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LANDSAT APPLICATION OF REMOTE SENSING TO SHORELINE-FORM ANALYSIS

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16. Abstract

The relationship between shoreline form and shoreline erosion for Cape Hatteras National Seashore was studied using data from Landsat imagery and low-altitude aerial photography. A significantly high correlation exists between coastal orientation and the standard deviation of rate of erosion for Ocracoke Island (greater than .9 at the 1% level). Low correlations for Hatteras Island were found. The results are compared to those for Assateague Island. The same correlations are high for coastal areas where the mean orientation approaches a northeast/southeast direction.

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PREFACE

Objective

Our objective is to quantify relationships between shoreline form and coastal dynamics and to predict areas vulnerable to shoreline erosion and storm-surge penetration. We are using Landsat enlargements, high-altitude aerial photography, and low-altitude aerial photography to accomplish these objectives.

Scope of Work

Results from our analyses of the correlation and regression between coastal erosion and coastal orientation on Cape Hatteras National Seashore are compared to the results of our analysis of Assateague Island (NASA Quarterly Report, March 1976). Base maps are now being drawn in preparation for the collection of shoreline-change data at Cape Lookout National Seashore. This data will enable us to test our ability to assess relative shoreline vulnerability-to-storm-damage from Landsat imagery.

Most of our work with Landsat has been in measuring linear configurations of long stretches of barrier islands. We recently began a project that will assess the usefulness of Landsat in detecting and measuring changes in surface area over a given period of time.

Field work now in progress is provding us with beach data that will be combined with data from Landsat and aerial photography so that process/response relationships of the barrier islands can be further explored.

Conclusions

For those sections of the mid-Atlantic coast which we have studied, the following relationship holds: When the mean orientation of a large section of the coast approaches a northeast/southwest direction, there is a significantly high correlation (greater than .9 at the 1% level) between coastal orientation (degrees north of south) and the standard deviation in rate of erosion (meters/year) for smaller coastal segments within the larger section. In this region, the dominant storm-wave approach is from the northeast. It is, therefore, plausible to conclude that along any sedimentary coasts where the mean orientation lies in the approximate direction of the dominant storm-wave approach, there will be a similar relationship between coastal orientation and coastal erosion. If this is true, then Landsat imagery for orientation measurements and a clear understanding of the climatic (dominant storm) regime are the 2 major requirements needed to determine historical erosional patterns and to predict future erosional patterns for such sedimentary coasts.

Summary of Recommendations

The existing data for Assateague and Cape Hatteras should be further analyzed. Cape Lookout should be mapped and analyzed to further test our hypothesis on the relationship between shoreline form and coastal dynamics. Our data base for the study of geomorphic processes will, thereby, be increased and will eventually assist in the maangement of the coastal zone. A developed area such as Fenwick Island or New Jersey should also be studied to assess man's impact on the process/response relationship along the coast.

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INTRODUCTION

Our previous quarterly report (for 12/2/75-3/2/76) described how we collect historical data on shoreline change from low-altitude aerial photography and current data on shoreline form from Landsat imagery. Our analysis of the relationship between coastal erosion and orientation for Assateague Island was also presented at that time.

In this report we present parallel data and analyses for Cape Hatteras National Seashore. Also presented are a progress report on our field work at Cape Hatteras and Assateague; a progress report on our assessment of multilevel remote sensing of gemorphic change; and a review of our plans for establishing base-line studies of vegetation and shoreline changes on Cape Lookout National Seashore.

ACCOMPLISHMENTS

We have computed the correlations between historical erosion and coastal orientation data for Cape Hatteras National Seashore. In this report, the initial results of these analyses are compared to the results from our Assateague Island studies.

We began our field work during this reporting period. A team of 4 students is now collecting data along the Cape Hatteras coast.

We have nearly completed our assessment of the relative merits of Landsat, high-altitude, and low-altitude imagery for quantifying change in surface area. Our specific site is the southern end of Assateague Island.

Earlier this month, the National Park Service agreed to purchase aerial photography of Cape Lookout National Seashore for our base-line studies of that area. We have, therefore, initiated a major project to supply the same type of data for Cape Lookout as we are now analyzing for Assateague and Cape Hatteras.

CORRELATION BETWEEN COASTAL EROSION AND COASTAL ORIENTATION FOR CAPE HATTERAS NATIONAL SEASHORE

In the March quarterly report we stated our hypothesis that there is a measurable relationship between shoreline form and coastal dynamics; i.e., the variance of shoreline change should increase as the shoreline approaches a north/south orientation when measurements are taken in the mesoscale range of 5 to 10 kilometers. We described our method of measuring historical shoreline change from low-altitude aerial photography and current shoreline form from Landsat imagery. We also described our method of testing the correlation between these 2 parameters for Assateague Island (Fig. 1), and we presented the results of our analyses.

We have now performed the same tests for 3 sections of Cape Hatteras National Seashore (Fig. 2): Ocracoke Island (base maps 2-9), South Hatteras (base maps 11-15), and North Hatteras (base maps 17-40).

Historical shoreline change (erosion or accretion) over the last 30 years has been measured at 100-meter intervals along the entire coast of Cape Hatteras National Seashore, from Ocracoke Inlet to Nags Head, 128 kilometers. Six sets of aerial photography were used: 1 July 1945; 10 October 1958; 13 March 1962; 13 December 1962; 3 October 1968; and 4 June 1974. The scope of this photography enabled us to measure the variance of shoreline change as well as the mean rate of change over all time periods.

We have measured shoreline orientation from Landsat imagery enlarged to 1:80,000 scale (frames 5014-14490-7 and 5014-14493-7). The angular orientation of straight-line segments of the shoreline was measured by degrees north of south (the supplement of the azimuth).

