

# **Modeling of Finite Depth Wind Wave Dissipation**

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## **LONG-TERM GOAL**

The long-term goal is to obtain a source function for the spectral wind wave energy dissipation rate due to wave breaking, based on understanding of the physics of the dissipation processes both in deep and finite depth environments. The resulting form must be applicable for use in routine wave prediction models.

## **SCIENTIFIC OBJECTIVES**

The objectives are to establish a description of the “white-capping” dissipation both as a spectral function and a function of environmental conditions. To date, knowledge of the spectral distribution of energy losses due to wave breaking is so poor that scientific debate continues on whether, in the spectral sense, low-frequency dissipation exists or not. Also there is little knowledge of the dependence of the dissipation rate function on wind and wave field characteristics, other hydrodynamic properties and interaction with the bottom. All of these factors make dissipation rate functions used in present day wave models, to a large extent, speculative.

## **APPROACH**

In a series of recent papers (Banner and Tian, 1998; Banner, Babanin, and Young, 2000; Babanin, Young and Banner, 2001; Song and Banner, 2002, Banner and Song, 2002, Banner, Gemmrich and Farmer, 2002), the investigators have proposed that whitecap dissipation is a result of the nonlinear hydrodynamic effects associated with deforming ocean wave groups. Based on these physical considerations, they have been able to describe the probability of breaking as a function of environmental conditions, which include properties of the local wind and wave field, shear current and bottom interaction. The function exhibits phase transition behaviour, with the threshold now well-established on the basis of diverse data, including those obtained during the ONR Lake George Project.

The breaking probability dependence is of a general form and applicable both in deep water and in finite water depths.

The next important stage is to recast the probability model into a source term capable of incorporation in a spectral wave prediction model. Investigation in deep water has been very encouraging, and a new dissipation function based on the threshold-like two-phase behaviour of the whitecapping process was suggested, with significant improvement in model performance (Alves and Banner, 2002). An extension of this wave energy dissipation form into fetch-limited finite depth conditions is the aim of this project, with this newly proposed form to undergo extensive calibration using the depth-limited data set collected at Lake George.

The calibration will require usage of a wave model. Initial tests of the source term formulations will be carried out using the one spatial dimension WTR model WAVETIME, developed by Gerbrant Van Vledder (Alkyon, The Netherlands) with a new formulation of the four-wave non-linear interaction term modified for finite depth conditions. In the second phase of the project, the source terms found to be optimal in the one-dimensional model will be incorporated into the two-dimensional WAVEWATCH model.

Extensive model testing of the new dissipation function requires an accurate representation of the other source terms. The atmospheric input, triad non-linear, bottom friction and the total dissipation terms are all being evaluated by the investigators as part of the related Lake George Project. Alex Babanin of the University of Adelaide, Australia is involved in development and tests of all the source terms involved.

## **WORK COMPLETED**

Of the four principal source functions needed for testing the dissipation function, three have been refined during the past year. These are the wind input function, the four-wave non-linear interaction term, and the whitecapping dissipation function itself. The wind input and non-linear interactions terms are now finalized, as well as the bottom interaction term completed last year. The integrated effort is described in a paper submitted to the Journal of Atmospheric and Oceanic Technology. The frequency-directional spectral dissipation term is being prepared for extensive model testing and will be finalized within a one-year no-cost extension of the Project.

Also, a new one spatial dimension WTR model has been developed. It is currently being tested for compliance with known non-linear evolution results.

The wind input study, presented in the previous year's report (progress report ONR N00014-00-1-0012 (CDYoun02), 2001), has been advanced and completed. One paper has been submitted to the Journal of Atmospheric and Oceanic Technology and two papers – on parameterization of the wind input spectral function and parameterization of the wind input enhancement due to wave breaking – are being prepared for submission to the Journal of Physical Oceanography. The wind input has been accurately measured and parameterized in terms of the local wind profile and spectral wave steepness properties, the sheltering coefficient being a function of wave age. Enhancement of the wind input as a function of wave breaking activity was investigated and evaluated. Results were presented at the 9<sup>th</sup> WISE meeting in Bergen, Norway in May, 2002.

For the four-wave non-linear interactions, the new finite-depth term of Van Vledder has been implemented. A study of free and forced triad interaction terms (joint with Yehuda Agnon of the Technion University, Israel and Dmitry Chalikov of NOAA, USA) is currently in progress.

Work on obtaining the total energy dissipation and verification of the total energy balance in the water column was completed and reported last year (progress report ONR N00014-00-1-0012 (CDYoun02), 2001). This year, particular attention was given to investigation of the dissipation spectral function based on the field measurements. Examples of both frequency and directional distribution of the dissipation were obtained, results were presented at the 9<sup>th</sup> WISE meeting in Bergen, Norway in May, 2002. In an independent effort, Lake George field data were used to study frequency distribution of wave breaking frequency and severity as shown in the Results below.

## RESULTS

### *Wind Input*

The Lake George Project (progress report ONR N00014-97-1-0234 (CDYoun01), 2001) allowed determination of the input function of the form:

$$I(f) = \frac{\rho_a}{\rho_b} g \gamma(f) f P(f), \quad (1)$$

where  $\gamma(f)$  was the growth increment function:  $\gamma(f) = a \left( \frac{U_{\lambda(f)/2}}{c} - 1 \right)^2$ . The coefficient  $a$  appeared not to be a universal constant, in comparison with other known results. Our efforts to make the wind input parameterization universal, led to further refinement of the parameterization this year.

