation is apparent toward the southeast roughly coinciding with the Gulf Stream. Examination of figure 4 shows that the outline of the "density" mass roughly coincides with the isothermal pattern. Although the temperature recordings were made on different days from the ERTS-1 recording, it is not unreasonable to assume that isothermal variations on the sea surface tend to follow predictable patterns during a given season along a particular coastal segment.

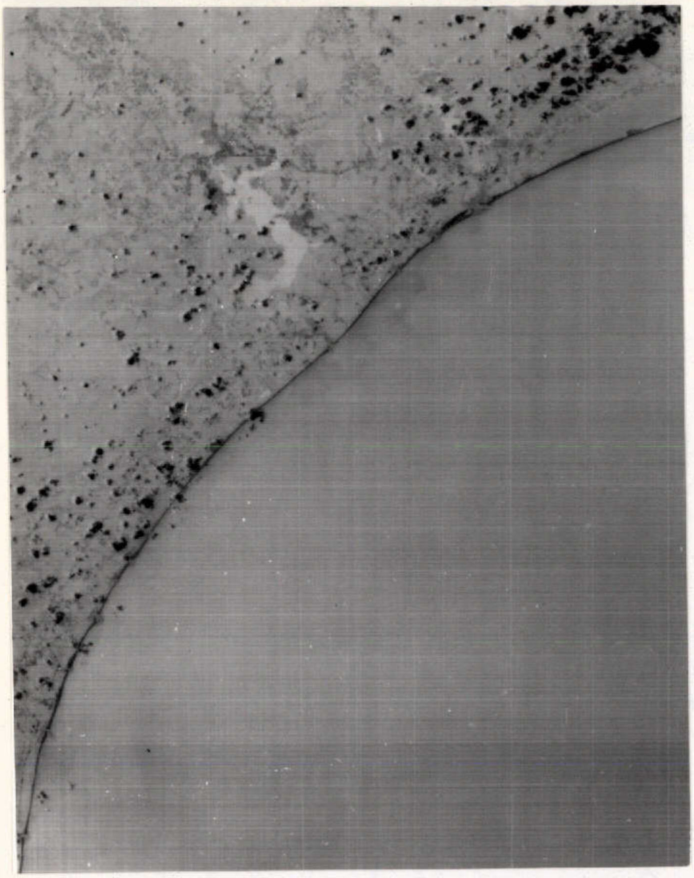
Inlet Bars: Bars generally are found at the landward and seaward ends of inlet channels. These bars usually appear as lobate or delta-shaped sand bodies, originating at the channel's ends. These bars are formed by deposition of sediment transported alongshore to the inlet and carried through the inlet by tidal flow. During flood tide the materials are carried through the inlet and deposited on what is often referred to as the inner bar. During ebb tide, some of the materials deposited in the inner complex are transported back through the inlet to an area frequently called the ocean bar. Ebb and flood tide channels form in both the ocean and inner bar formations, and both the bars and channels generally migrate. Geometry and migration of these featrues are related to the rate of littoral material movement to and within the inlet and the prevailing tidal currents.

Inlets are important coastal features from the standpoint of private and commercial water traffic because often they are the only means of access from mainland areas to the ocean. Consequently bar migrations and shoaling rates must be monitored closely by coastal engineers in order that appropriate maintenance dredging measures can be planned to maintain the inlet channels in navigable condition.