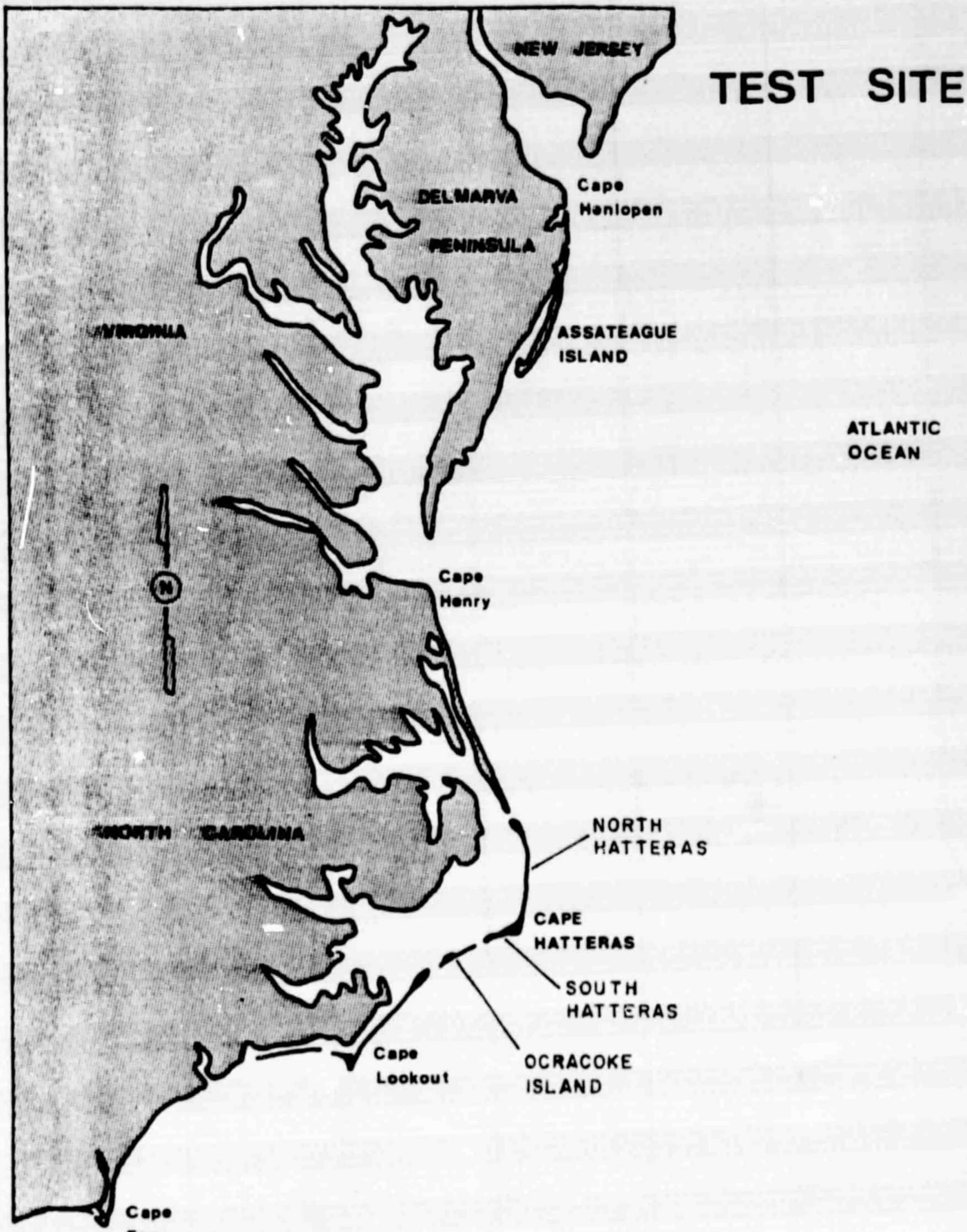

Figure 1: Barrier Islands of the Mid-Atlantic Coast

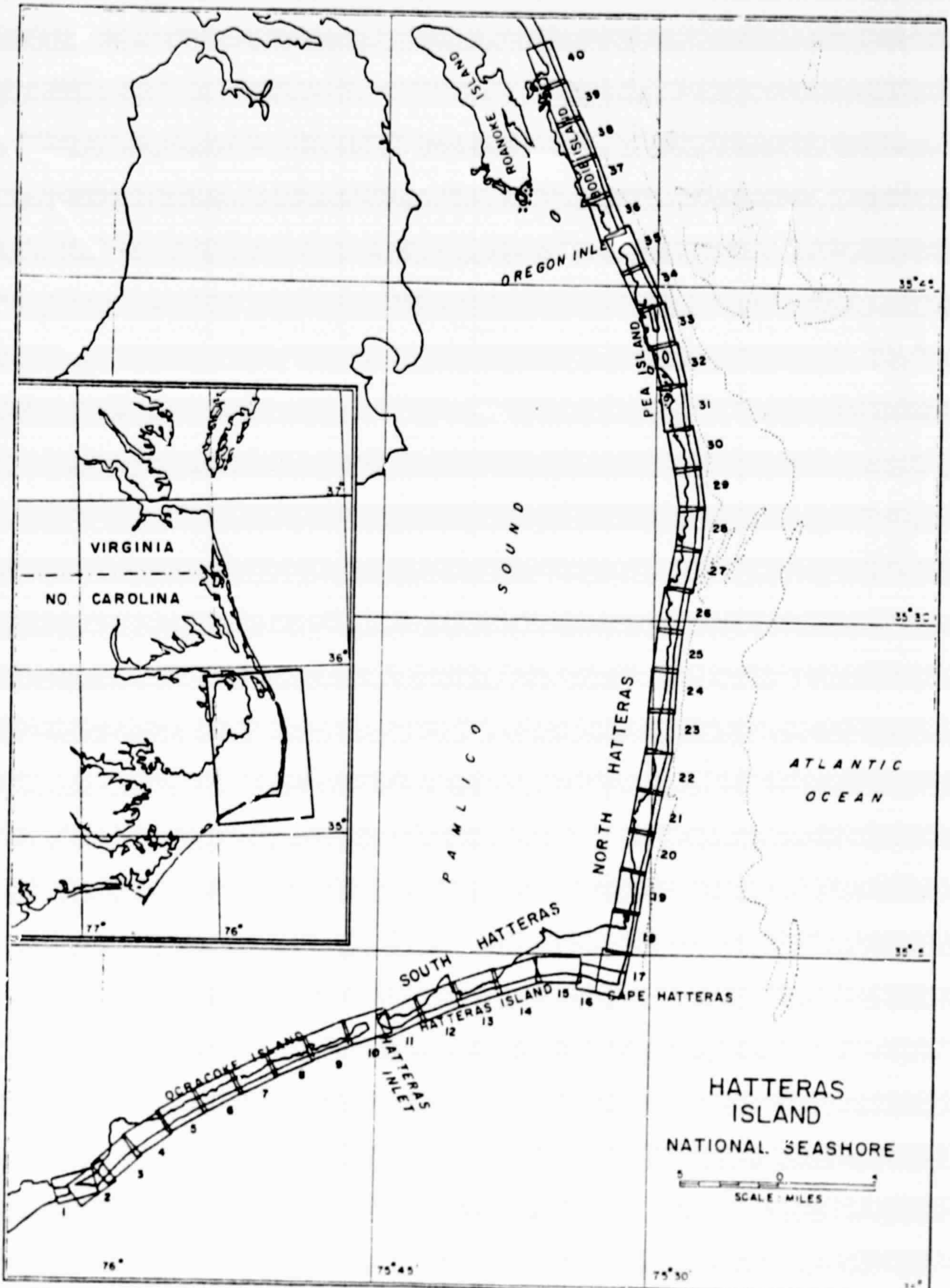

Figure 2: Base maps for Cape Hatteras National Seashore

The data was also used for regression analyses as described in the March report. Correlation statistics are presented in this report for the standard deviation of rate of erosion (meters/year) versus orientation (degrees) (Tables 1, 2, and 3). Similar correlations for Assateague are shown in Table 4 for comparison purposes.

When we submitted coastal orientation data to the computer, we also indicated a threshold angle (Orientation-Change Threshold) which the computer used to determine how many straight segments the coast would be divided into (Numbers of Segments) and where the divisions would occur (Fig. 3). For example, an entry of 1.5° in the first column of Table 1 means that the supplement of the obtuse angle between adjacent straight segments of the coast is at least 1.5°. With each successive run, the threshold angle is increased. This usually results in a decrease in number of segments and an increase in mean segment length as the mesoscale range of 5 to 10 kilometers is approached.

TABLE 1. CORRELATION BETWEEN COASTAL ORIENTATION AND COASTAL EROSION FOR OCRACOKE ISLAND

Orientation = Degrees north of south
Erosion = Standard deviation of rate of erosion, meters/year

