DEVELOPMENT OF A COUPLED COASTAL DYNAMIC MODEL
PHASE I: A NEW NUMERICAL COASTAL WAVE MODELING

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Award # : NOOO14-95-F-0053

LONG-TERM GOAL

The long rang plan for this project is to develop a coupled wind-wave-current model for the coastal region. This model can provide the boundary condition for a global model, and the contribution of the coastal waters to the global air-sea heat balance. The specific goal of this project is more limited: to establish a coastal wave model as the first step towards the long term goal.

SCIENTIFIC OBJECTIVES

The specific objectives of this efforts are as follows:
1. to establish numerical code for computing the wave propagation,
2. to incorporate the nonlinear dispersive relationship into the wave kinematics,
3. to evaluate the nonlinear wave-wave interaction processes and to found the most computational effective means to compute the results.

APPROACH

In this study, we have approach the coastal wave modeling from three directions: numerical modeling, theoretical analysis, and analysis of observed coastal wave data.

Numerical and analysis was used to identify the best code, which is then used to test pure propagation of swells in a coastal region. Furthermore, we have also coded the four wave interaction computation in the nonlinear source function based on the Zakharov formulation. Though the final form still does not have a Homiltonian structure, the formulation resulted in a great reduction of computation time. Additional investigation into the higher order (five-wave) interaction was also conducted.

On theoretical study, we investigated of the mechanism of nonlinear wave evolution. In the process,

Report Documentation Page

Form Approved
OMB No. 0704-0188

1. REPORT DATE **30 SEP 1997**	2. REPORT TYPE	3. DATES COVERED **00-00-1997 to 00-00-1997**
4. TITLE AND SUBTITLE **Development of a Coupled Coastal Dynamic Model Phase 1: A New Numerical Coastal Wave Modeling**		5a. CONTRACT NUMBER 5b. GRANT NUMBER 5c. PROGRAM ELEMENT NUMBER
6. AUTHOR(S)		5d. PROJECT NUMBER 5e. TASK NUMBER 5f. WORK UNIT NUMBER
7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES) **National Aeronautics and Space Administration (NASA),Goddard Space Flight Center,Code 971,Greenbelt,MD,20771**		8. PERFORMING ORGANIZATION REPORT NUMBER
9. SPONSORING/MONITORING AGENCY NAME(S) AND ADDRESS(ES)		10. SPONSOR/MONITOR’S ACRONYM(S) 11. SPONSOR/MONITOR’S REPORT NUMBER(S)
12. DISTRIBUTION/AVAILABILITY STATEMENT **Approved for public release; distribution unlimited**		
13. SUPPLEMENTARY NOTES		
14. ABSTRACT		
15. SUBJECT TERMS		

16. SECURITY CLASSIFICATION OF:			17. LIMITATION OF ABSTRACT	18. NUMBER OF PAGES	19a. NAME OF RESPONSIBLE PERSON
a. REPORT **unclassified**	b. ABSTRACT **unclassified**	c. THIS PAGE **unclassified**	**Same as Report (SAR)**	**4**	

Standard Form 298 (Rev. 8-98)
Prescribed by ANSI Std Z39-18

we discovered a new nonlinear and nonstationary data analysis method, the Empirical Mode Decomposition and Hilbert Spectral Analysis method.

We have also examined both historical and recent data of the directional wind-wave development for fetch limited conditions. The data were from the Surface Contour Radar and the Scanning Radar Altimeter. All the data show that the wind waves are not aligned with the local wind direction.

WORK COMPLETED

As the research proceeded, we found the goal set at the beginning too ambitious. The time and manpower available for this task is order of magnitude smaller than either WAM or WISE program. So, our efforts centered on the identification of the mechanisms that would influence the coupled coastal dynamics model. Towards that end, I have proposed a Special Workgroup under SCOR (Scientific Committee for Oceanic Research) to further delineate the scientific issues related to the coupled coastal dynamics modeling. The proposal has been approved by the SCOR Executive Council. The duration for the Workgroup is for three years starting 1998.