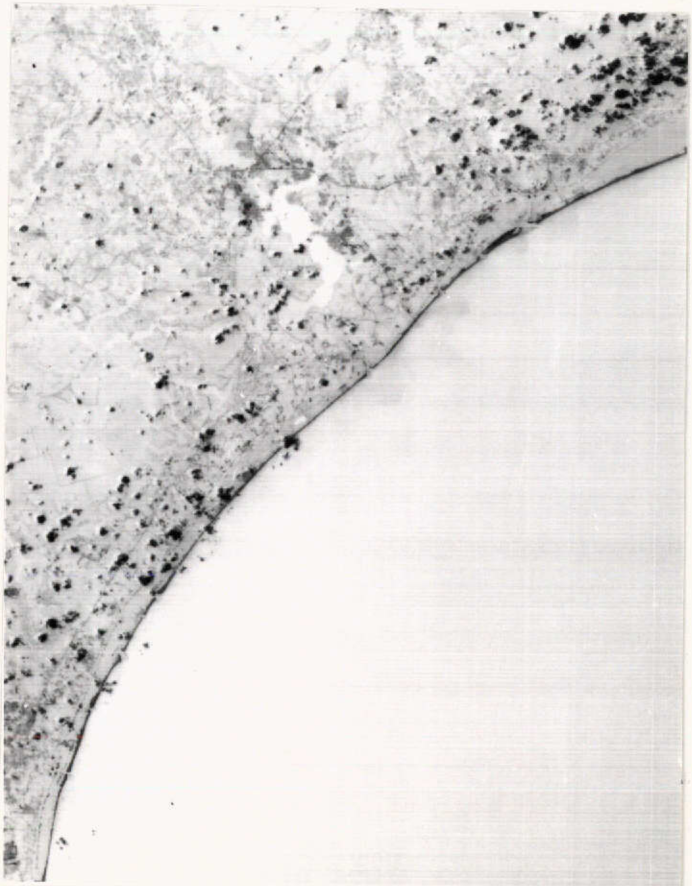
Inlet bars are visible around Carolina Beach and Masonboro Inlets in ERTS 1007-15142 (30 July 1972) in figure 6. These bars are barely visible in band 6 but are most striking in bands 4 and 5. Southbound littoral drift at Masonboro Inlet is controlled by a weir jetty at the mouth of the inlet on the north side with the result that the ocean bar is of a different geometry and position from the one at Carolina Beach Inlet. The ocean bar at Masonboro Inlet is roughly linear in form and is displaced toward the south of the inlet channel which is bordered on the north side by the jetty. The bar trends approximately parallel to the channel and jetty, toward the southeast, and is separated from Masonboro Beach by what is apparently a secondary tidal channel.

Capes: Capes Fear and Lookout each have a southeast-trending bar extending from the tip of each cape. These bars are seen best in spectral bands 4 and 5. The bar off Cape Lookout is the longer of the two, measuring about four miles compared to one mile for the one off Cape Fear. Figure 3 shows this feature off Cape Fear, and the extension of Cape Lookout is visible in figure 7.

Historical records have shown that these two capes are the sites of shifting current directions (9). Sediment transported toward the tip of each cape by longshore currents is deposited in the shoaling areas as the sediment laden waters reach the tip. Diffraction around the tip



