Wave Breaking and Coupled Boundary Layers in Strong Wind Forcing Development, Testing and Implementation of an Improved Dissipation Source Function in Navy Operational Wave Models

Robert E. Jensen
USAE Engineer Research and Development Center
Coastal and Hydraulics Laboratory
Vicksburg, MS 39180-6199
Phone: 601-634-2101 fax: 601-634-2055 email: jensenr@wes.army.mil

Award Number: N0001401MP20034

LONG-TERM GOALS

The principal goal of this project is to improve our understanding of the role of the dissipation source function (S_{ds}) governing the spatial and temporal evolution of surface waves. This will be accomplished through a coordinated modeling effort and using available field data obtained from the Coupled Boundary Layers/Air-Sea Transfer (CBLAST) field experiment augmented by data obtained from the Shoaling Waves Experiment, and controlled laboratory investigations. The results of this study will support the Naval Operational wave forecasting needs for improved accuracy in high wind/wave scenarios.

SCIENTIFIC OBJECTIVES

The principal objective of this project is to focus on a modeling effort, testing and evaluation of existing dissipation (S_{ds}) source term formulations in the context of the exact solution to the nonlinear wave-wave interaction (S_{nl}, Resio et al 2001) and data obtained from the Shoaling Waves field experiment. Testing of historical S_{ds} relationships will be carried out using a research wave model for proper growth rate characteristics and source term balance. Further investigations and evaluations of these formulations will be performed in a controlled laboratory environment (obtained from the USAE Engineer Research and Development Center's Coastal and Hydraulics Laboratory) where directional wave spectra evolve without an atmospheric input (S_{in}) source term. Preliminary source term balances will be recovered using the research model describing S_{in} from the Shoaling Waves Experiment and determine the net S_{ds} required from closure of the action balance equation. A formulation based on results obtained from the CBLAST fieldwork will be cast into a representative S_{ds}. Renewed testing of the source term balance will be initiated. Ultimately the S_{ds} results including sensitivity testing of the S_{in} (Shoaling Waves Experiment-SHOWEX), S_{nl} (derived from recently completed Advanced Wave Prediction Program) will be transitioned to the Navy's operational wave forecasting model.

APPROACH

The solution to the action balance equation describes the spatial (i.e. propagation, refraction/shoaling) and temporal evolution of directional wave spectra. The temporal changes in the spectrum are determined from the external mechanisms consisting of the atmospheric input (S_{in}), the nonlinear wave-wave interaction (S_{nl}), dissipation due to white-capping (S_{ds}), and in arbitrary water depths wave-bottom interactions (S_{w-b}), as well as depth induced wave breaking (S_{wb}). This work will focus initially

Report Documentation Page

Form Approved
OMB No. 0704-0188

1. REPORT DATE **30 SEP 2001**	2. REPORT TYPE	3. DATES COVERED **00-00-2001 to 00-00-2001**

4. TITLE AND SUBTITLE **Wave Breaking and Coupled Boundary Layers in Strong Wind Forcing Development, Testing and Implementation of an Improved Dissipation Source Function in Navy Operational Wave Models**	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) **USAE Engineer Research and Development Center,,Coastal and Hydraulics Laboratory,,Vicksburg,,MS, 39180**	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

The principal goal of this project is to improve our understanding of the role of the dissipation source function (Sds) governing the spatial and temporal evolution of surface waves. This will be accomplished through a coordinated modeling effort and using available field data obtained from the Coupled Boundary Layers/Air-Sea Transfer (CBLAST) field experiment augmented by data obtained from the Shoaling Waves Experiment, and controlled laboratory investigations. The results of this study will support the Naval Operational wave forecasting needs for improved accuracy in high wind/wave scenarios.

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)**	**6**	

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

on the deepwater regime and ultimately transition to arbitrary depths. With the combined field experiments of SHOWEX and CBLAST, source terms including S_{in}, S_{ds} and S_{w-b} will be measured. Processes in the air/sea interface and re-specification of these source terms can be evaluated. Testing of these formulations will be carried out via source term balances with the exact S_{nl} (Resio et al 2001) embedded in the research wave model. Collaboration with the CBLAST wave modeling team will test and improve existing pseudo-linear coupling (e.g. Jannsen 1991) in present 3rd generation wave models. Supplementing the field investigations, laboratory data recently collected at CHL will be used to isolate the response of wave regimes in the presence of no atmospheric input source term (or $3S = S_{nl} + S_{ds} = 0$).