Orientation Change Threshold	Number of Segments	Mean Segment Length	Correlation Coefficient (r)	Significance of r (s)	Standard Error of Estimate of r (e)
.5°	24	1.0 km	.86**	.00001	3.1
1.0	17	1.5	.86**	.00001	3.5
1.5	13	1.9	.89**	.00003	2.8
2.0	11	2.3	.87**	.00026	3.1
2.5	10	2.5	.87**	.00047	3.1
3.0	8	3.1	.87**	.00260	3.2
3.5	7	3.5	.86**	.00637	3.3
4.0	7	3.5	.86**	.00633	3.1
4.5	6	4.1	.91**	.00600	2.9
5.0	5	5.0	.92*	.01233	2.9
5.5	5	5.0	.93*	.01163	2.8
6.0	5	5.0	.94**	.00963	2.6
6.5	4	6.2	.95*	.02499	2.6
7.0	4	6.2	.96*	.02128	2.3
7.5	4	6.2	.95*	.02543	2.5
8.0	4	6.2	.95*	.02543	2.5
8.5	4	6.2	.92*	.03780	2.9
9.0	3	8.3	.96	.09050	2.8

**Significant at the 1% level
*Significant at the 5% level

TABLE 2. CORRELATION BETWEEN COASTAL ORIENTATION AND COASTAL EROSION FOR SOUTH HATTERAS

Orientation = Degrees north of south
Erosion = Standard deviation of rate of erosion, meters/year

Orientation Change Threshold	Number of Segments	Mean Segment Length	Correlation Coefficient (r)	Significance of r (s)	Standard Error of Estimate of (e)
.5°	24	.6 km	.49**	.00727	2.1
1.0	19	.8	.43*	.03382	2.3
1.5	12	1.2	.41	.09278	1.9
2.0	10	1.5	.36	.15468	2.0
2.5	9	1.7	.36	.16881	2.1
3.0	8	1.9	.42	.15121	2.1
3.5	7	2.1	.42	.17098	2.2
4.0	4	3.7	.22	.38860	.7
4.5	4	3.7	.22	.38860	.7
5.0	4	3.7	.17	.41427	.8
5.5	4	3.7	-.26	.36753	1.2
6.0	3	5.0	.37	.38098	.8
6.5	3	5.0	.30	.40140	.8
7.0	3	5.0	.30	.40140	.8
7.5	3	5.0	.24	.42317	.9
8.0	3	5.0	-.18	.44138	1.4
8.5	3	5.0	-.36	.38418	1.6