Band 4



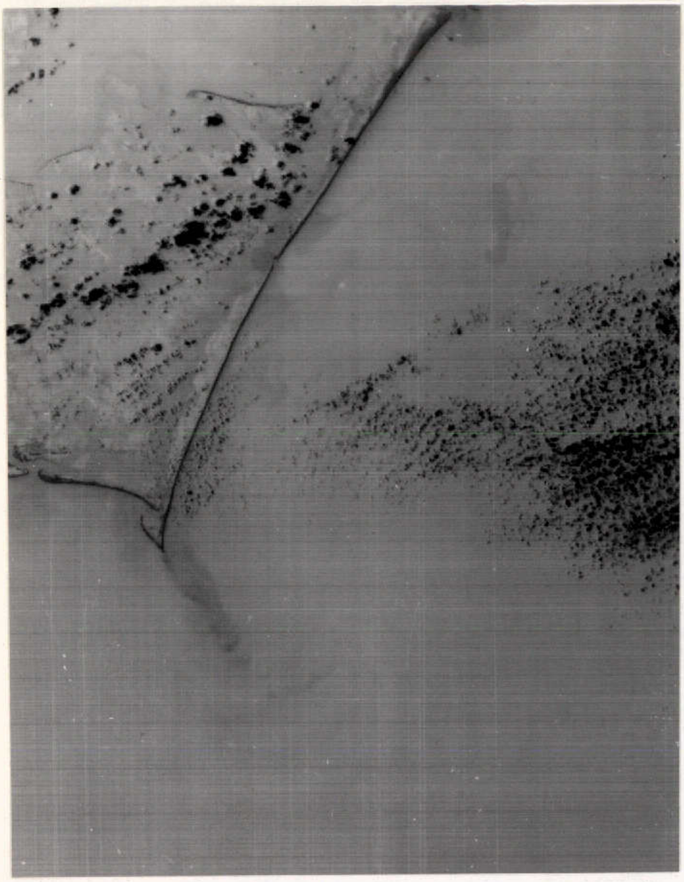
Band 5

fig. 6 - ERTS 1007-15142. Inlet bars.

Band 6

Band 7

fig. 6 (cont'd)



Band 4

Band 5

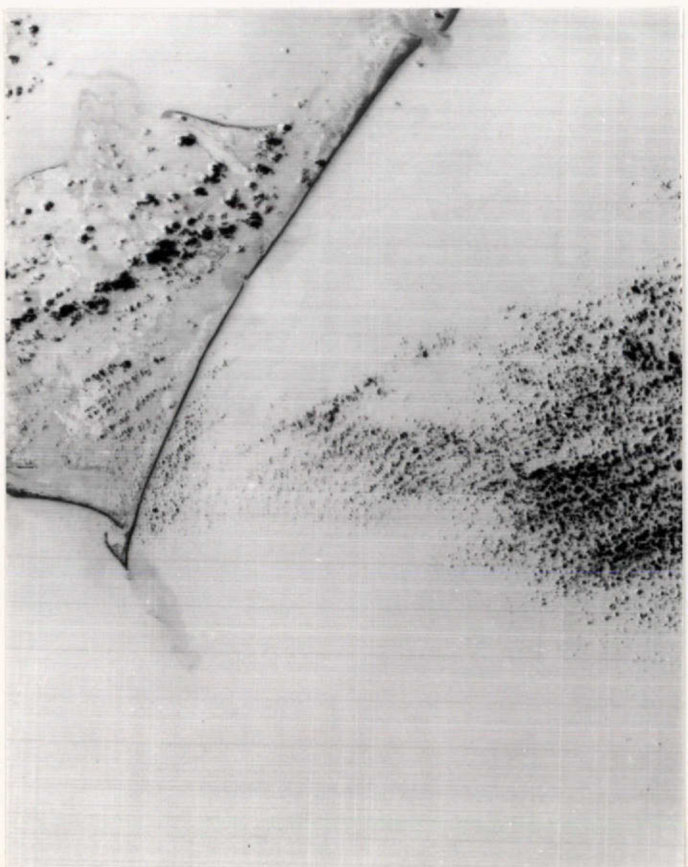


fig. 7 - ERTS 1007-15142. Bar off Cape Lookout.

Band 6

Band 7

fig. 7 (cont'd)

causes waves to lose energy which in turn reduces the sediment carrying capacity of those waves. Shifts in longshore current direction probably prevent these shoals from approaching a direction parallel to the current. The shoals visible in the ERTS-1 imagery are oriented in a direction that reflects net deposition by shifting currents.

Bumpus (2) points to converging currents as the mechanism for bar formation off the capes of North Carolina. A southwesterly wind, the prevailing wind during many months of the year, blows parallel to the direction of the coast south of Cape Hatteras. This wind will pile up water on the south side of the capes resulting in an hydraulic current flowing out over the projecting bars. This current will deflect offshore any southward current approaching the cape from the north side. The resulting decrease in current velocity will cause deposition of the sediment load, thus providing a source of sediment for the bars.

Morphological Changes In The Study Area

Coastal land features continually undergo erosion and accretion due to the constant action of wind, waves and currents. As a result the morphology of the land is constantly subject to change. Some of these changes occur over very short periods of time. Inlets through barrier islands for example have been known to open up in a matter of hours during storms. Those same inlets have been observed to close up again in a matter of weeks or months. Whole beaches have eroded away within a few years due either to natural processes or the influence of man; other beaches have formed in as much time. In addition to one-time changes, there are such changes as seasonal variations in beach width, steady growth of spits and hooks, and migrations of capes and inlets.