WORK COMPLETED

The pursuit of an improved dissipation source function is a two-phased approach. The first phase is testing and evaluation of various dissipation source function algorithms (e.g. Banner et al 2000; Hanson and Phillips 1999; Tolman and Chalikov, 1996; Komen et al 1984). These academic tests are performed with an exact specification of the nonlinear wave-wave interaction source function (Resio et al 2001). The second phase of this study investigates present state-of-the-art wave modeling technologies. One of the identifiable deficiencies in present 3rd generation wave model technologies (e.g. WAM, Komen et al 1994; WAVEWATCH III, Tolman 1990) has been the trend to underestimate significant wave heights (H_{mo}) in high wind/wave scenarios. Recent work by Resio et al (1999) suggests wind speed scaling in *fully developed seas* taken from a fixed elevation above the sea surface may not be correct. Isolation of historical wave data and model simulations with this new scaling has been preformed.

RESULTS

Prior to the synthesis of SHOWEX and CBLAST data, preliminary wave modeling activities can be performed. Two phases of this study have been initiated. The first involves testing and evaluation of various dissipation source functions in the context of a research wave model. All 3rd-generation wave modeling technologies use a form of the Discrete Interaction Approximation (DIA, Hasselmann and 1985). There have been observable deficiencies in this formulation compared to exact solutions (Resio and Perrie 1991). Despite the significant contribution using the DIA to wave modeling technologies, the deficiency in its approximation will have an impact on the overall source term balance, and produce potentially ill posed forms of the S_{in} and S_{ds}. To rectify this situation, the research model uses an exact representation of the nonlinear wave-wave interaction, combined with the best estimation for the atmospheric input. From closure to source term balance, a relationship for the S_{ds} can be sought. This work, in addition to posing the S_{ds} in specific algorithmic forms (e.g. Banner et al 2000) is presently underway. The work will allow detailed analyses of the temporal and spatial evolution in directional wave spectra, however the results will be dictated by an exact S_{nl} formulation. One can visualize these tests as the basis for the final implementation of S_{in} derived from SHOWEX as well as CBLAST and a new computationally efficient S_{nl} provided by the Advanced Wave Prediction Program.

The second phase of this work has focused on high wind/wave environments. Wave data accessed from the National Oceanic and Atmospheric Administration's National Data Buoy Center (NDBC) at a location in the Bering Sea (NDBC 46035) contains valuable information for preliminary assessment of the Resio et al (1999) scaling of *fully developed seas*. Significant wave heights in excess of 8 m consist of approximately 1 percent of the entire population over a period of 15-years. A timely wave hindcast effort (part of a USACE project north of the Bering Sea) provided the necessary wind fields, to study the net effect of altering the scaling at high wind/wave conditions. Time paired 3rd-generation modeling to measurements H_{mo} results are displayed in Figure 1. Individual wave heights are grey points; the magenta symbols indicate a bin averaging, with vertical bars identifying one standard deviation from the mean error. These results demonstrate an over-estimation in the model results for high wind/wave regimes, suggesting alternative scaling may provide better overall H_{mo} estimates. However, these results are based on a single data source, and further assessment must be performed to form irrefutable conclusions. Gathering these types of data sets for future testing will provide the means for a quality assessment over a wide-variety of meteorological and wave conditions.

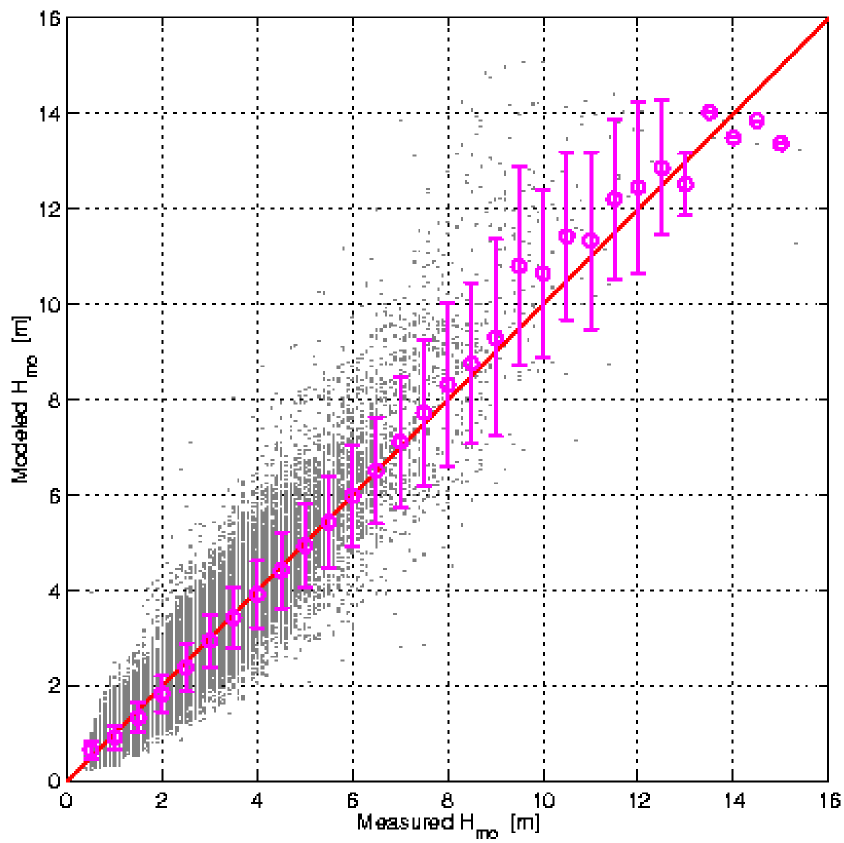

Figure 1. Time-paired comparison of H_{mo} 3rd-generation model to NDBC 46035 measurements.