**Significant at the 1% level
*Significant at the 5% level

TABLE 3. CORRELATION BETWEEN COASTAL ORIENTATION AND COASTAL EROSION FOR NORTH HATTERAS

Orientation = Degrees north of south
Erosion = Standard deviation of rate of erosion, meters/year

Orientation Change Threshold	Number of Segments	Mean Segment Length	Correlation Coefficient (r)*	Significance of r (s)	Standard Error of Estimate of r (e)
.5°	59	1.3 km	-.15	.13214	3.2
1.0	45	1.8	-.13	.18896	3.3
1.5	39	2.0	-.18	.13187	3.4
2.0	26	3.1	-.22	.13773	2.9
2.5	18	4.4	-.23	.17876	2.9
3.0	21	3.8	-.26	.13146	2.8
3.5	17	4.7	.03	.45390	1.6
4.0	13	6.1	-.29	.16552	1.4
4.5	11	7.2	-.24	.23535	1.4
5.0	10	7.9	-.19	.29906	1.2
5.5	9	8.8	-.26	.24915	1.1
6.0	8	9.9	-.39	.17199	1.3
6.5	8	9.9	-.25	.27449	.9
7.0	8	9.9	-.34	.20702	.7
7.5	8	9.9	-.35	.19869	.8
8.0	8	9.9	-.28	.25091	1.1
8.5	8	9.9	-.31	.23087	1.1
9.0	5	15.9	-.23	.35695	.9
9.5	5	15.9	-.37	.27102	.7
10.0	5	15.9	-.24	.34567	.8

*No correlations are significant at the 1% or 5% levels.

TABLE 4: CORRELATION STATISTICS AFTER REMOVAL OF ANOMALISTIC SEGMENTS

CORRELATION STATISTICS FOR SHORELINE FORM VS. COASTAL DYNAMICS FOR ASSATEAGUE ISLAND

Angular Orientation (Degrees North of East)
x Standard Deviation of Rate of Erosion (Meters/Year)

Orientation Change Threshold	Number of Segments	Mean Segment Length	Correlation Coefficient (r)	Significance of r (s)	Standard Error of Estimate of r (e)
.5°	55	1.0km	.80 **	.00001	2.0
1.0	33	1.7	.80 **	.00001	1.9
1.5	25	2.2	.84 **	.00001	1.7
2.0	17	3.3	.86 **	.00001	1.6
2.5	14	3.9	.84 **	.00009	1.8
3.0	15	3.7	.75 **	.00057	2.9
3.5	10	5.5	.90 **	.00022	1.5
4.0	8	6.9	.92 **	.00054	1.4
4.5	8	6.9	.93 **	.00036	1.4
5.0	6	9.2	.93 **	.00364	1.5
5.5	5	11.1	.92 *	.01330	1.3
6.0	3	18.4	.99	.05143	0.7
6.5	5	11.1	.92 *	.01290	1.4
7.0	3	18.4	.97	.08314	1.2
7.5	3	18.4	.97	.08134	1.2
8.0	3	18.4	.96	.09389	1.5

** Significant at the 1% level.

* Significant at the 5% level.

