REPORT DOCUMENTATION PAGE	*Form Approved* *OMB No. 0704-0188*

1. AGENCY USE ONLY (*Leave blank*)	2. REPORT DATE	3. REPORT TYPE AND DATES COVERED
	7/3/03	Final Technical Report for period 1 JAN 02 - 31 DEC 02

4. TITLE AND SUBTITLE
~~The Nearshore as a Complex System~~

5. FUNDING NUMBERS
N00014-02-1-0096

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8. PERFORMING ORGANIZATION REPORT NUMBER

9. SPONSORING/MONITORING AGENCY NAME(S) AND ADDRESS(ES)

Office of Naval Research
Ballston Centre Tower One
800 North Quincy Street
Arlington, VA 22217-5660

10. SPONSORING/MONITORING AGENCY REPORT NUMBER

11. SUPPLEMENTARY NOTES

12a. DISTRIBUTION/AVAILABILITY STATEMENT

12b. DISTRIBUTION CODE

13. ABSTRACT (*Maximum 200 words*)

The long-term goal of this research is to develop and test predictive models for nearshore processes. This is to be accomplished within the framework of the nearshore as a hierarchical complex system, wherein, at discretely ordered space and time scales, a small number of variables emerge as the dominant influences on the dynamics of this nonlinear, open system and the interactions between these dominant variables give rise to complex, emergent behavior.

14. SUBJECT TERMS
near shore processes

15. NUMBER OF PAGES
5

16. PRICE CODE

17. SECURITY CLASSIFICATION OF REPORT	18. SECURITY CLASSIFICATION OF THIS PAGE	19. SECURITY CLASSFICATION OF ABSTRACT	20. LIMITATION OF ABSTRACT
unclassified	unclassified	unclassified	

MODELING NEARSHORE PROCESSES AS COMPLEX SYSTEMS

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N00014-96-1-0078 Final Report

LONG-TERM GOALS

The long-term goal of this research is to develop and test predictive models for nearshore processes. This is to be accomplished within the framework of the nearshore as a hierarchical complex system, wherein, at discretely ordered space and time scales, a small number of variables emerge as the dominant influences on the dynamics of this nonlinear, open system and the interactions between these dominant variables give rise to complex, emergent behavior.

OBJECTIVES

Attractors, states to which a system evolves from a broad range of initial conditions, are robust features of systems characterized both by significant nonlinearity and high rates of dissipation, such as the nearshore. The evolution of a system to an attractor selects a temporal hierarchy of dominant dynamical variables, ordered so that variables characterized by a particular time scale enslave faster variables and evolve within a context determined by slower variables.

Motivated by a hierarchical, complex systems framework for nearshore processes, the specific objectives of this research project are (i) to identify the dominant variables and processes operative in the nearshore; (ii) to formulate and develop predictive, complex systems models for nearshore processes and features, including sand bars, megaripples, breaking waves, infragravity wave generation, surf zone currents, and swash zone flow and morphology; (iii) to test these models with existing field data; (iv) to relate complex systems models to measurements acquired through remote sensing; (v) to propose and design new field experiments capable of refuting these models.

APPROACH

Computer simulations, theory and field observation and experimentation are combined to formulate, develop, test and refine models for nearshore hydrodynamics and bathymetry.

Nearshore processes are nonlinear and dissipative. For systems with these characteristics, the traditional **Reductionist Approach** (fundamental physics/equations) fails because of a lack of defensible criteria for selecting dominant dynamical variables; and **Universalist** approaches (simple mechanisms that apply across a broad spectrum of systems) fail because the simplifying assumptions underlying Universalist models necessarily imply an inability to treat the variability and complexity inherent in the natural environment (external to the system being studied).

In contrast, the modeling and model-testing methodology adopted for this research is in concert with the nonlinear, open nature of nearshore processes. This **hierarchical modeling approach** for nearshore systems partially overlaps with methodologies adopted in physics (e.g., Synergetics: Haken, 1983) and ecology (Hierarchy Theory: Ahl and Allen, 1996), but differs from the former in avoiding the need to use systems of equations as a starting point and from the latter in its emphasis on variable selection via observation and description. It can be summarized with the following four steps:
(i) delineate the boundaries of the open system;
(ii) identify and temporally order dynamical variables of the systems and variables in the external environment affecting the system dynamics;
(iii) for selected levels in this temporal hierarchy, encapsulate the dynamics of faster variables into a minimal set of rules that relate variables at this level to each other and to the external environment;
(iv) formulate models at these selected levels and derive testable predictions of the models.