IMPACT

The temporal and spatial change in directional wave spectra is affected by external mechanisms, defined in the source/sink term specification. The proper specification of these mechanisms for growth under a wide range of meteorological and oceanographic conditions is critical to the success of any operational wave forecast. What has been found thus far is by adjusting the *fully developed* scaling in high wind/wave regimes better approximations have been obtained for the significant wave heights in 3rd-generation wave models. However, further studies with additional data are required before these results become the standard. The only way to determine a suitable dissipation source function is to either measure it, and/or determine from numerical source term balances. The difficulties of measuring S_{ds} are real; however, the anticipated benefit from SHOWEX and its data synthesis is to have for the first time a means to describe the dissipation source function. Through source term balance using the exact S_{nl}, assessment of the dissipation mechanism may be indirectly validated.

TRANSITIONS

The results derived from this study will be further developed in the research model, and posed in existing Navy operational wave modeling technologies. Combining field data and laboratory data, development, testing and validation of the evolutionary processes in directional wave spectra will be performed. Ultimately, the results from this project and collaboration from the CBLAST modeling group will yield newly formulated approximations for the dissipation source function, and proper coupling of the air/sea interface and for Naval Operational Wave Forecasting Systems.

RELATED PROJECTS

Listed below are various projects that are directly related to the SHOWEX and AWPP.

1. Headquarters, U.S. Army Corps of Engineers: "Improving Wave Estimates for Coastal Waters." Laboratory experiments in the directional wave flume, for the investigation, validation of modeling technologies and transition to the U.S. Army Corps district, division offices and in-house CHL staff for use in the estimation of wave conditions in the nearshore domain.

2. U.S. Army Corps of Engineers, Alaska District. "Wind and Wave Hindcast Study for the Delong Mountain Terminal Project." Long-term wind and wave hindcast study, with verification of wave modeling results to point source measurements.

REFERENCES

Banner, M.L, Babanin, A.V., and Young, I.R., 2000. "Breaking probability for dominant waves on the sea surface," *J. Phys. Ocenaogr.* **30**, 3145-3160.

Hanson, J.L, and Phillips, O.M., 1999. "Wind sea growth and dissipation in the open ocean," *J. Phys. Ocenaogr.* **29**, 1633-1648.

Hasselmann, S., Hasselmann, K., Allender, J.H., and Barnett, T.P., 1985. "Computations and parameterizations of the nonlinear energy transfer in a gravity wave spectrum, part 2: Parameterization of the nonlinear energy transfer for application in wave models," *J. Phys. Ocenaogr.* **15**, 1378-1391.

Janssen, P.A.E.M., 1991. "Quasi-linear theory of wind wave generation applied to wave forecasting," *J. Phys. Ocenaogr.* **21**, 1631-1642.

Komen, G.T., Hasselmann, K., and Hasselmann, S. 1984. "On the existence of a fully developed windsea spectrum," *J. Phys. Ocenaogr.* **14**, 1271-1285.

Komen, G.T., Cavaleri, L., Donelan, M., Hasselmann, K., Hasselmann, S., and Janssen, P.A.E.M., 1994. "Dynamics and Modelling of Ocean Waves," Cambridge University Press.

Resio, D.T., and Perrie, W., 1991. "A numerical study of nonlinear energy fluxes due to wave-wave interactions. Part 1: methodology and basic results," *J. Fluid Mech.*, **223**, 609-629.

Resio, D.T., Swail, V.R., Jensen, R.E., and Cardone, V.J., 1999. "Wind speed scaling in fully developed seas," *J. Phys. Ocenaogr.* **29**, 1801-1811.

Resio, D.T., Pihl, J.H., Tracy, B.A., and Vincent, C.L., 2001. "Nonlinear energy fluxes and the finie depth equilibrium range in wave spectra," *J. Geoph. Res.*, Vol. 106, No. C4, 6985-7000.

Tolman, H.L., 1992. Effects of numerics on the physics in a thrid-generation wind-wave model," *J. Phys. Ocenaogr.* **22**, 1095-1111.

Tolman, H.L., and Chalikov, D. 1996. "Source terms in a third generation wind wave model," *J. Phys. Ocenaogr.* **26**, 2497-2518.