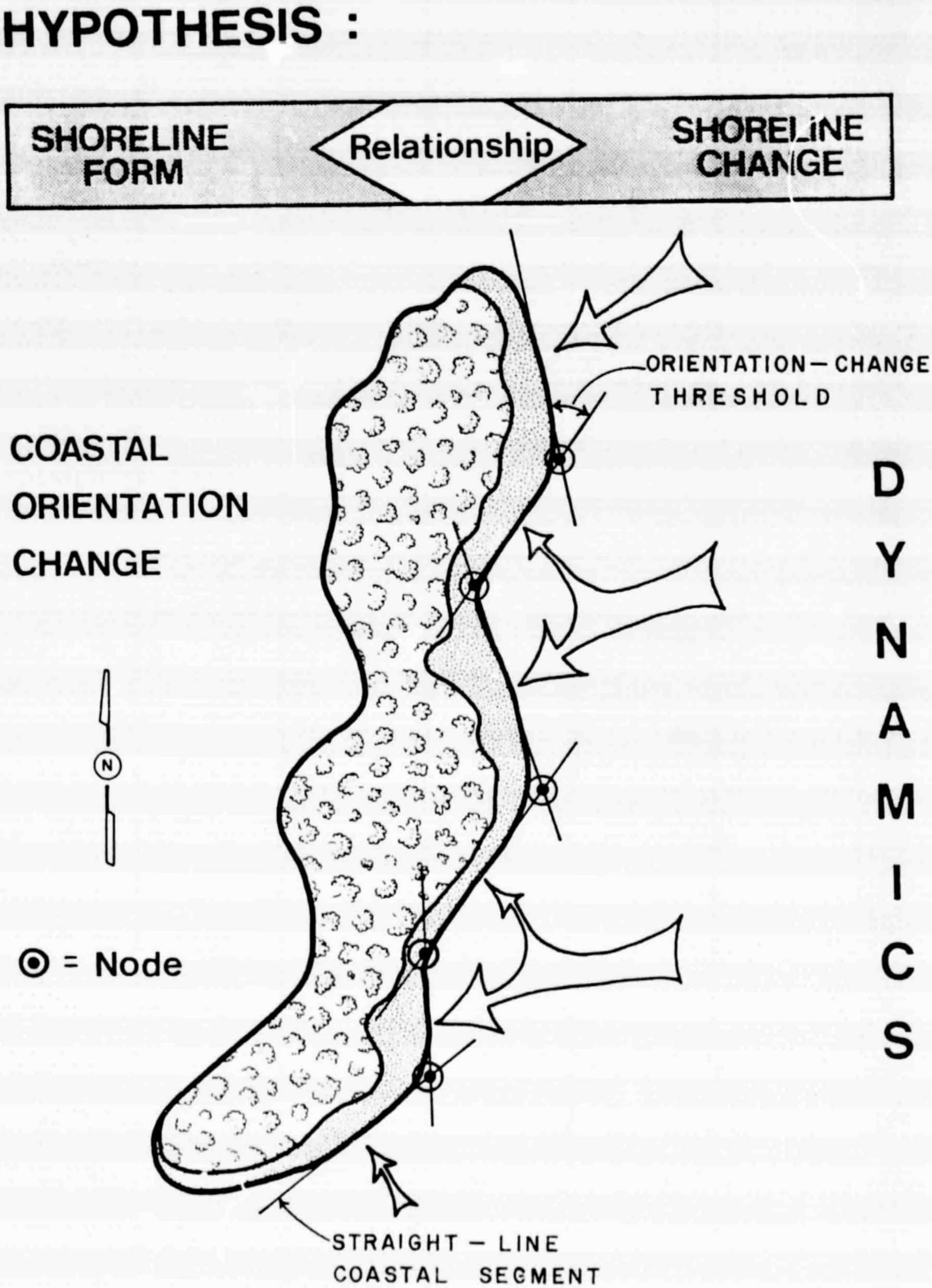

Figure 3: Straight-Line Coastal Segments and Orientation-Change Threshold.

SIGNIFICANT RESULTS

The correlation coefficients versus the number of coastal segments are plotted in Figure 4. The data for Assateague Island and Ocracoke Island show significantly high correlations between coastal orientation and erosion (greater than .9 at the 1% level in many cases). However, South Hatteras has low correlations and North Hatteras has low negative correlations. Because all 4 areas are essentially in the same mid-Atlantic climatic regime, process/response relationships should be similar. In the past the most extensive coastal damage in our study area has been caused by extra-tropical storms. As these storms move northeast with their winds circulating counter-clockwise around the eye of the storm, the highest and most damaging waves approach the coast from the northeast (Fig. 5).

Correlations for the 4 areas may differ considerably because of inadequate assumptions in our original model. We feel that the key is the mean orientation of the specific coastline being studied.

Mean orientation obtained from Landsat imagery for North Hatteras is 183.5° north of south; for Assateague, 156.5° north of south; for Ocracoke, 121.5° north of south; and for South Hatteras, 107.6° north of south (Fig. 6). There appears to be an "orientation window" surrounding due northeast (135° north of south) in which our hypothesis holds.