Variable selection in the nearshore depends largely on spatial and temporal localization of features and dynamics (e.g., the crests of bedforms), but cannot be predicted from first principles; rather, observations are a necessary step in determining the position of and relationships between variables in the hierarchy. Sensitive tests of models rely on the prediction and measurement of transient behavior, which is a fundamental aspect of natural (in contrast to laboratory) systems.

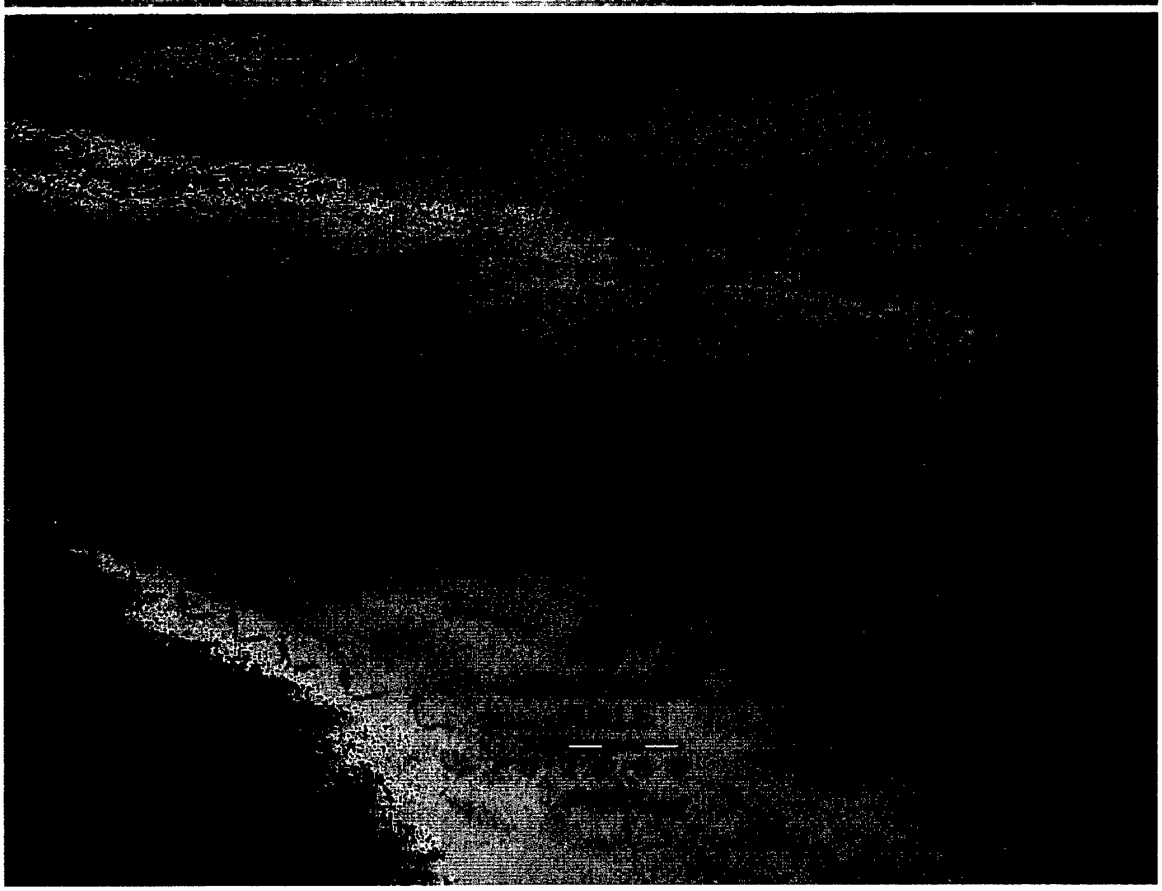
WORK COMPLETED

A new remote sensing video technique was developed to measure the inception, evolution and destruction of megaripples and other nearshore bathymetric features, a hierarchical set of models was formulated for bedforms and a model for rip currents based on newly hypothesized interactions was developed.