Because changes to coastal landforms are continuous and often rapid, maps of these areas tend to become obsolete very quickly. With the repeated coverage offered by satellite imagery, it is possible to virtually eliminate the problem of obsolescence inherent in current methods of mapping. Photographs obtained from satellite imagery not only provide an up-to-date supplement to existing maps, but repeated coverage over relatively shore time intervals also provides a means of monitoring changes that are occuring in landforms, as long as those changes are large enough to be resolved by satellite sensors.

This section is devoted to discussion of those morphological changes that have occured in each of the five coastal features of interest off the coast of North Carolina: Carolina Beach, Carolina Beach Inlet, Masonboro Beach, Masonboro Inlet and Wrightsville Beach. Emphasis will be placed on comparison of what is observed in the ERTS-1 imagery to low-altitude aerial photography and ground truth data.

General Comments: Figure 8 contains blow-ups of the study area obtained from the first and last ERTS-1 films analyzed: 30 July 1972 and 2 June 1973. Band 7 of figure 8(a) is provided with an overlay of the land-water interface traced directly from the ERTS-1 photograph in figure 8(b) allowing direct comparison of shoreline change between the two dates. Comparison of the two ERTS-1 films was done using a Zoom Transfer Scope (1). Figure 9 shows mosaics of underflight infrared color photographs provided by NASA showing the study area photographed on 19 July 1972 and 15 June 1973. The following discussion relates directly to figures 8 and 9. The location map in figure 1 should be used to pinpoint locations of the various features.

fig. 8(a) - ERTS 1007-15142. Enlargement of study area recorded on 30 July 1972.

Carolina Beach: Comparison of the two underflight mosaics shows that significant erosion has occured along the arched portion of Carolina Beach immediately south of Carolina Beach Inlet. This same shoreline recession is apparent in the ERTS-1 photographs although not as readily as in figure 9 because of the lower image resolution and scan line distortion in ERTS-1 imagery. No erosion is apparent along the beach south of the arched portion. A recent report of the Wilmington District (12) states that prior to the opening of Carolina Beach Inlet in 1952, the now-curved portion of Carolina Beach was continuous with the shoreline to the south and Masonboro Beach to the north. Subsequent erosion of the segment immediately south of the inlet has been in progress ever since the opening of the inlet. This erosion was a natural development resulting from a deficit of littoral drift from the north, caused by material entrapment in the inlet.

Carolina Beach Inlet: Because of the erosion at Carolina Beach noted in the preceding paragraph, Carolina Beach Inlet has a well-defined offset, the southern ocean edge displaced landward of the projected ocean edge of Masonboro Beach. The portion of the inlet channel between the barrier islands is arched northward. These features can be seen clearly in the ERTS-1 photographs. Comparison with the overlay reveals that the inlet is migrating northward with a concomitant increase in the bending of the channel. There does not appear to be any significant shift in position of the channel's mouth. However, close examination of the inlet in the underflight mosaic for 19 July 1972 shows a long (about 1000 ft.) narrow bar normal to the shore, positioned on the south side of the inlet and detached from land, and extending seaward from well within the inlet. This bar is faintly visible in the ERTS-1 photograph, figure 8(a), as well. Examination of underflight imagery subsequent to that photographed on 19 July 1972 shows that the northern tip of the Carolina Beach extension accreted and filled in the gap between it and the linear bar, the latter thus forming a sort of cap to the barrier island's growth. This accretion was accompanied by apparent erosion on the north side of the channel. This combination of accretion and erosion accounted for the apparent increase in the channel arching.