We have also studied the nonlinear evolution of the water waves. We found that the process of frequency downshift to be a discrete fusion mechanism rather than a continuous process. Because of the fusion is local, the phase and frequency variation is not really gradual as assumed in the classical wave theory. The frequency changes behave like the propagation of defects: A local fusion of two waves into one wave, and the defect propagates to the general case of n-wave becoming (n-1)-wave. The result is published in an invited article in the Advances in Applied Mechanics.

To study this local discrete process, the traditional Fourier analysis used in spectral analysis is useless. We have developed a new method, the Empirical Mode Decomposition (EMD) method and the Hilbert Spectral Analysis (HSA) method for nonlinear and nonstationary time series analysis. This method is a generalized Fourier analysis with variable amplitude and frequency for each component. The basis for the EMD expansion is based on and derived from the data; therefore, it is totally adaptive. It also introduces the new concept of intra-wave frequency modulation with which the spurious harmonics are no longer needed for the wave form deformation due to the nonlinear effects. The manuscript has been accepted for publication in the Proceedings of the Royal Society of London.

RESULTS

In our study, we found that the effect of nonlinear wave-wave interactions is dominated by four wave interactions. For water of finite depth, McLean (1982 a and b) proposed the higher order wave interactions, in which interactions among five gravity waves could also be important. The extension of McLean's computation to spectral representation was accomplished by Krasitski (1993, and 1994), and Kalmykov (1993). Kalmykov, further analyzed the numerical results, and found that the effects of higher order interactions small compared to the four wave cases. One interesting effect of the higher order wave interactions is to cause the energy flux to flow to a higher wave number, but in a direction different from the main wave propagation angle. In general, all nonlinear wave-wave interactions involve odd-number of waves will cause a cascade of energy from long to short waves. The only exception is for one-dimensional or near one-dimensional spectra, such as the propagation of swell from a remote location, the condition studied by Dyachenko et al. (1995). Under such a condition, there could be a coexistence of direct cascade and inverse cascade. But such a spectrum is unstable to oblique wave excitations. For a finite width spectrum, the off-the-main-direction energy flux may be added to the wave spectral tail split even in deepwater as modeled by Banner and Young (1994) using only four-wave interactions. Whether this is also responsible for the initial wind wave spectral directional spreading is an open question.

The field data analysis showed that the directions of the wind wave propagation are always deviated from the local wind. The limited data sets are not sufficient for us to deduce a definite relationship between the wave direction and that of the local wind. None of the presently available can fully explain the phenomenon. The sum of the data is not inconsistent with Phillips (1957) resonant wind-wave generation theory. Additional research should be conduct to settle this important mechanism.

We developed a new nonlinear nonstationary time series analysis method. This method has a much wider application than just for wave problems. Currently, we are also using it for analysis the data from earthquake and building response, arrhythmic heart beats, and other climate and geophysical data.

IMPACT/APPLICATION

The new EMD HSA method for nonlinear and nonstationary time series analysis has the potential of replace Fourier analysis in time series analysis. It is clear the new method has a much better temporal location and frequency resolution than any window Fourier or Wavelet analysis methods. Currently, we are working with the engineering community to apply the method for earthquake signal and building response. We are also working with bio-medical community to study the arrhythmia of heart, brain waves, and other climate and geophysical data.

Based on this study, we have gained enough understanding of the coastal dynamics to propose a SCOR Workgroup to investigate the scientific issues in the coupled coastal dynamics.

RELATED PROJECTS

This effort is intimately related to two other research projects:

The first is the Experimental and Theoretical Studies of Wind-wave generation and Evolution, in which we are concentrated on the wind-wave dynamics.

The second is the earthquake signal analysis supported by the National Science Foundation. The method used is developed under partial support of this project.

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