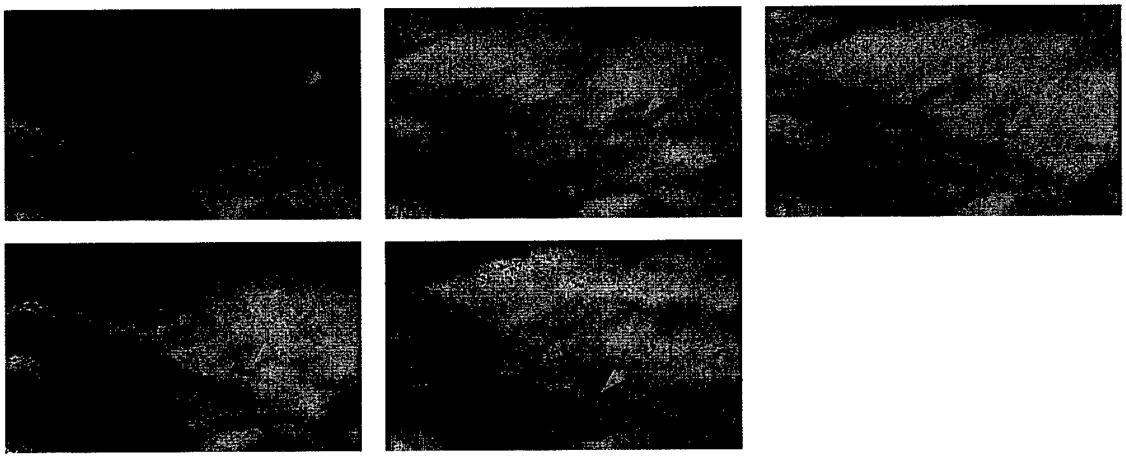
RESULTS

If the nearshore is a hierarchical complex system, it is expected that the formation and evolution of medium-scale bathymetric features such as megaripples are more influenced by the context set by longer-time-scale, larger-spatial-scale features (such as sand bars) than by smaller-scale sediment transport and fluid mechanics. Therefore, model development and testing requires techniques that can capture bathymetric evolution on time scales relevant to megaripples (less than hours) and spatial scales relevant to sand bars and larger features (hundreds of meters).

In an effort led by graduate student Linden Clarke, a new technique for imaging nearshore morphology with video has been developed and is being applied to the study of megaripples. Video frames of an oblique view of a surf/swash zone are downloaded to a workstation, processed to remove pixels from breaking waves or foam, averaged over a period of several minutes and false-color-enhanced to bring out bathymetric features. (See http://complex-systems.ucsd.edu/bathcam - available ~2/1/98.) Depending on conditions, megaripple crests, sand bar and rip channel locations, and sediment and cobble transport patterns can be extracted. Resolution is degraded by large waves, sediment-laden or bio-fouled water and glare. Below, two typical patterns on Scripps Beach are pictured: isolated patches of long-lived lunate megaripples and extensive, short-lived three-dimensional bedform patterns.