Masonboro Beach: No significant change is observed to have occurred in the shoreline position of Masonboro Beach either through ERTS-1 or underflight imagery. Evidently the sand budget along this coastal segment was relatively stable for the period of time under consideration. It is probable that much of the sand replenishing at least the southern part of Masonboro Beach may be derived from the outer bar of Carolina Beach Inlet during times when the direction of littoral drift is toward the north. At the north end it is likely that some littoral drift is moved south from the shoal on the south side of Masonboro Inlet.

Masonboro Inlet: An apparent narrowing of the channel through Masonboro Inlet has occurred between the time of the two ERTS-1 observations shown in figure 8. The narrowing occurred as the result of accretion of the northern tip of Masonboro Beach while the northern edge of the inlet channel remained stationary. An apparent increase in size of the shoal on the south side has narrowed the channel along the above-water portion of the jetty as well. Survey data obtained in recent years has revealed a steady northward migration of the channel thalweg since the installation of the weir jetty (see figure 10). Thus, what is observed in the ERTS-1 photography most likely reflects

fig. 9(a)

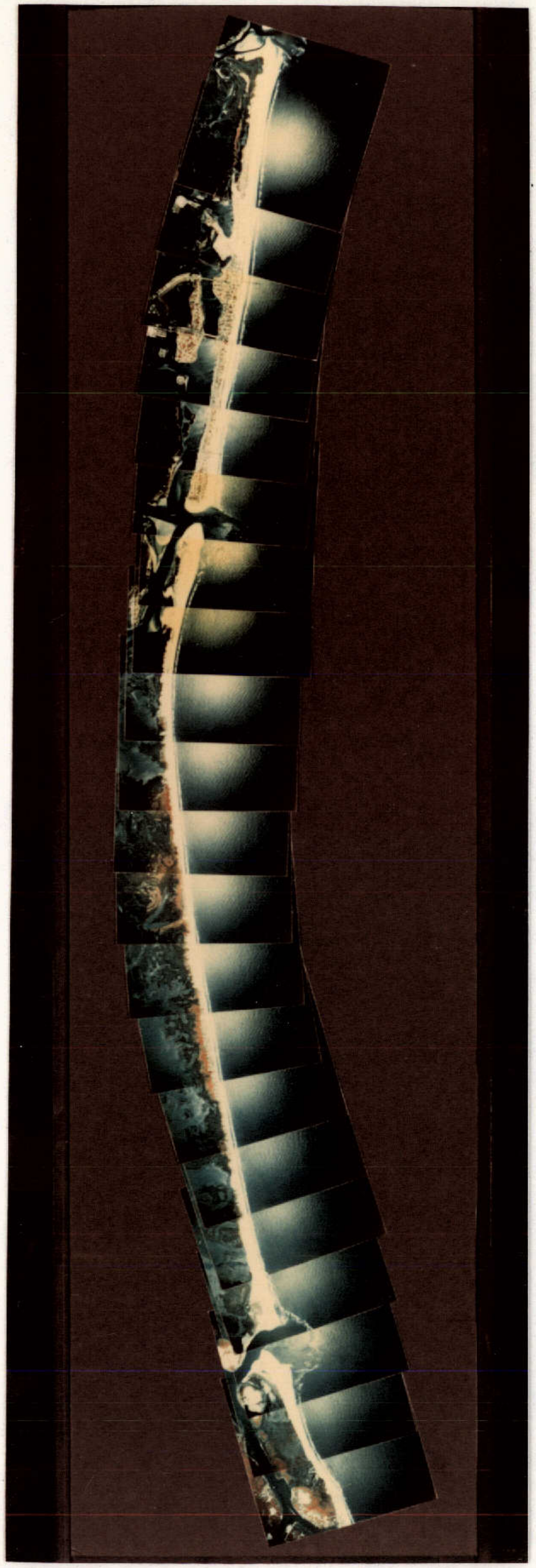


fig. 9(b)