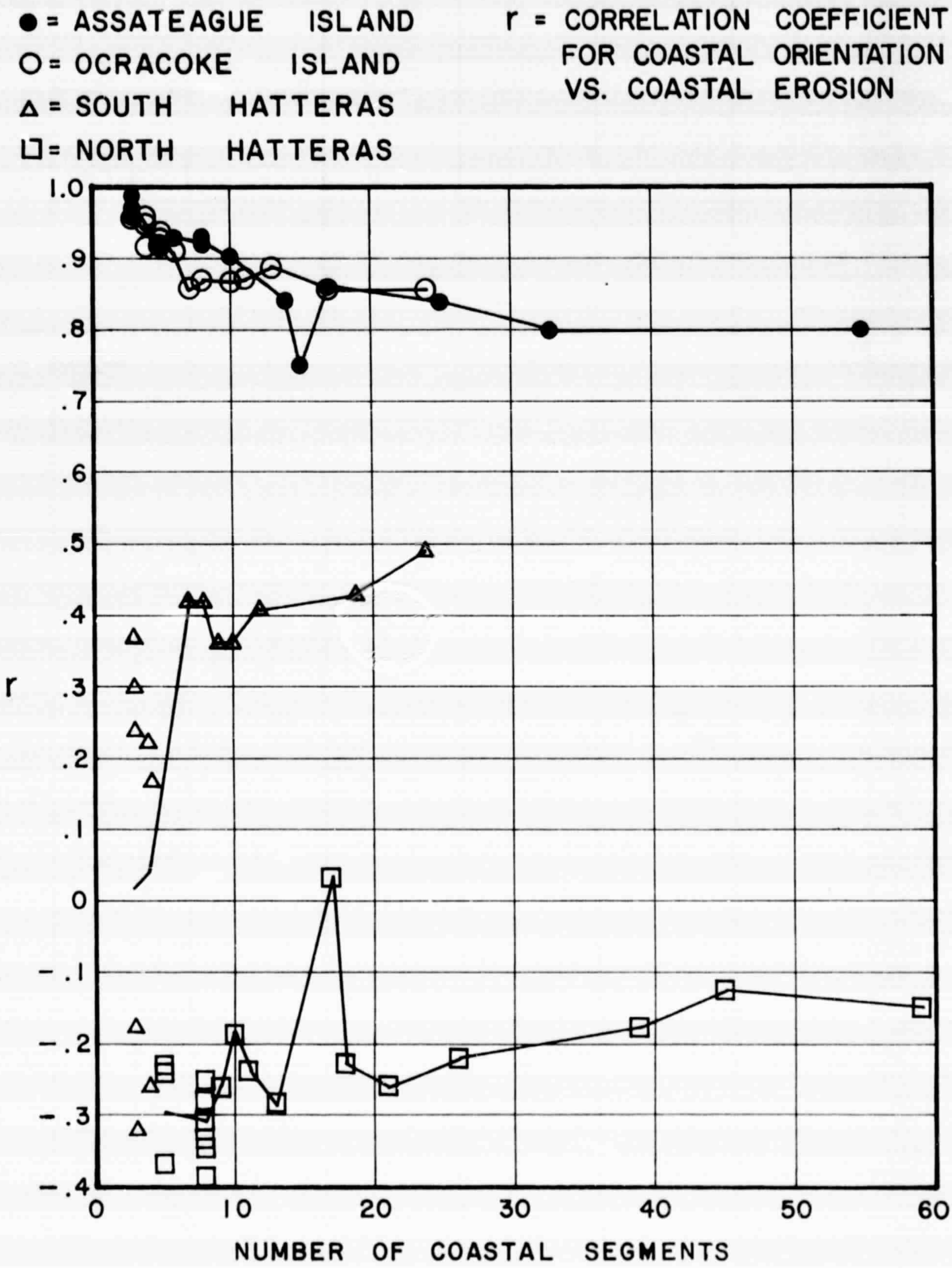

Figure 4: Correlation Coefficients versus Number of Coastal Segments

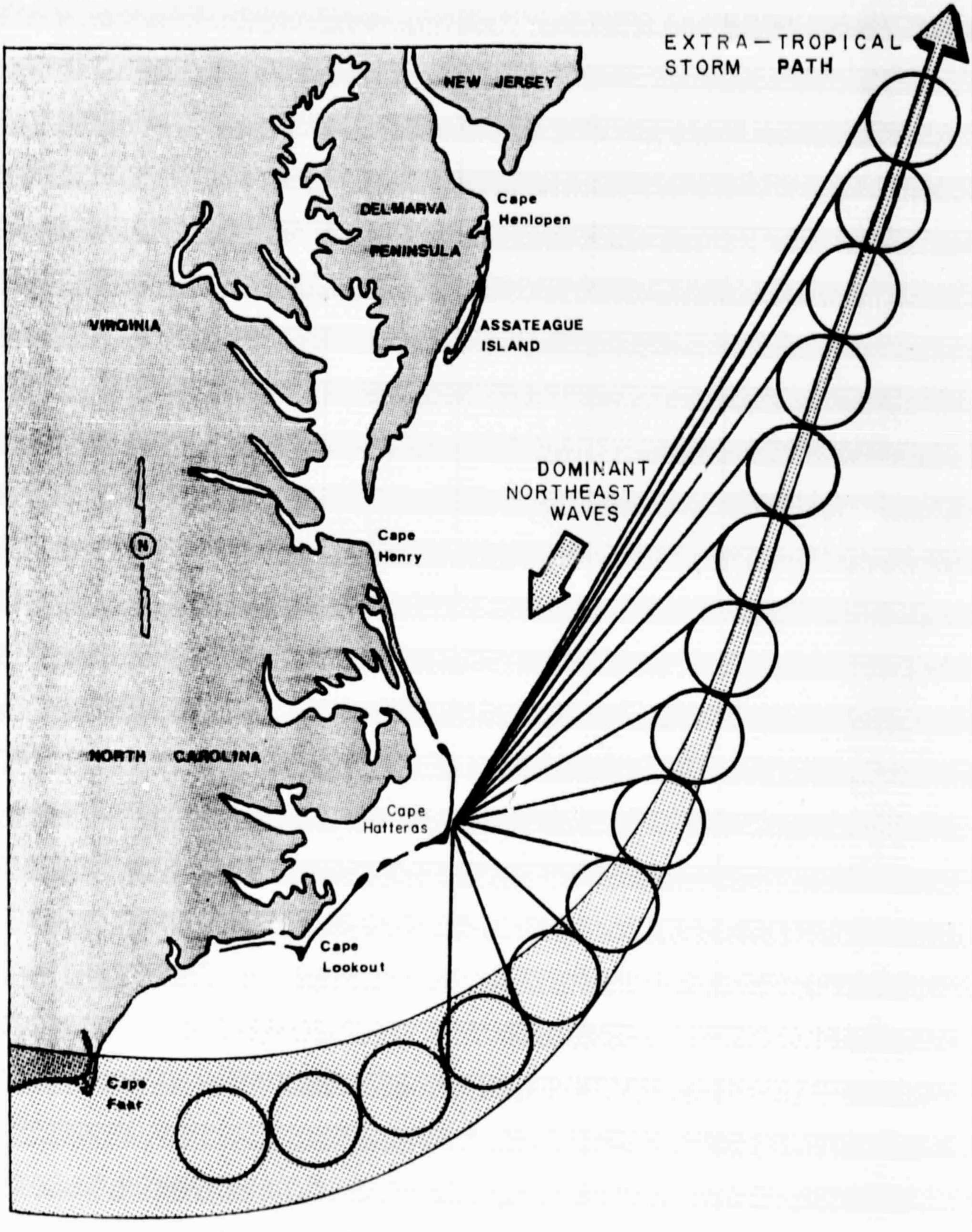

Figure 5: Dominant Storm-Wave Approach.