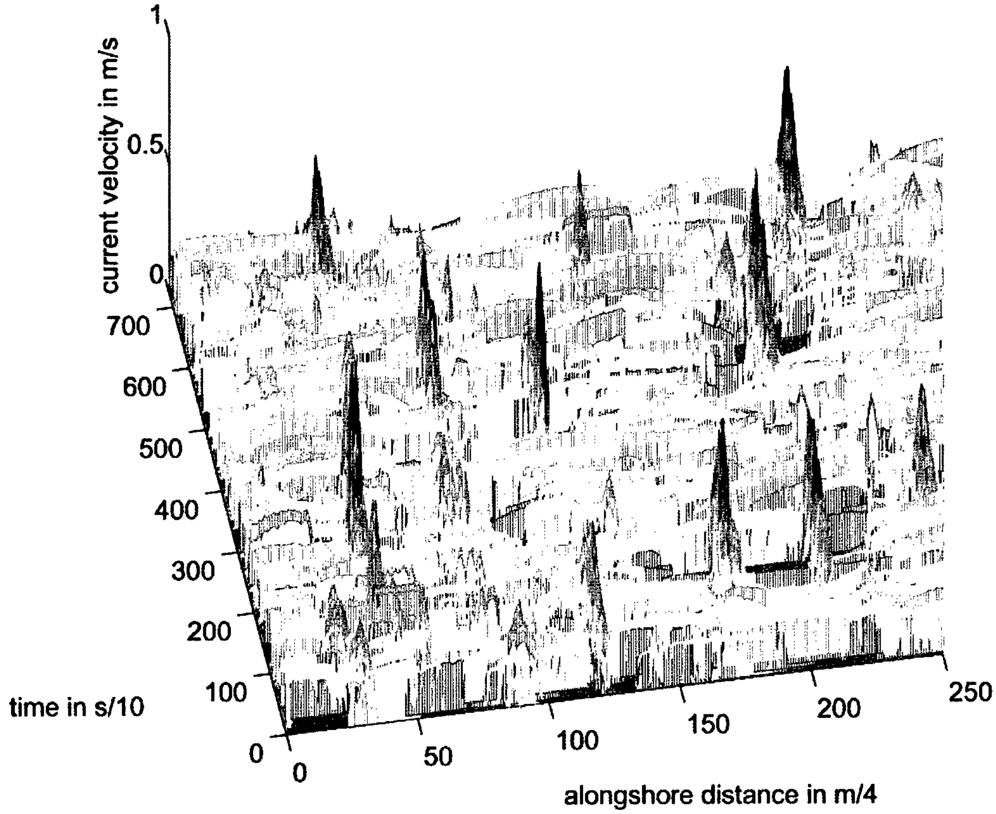
Onshore motion of cobbles in the surf and swash zones is detectable, as seen in the sequence of frames on the following page.



A hierarchical array of models has been developed for nearshore bedforms. At the longest time scales, pattern-scale variables including orientation and spacing are related to faster scales by the dynamics of defects to the bedform pattern (ends of crests). One level down in the hierarchy (faster time scale), the positions of bedform crests evolve within the context of the pattern-scale variables using an encapsulation of the mechanisms governing patterns of sediment transport. At the next faster level, sediment transport patterns are influenced by the slower-evolving positions of bedform crests and depend on simple characteristics of the details of sediment transport and fluid flow over and around bedforms. Models for the three top levels have been developed, with a focus this year on pattern-scale dynamics. Predictions for pattern-scale variables include: (i) steady-state bedform orientation and the rate of bedform re-orientation following a change of conditions depend on bedform size, density of defects and the relationship between the time scale of variations in transport direction and the time scale for defect migration; (ii) bedforms of different size and orientation that develop through essentially the same mechanisms can coexist; and (iii) bedform spacing increases (often slowly) with time under unchanging external conditions, as defects to the pattern migrate and annihilate.

Although rip currents generally are accepted as an alongshore intensification of return flow through the surf zone, the specific mechanisms driving their formation and evolution remain uncertain and somewhat unconstrained. Issues about which considerable uncertainty remain include: the very narrow width of rip currents relative to their spacing, which typically exceeds surf zone width; pulsation of rip currents; and rip current formation in the absence of alongshore bathymetric variations.

Postgraduate researcher Brad Murray has developed a cellular numerical model to address these issues. In the model, the complicated processes of water transport by waves and currents and sediment transport are encapsulated into minimal rules that express the effect of these processes at the length and time scales of rip currents. A key feature of the model is a newly proposed interaction in which a rip current decreases the wave height locally, as commonly has been noted from visual observations. This interaction could make an alongshore-uniform set up unstable. To date, the model has been found to predict narrow, pulsating rip currents and modeled rip current spacing, width, velocity and duration have been found to depend on basic characteristics of waves, including wave height and alongshore continuity of crests. Model prediction of spatial and temporal variation in offshore current velocity are qualitatively consistent with measurements made on Scripps Beach (Smith and Largier, 1995). Below, current velocity at the break point is graphed on a 1km section of coast over two hours.



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