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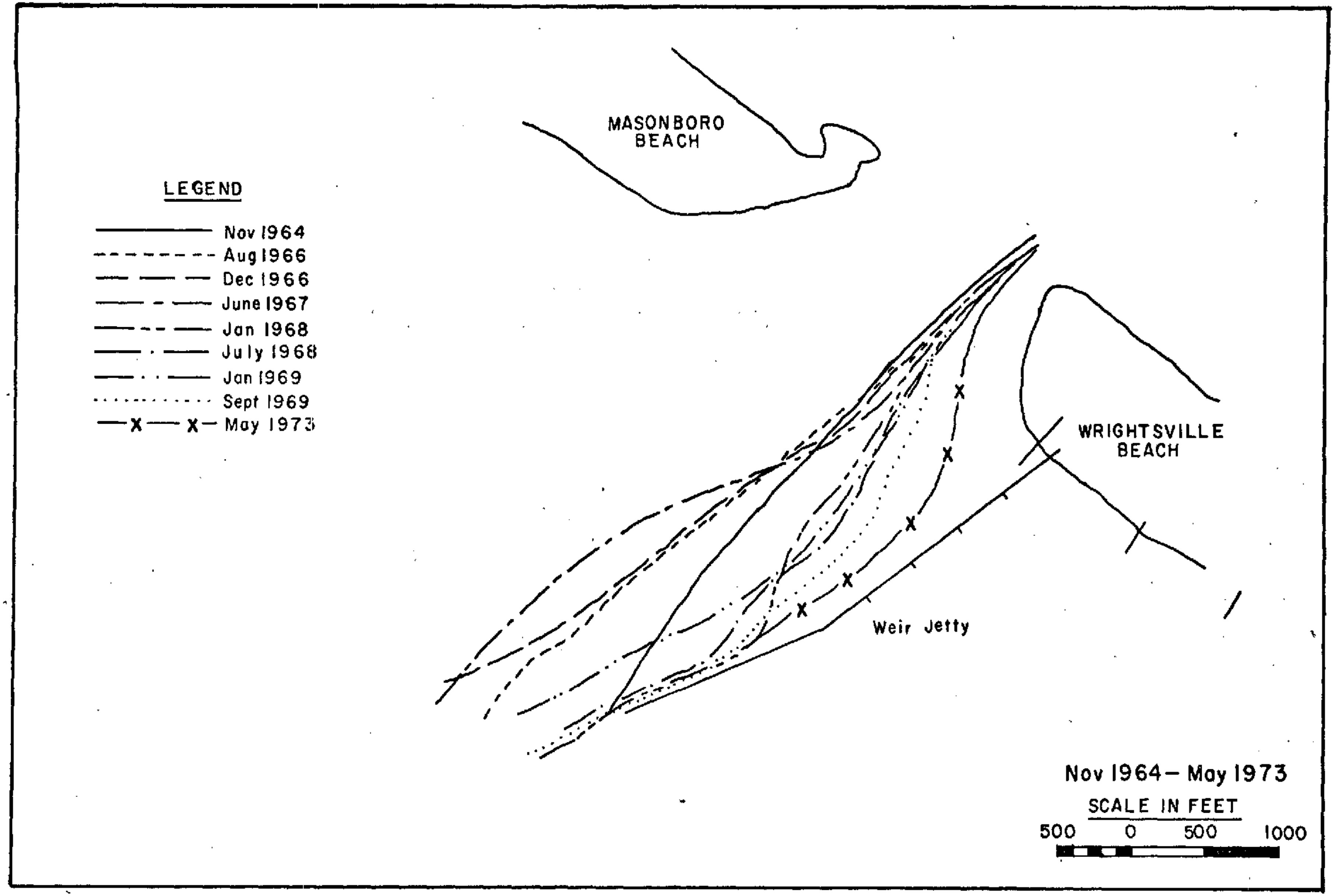

fig. 10– Channel thalwegs of Masonboro Inlet (CERC).

a part of this general trend.