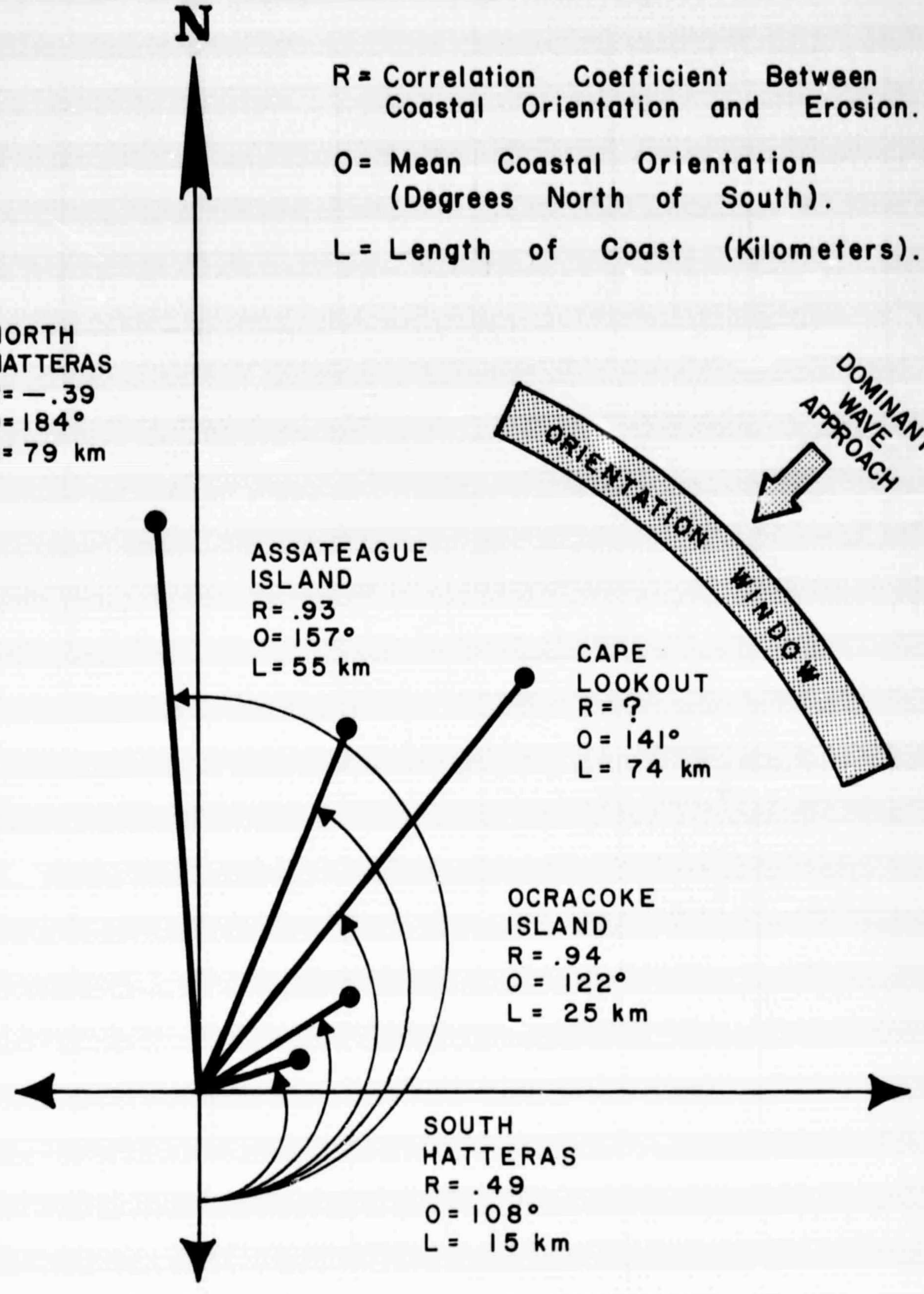

Figure 6: Mean Orientation of Coast Line.

CONCLUSIONS

We have now tested our hypothesis--as a straight-line section of coast approaches a north/south orientation, the standard deviation of rate of erosion increases--on 4 areas of the mid-Atlantic coast. The closer the mean orientation of the coastline is to a northeast direction, the stronger our hypothesis holds, thereby supporting the conclusions stated in our March report. However, the key is in first determining the mean orientation of a given stretch of coast; this is best accomplished with the use of Landsat imagery. Therefore, for any major stretch of sedimentary coast in the mid-Atlantic region with a mean orientation within approximately 20° of due northeast, the relative historic erosional patterns can be assessed and future relative erosional patterns can be predicted simply by studying the current form of the shoreline; i.e., by measuring the orientation of straight-line segments of the coast.

We know that shoreline form and shoreline erosion are responses to physical dynamics (i.e., storm activity) of a given region. We have shown that our hypothesis holds for coasts located within a certain "orientation window" with a dominant wave approach from a known direction. Therefore, our hypothesis should hold for sedimentary coasts elsewhere in the world simply by adjusting the numerical expression for orientation to conform with the dominant wave approach of the specific climatic regime.

Our findings stress the importance of using 3 scales of observation in attempting to use shoreline-form analysis to study erosional trends: the macroscale to determine mean orientation of a major stretch of coast (Landsat); the mesoscale to determine relative degrees of variance in shoreline movement over shorter sections of the coast (Landsat and U-2); the microscale to measure absolute erosion rates at specific sites (low altitude).

PROBLEMS

We are now closer to determining the natural relationship between shoreline form and coastal erosion. Yet there are many questions remaining, and our findings are based on a relatively limited area. We do not know the size of our "orientation window." We have not defined the window of dominant wave approach, other than to say it is from the northeast. What is the relationship between orientation and erosion for those coastlines outside the "orientation window"? What effect does offshore and inshore bathymetry have on the relationship between shoreline form and erosion? Are there other important indicators in the microscale, such as sand-grain size or beach slope, that relate to coastal erosion in the mesoscale?