Accretion of the northern tip of Masonboro Beach and the increase in shoaling along the south side of Masonboro Inlet may be due to any combination of several factors in addition to normal shoaling associated with inlet tidal flow. One of these factors is northbound littoral drift. During the fall and winter months, waves approach the area around Masonboro Inlet more frequently from the northeast and east, producing southbound littoral currents. During the spring a transition period is observed during which waves strike the beach with almost equal frequency from all directions, resulting in frequent reversals in the direction of littoral transport. During the summer, waves are more likely to come from the southeast and south and produce northward drift (11). Although on an annual basis the predominant direction of wave attack is from the northeast and east, shoaling and accretion on the south side continue because of the occasional contribution made by northward moving currents. Moreover, during those times when the waves are coming from the northeast and east, the shoal is protected by the weir jetty.

Another factor that may contribute to the shoaling is wave diffraction. Waves approaching the end of the jetty are diffracted, and the resulting loss in wave energy causes whatever sediment load there is to be deposited in the shoaled area. This phenomenon of wave diffraction around the jetty's end is visible in figure 9(b).

Wrightsville Beach: No discernible change has taken place on Wrightsville Beach as viewed in the ERTS-1 imagery. Like Masonboro Beach the amount of sand lost approximately equaled the amount gained during the time interval under consideration. Some accretion is visible on the north side of the Masonboro jetty but, like the rest of the beach, apparently has remained stable in the time period between ERTS-1 observations.

Summary and Conclusions

The present study was undertaken in order to determine how satellite imagery may be applied to specific coastal engineering problems. The study revolved around unenhanced imagery recorded by the four spectral channels of the ERTS-1 multi-spectral scanner. Some of the problems encountered with analysis of the ERTS-1 imagery were discussed, as were the advantages offered by examination of each spectral band separately. In addition a number of coastal features seen in ERTS-1 films including sediment plumes discharged from inlets, a change in water coloration, inlet bars and cape bars were examined and discussed. These features were correlated wtih ground truth data. Morphological changes in selected coastal land features were determined by direct comparison of ERTS-1 films obtained about one year apart. It is expected that the observations presented in this report will provide significant input into other coastal studies being conducted along the coastal segment of North Carolina under consideration.

Two characteristics of satellite imagery are considered essential attributes when applied to coastal engineering problems. The first characteristic is adequate water depth penetration. It has been shown that depth of water penetration by light increases as wavelength decreases. This property of light has allowed examination of certain underwater features in the lower MSS bands of the ERTS-1 imagery. As can be inferred from the imagery presented in this report, specifically in reference to the shoals and bars, depth penetration in MSS channel 4 is estimated to be on the order of tens of feet. (Actual depth penetration by light of a given wavelength can vary greatly, depending on the physical characteristics of seawater). While this penetration capability may not be adequate for deeper areas, it has been shown to be adequate for making useful qualitative observations of estuarine and nearshore underwater features.

The other important characteristic is image resolution capable of discerning small-scale features normally required in coastal studies. Some of these features include: wave patterns, nearshore current patterns, morphological features on beaches, and engineering structures such as groins, seawalls, jetties and breakwaters. At present, such features must be sufficiently large so as to fall within the limits of the ERTS-1 sensor's resolving capability. Examination of the ERTS-1 imagery has shown that, although many of the smaller scale features of interest in coastal engineering are not visible in the imagery, many important observations of gross features can be made.

Most notable of these were the temporal changes in morphology of tidal inlets and barrier islands observed by direct comparison of ERTS-1 images. In addition the current resolving capability of the Multi-Spectral Scanner appears to be adequate for mapping land-water interfaces with a degree of accuracy that compares favorably with current methods of mapping.

Recommendations

From the point of view of coastal engineering, improvements in depth penetration capability and resolving power probably would lead to wider application of satellite imagery in coastal studies. While the ERTS-1 imagery has been shown to be useful in analyzing gross surface and near-shore features, much of what needs to be examined in the solution of coastal engineering problems is found below water level and at scales too small for or bordering on the present resolving capability of the Multi-Spectral Scanner. A resolving power of fifty feet or better would be adequate to cover most structures and features of interest in coastal engineering. It is anticipated that improvements in optical technology to be incorporated in future satellites will include increased resolving capability. Greater water penetration capability may be afforded by the addition of a blue-band channel in future satellite-borne sensors.

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