RECOMMENDATIONS

Our findings are supporting our hypothesis. However, the data for North Hatteras and South Hatteras should be analyzed in greater depth to further explain why the correlations are so low.

The National Park Service recently declared their support of our studies of Cape Lookout National Seashore by purchasing historical aerial photography for our use. We hope to obtain additional flight support from them. The mean orientation of these Outer Banks is approximately 141° north of south. This falls in the middle of the "orientation window" defined for our site. We should, therefore, be able to determine the historical erosional patterns from Landsat imagery with very high accuracy. We plan to test our hypothesis on Cape Lookout by mapping the relative magnitudes of shoreline change based solely on present coastal configuration as seen on Landsat imagery. We will then test our accuracy by measuring that change from the low-altitude historical photos. This will also supply us with an additional data bank for future studies. Rather than mapping the data at a scale of 1:5,000, we will draw our base maps at 1:10,000, which will greatly reduce the time required for data collection.

A developed area, such as Fenwick Island or New Jersey, should be studied to determine to what degree man's impact has affected the natural process/response relationship along the coast.

ASSESSMENT OF MULTILEVEL REMOTE SENSING

In March we reported on the best applications for Landsat imagery. We are now assessing the relative merits of Landsat, small-scale (1:130,000), and large-scale (1:24,000) aerial photography for detecting and quantifying changes in area and configuration of the land at the southern end of Assateague Island. For mapping purpose, 1:80,000 is a useful scale at which to enlarge the 70 mm. Landsat transparencies.

Based on the availability of aerial photography, we have selected spring 1975 and winter 1976 as the two time periods between which change will be measured. Dates for Landsat imagery were then chosen accordingly.

The 1:24,000-scale photography was taken on 17 April 1975 and 19 February 1976; the 1:130,000-scale photography on 8 May 1975 and 25 February 1976; and the Landsat imagery on 22 May 1975, 31 May 1975, and 24 February 1976.

After making test enlargements, MSS band 7 proved to be the most useful for comparing the test site to that seen in the photography. Thus, band 7 will be used in future comparisons.

The test site was measured with a compensating planimeter and the variable-enlargement K&E KARGL reflecting projector. A complete review of our findings will be presented in the next quarterly report.

FIELD WORK

On 24 May, 4 students began collecting field data along the coast of Cape Hatteras National Seashore. Information on beach width, beach slope, fore-dune height, and sand-grain size (Fig. 7) is being collected at 180 locations which have been randomly chosen from Ocracoke Inlet to Nags Head. Each location coincides with a transect where historical shoreline change was measured. Our research team will then move to Assateague Island to collect data at 90 sites from Chincoteague Inlet to Ocean City Inlet. These data will be used to conduct further studies related to shoreline form, coastal erosion, and general barrier-island geomorphology.

BEACH DATA AT CAPE HATTERAS NATIONAL SEASHORE
June, 1976 (Measurements in Meters)

Site No.__________ Map No.__________ Transect No.__________

Date________ Time________ High Tide________ Low Tide________ Tide Range________

Measurements

	Foredune	Subaerial Beach		Swash Zone		Total Beach
Rod Height	________	________		________		________
Level Height	________	________		________		________
Elevation	________	________	+	________	=	________
Distance	________	________	+	________	=	________
Comp. Slope	________%	________%		________%		________%
Meas. Slope	________°	________%		________°		________%
	(Fore dune)			(Swash Zone)		

Visual Description

Beach: Straight________, Cusping________, Sand Wave________, Cape________

Distance Between Nodes: ________ ________

Foredune: Scarped________, Sloping________, Throat of Fan________, Absent________

Overwash Fan: Width at dune________, Length________, Flats________

Sand Samples	Base of Dune	Berm Crest
Mean Grain Size:	________	________
Standard Deviation:	________	________
Sample Size:	________	________

Comments:

Figure 7: Sample Data Sheet for Field Work.

LANDSAT USER BENEFITS

Landsat imagery is an indispensable tool for quantifying coastal orientation in the mesoscale and macroscale range. This information, with knowledge about storm regimes, can be used to ascertain relative historical erosional patterns and, in turn, to predict relative future erosional patterns.

Landsat can be used to detect change in coastal geomorphology. We are now attempting to determine how large the change must be before it can be detected and measured with any degree of accuracy with simple techniques available to most photo interpreters.

PROGRAM FOR NEXT REPORTING INTERVAL

Work will continue with the analysis of data already gathered for Assateague and Cape Hatteras. When the base maps for Cape Lookout have been completed and all historical photography has been received, we will begin mapping shoreline and vegetation data for that area.

We will begin mapping a section of developed coast north of Ocean City Inlet, Maryland: the New Jersey coast and Fenwick Island are under consideration.

Field work will be completed in July. Analysis of this new data will begin in the fall when student assistance is available.

We have received low-altitude photography of Assateague from the Chesapeake Bay Ecological Program Office at NASA-Wallops dated 19 February and 15 March 1976. These 2 sets bracket one of the major storms of the 1975-1976 storm season. We have already identified those sections of Assateague Island that have been most vulnerable to storm activity in the past. As time permits, we will map the shoreline from this imagery to determine if we can predict from historical photography which areas of the coast are most vulnerable to storm damage.

PUBLICATIONS

Much of the base-line work for this project began in 1974 with support from the National Park Service. Through their continuing support, we have contracted to produce an Atlas of Environmental Dynamics for Assateague Island National Seashore. This will be a limited-edition publication that will serve as a management tool and information source for Assateague Island. It may also serve as a prototype for future publications on coastal-zone management. It will contain data and information obtained through studies supported by NASA and presented in the last 2 NASA quarterly reports.