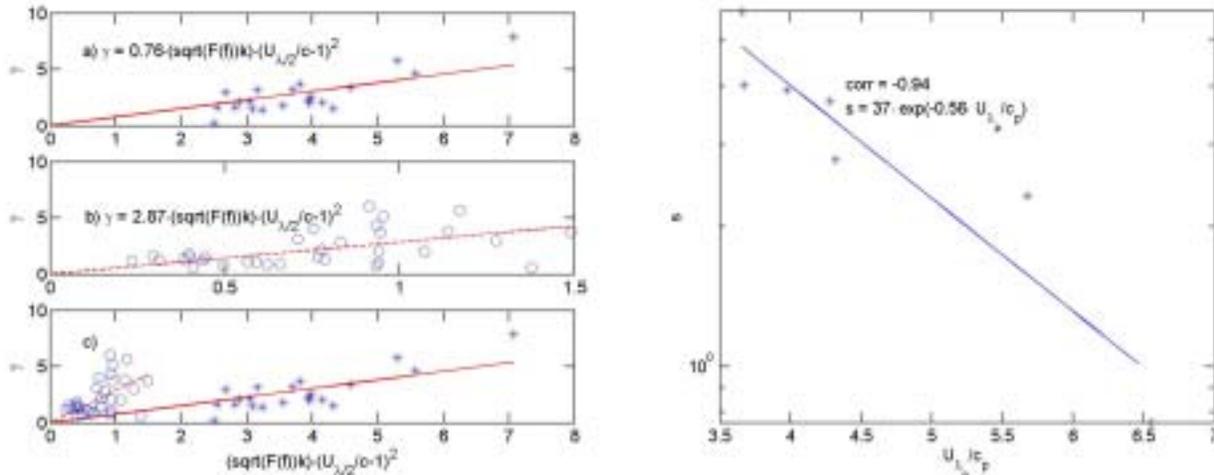
Fig. 1 (left) illustrates dependence of  $\gamma$  on the newly introduced wind-steepness parameter (this work is done in collaboration with Mark Donelan from the University of Miami, USA):

$$\gamma(f) = s (\sqrt{F(f)k}) \left( \frac{U_{\lambda(f)/2}}{c} - 1 \right)^2. \quad (2)$$

Here,  $\sqrt{F(f)k}$  is a spectral analogue of the wave steepness at a particular frequency. The Lake George data clearly collapse into two distinct groups, with different proportionality coefficients  $s$ . The difference is attributed to the different level of flow separation over the waves. The separation coefficient  $s$  is a function of the inverse wave age itself, as shown in Fig. 1 (right):

$$s = 37 \exp(-0.56 \cdot U_{\lambda_p} / c_p). \quad (3)$$

These formulas can be used directly to calculate the wind input based on the wave spectrum and the local mean wind information, which is usually available. The spectral steepness analogue  $\sqrt{F(f)k}$  is dimensional and so we are seeking a suitable non-dimensional formulation of spectral steepness.



**Fig.1. Left: (Top)  $\gamma$  versus  $(\sqrt{F(f)k})(U_{\lambda/2}/c-1)^2$ , Lake George data and dependence (2) for a fully separated flow,  $s=0.76$ . (Middle)  $\gamma$  versus  $(\sqrt{F(f)k})(U_{\lambda/2}/c-1)^2$ , Lake George data and dependence (2) for a non-separated flow,  $s=2.44$ . (Bottom)  $\gamma$  versus  $(\sqrt{F(f)k})(U_{\lambda/2}/c-1)^2$ , the two groups of data plotted together, the differences between the two data clusters and the two dependences are clear. Right: Lake George data and dependence (3).**

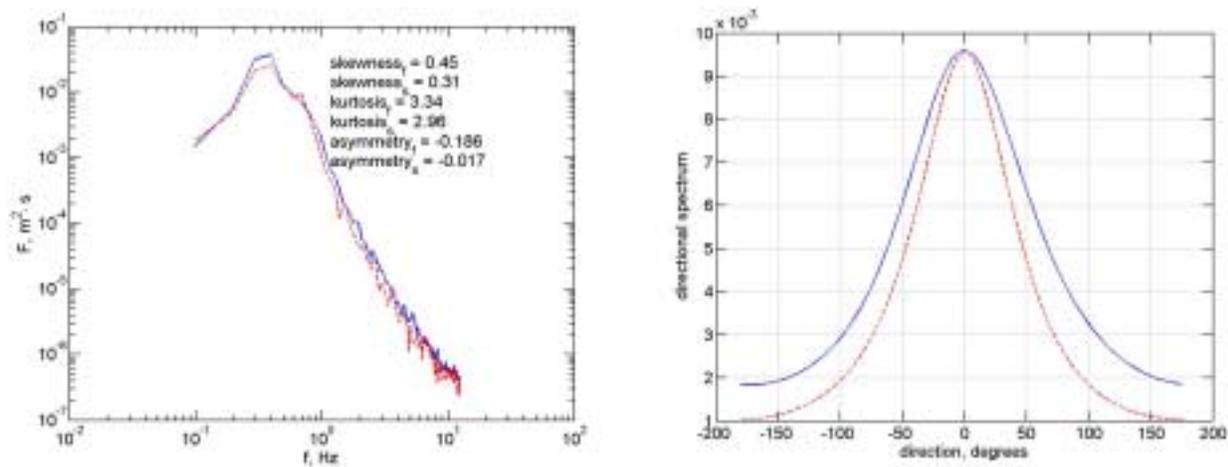
Enhancement of the wind input due to wave breaking and dependence of the total wind input on the breaking statistics was discussed in the previous year report (progress report ONR N00014-00-1-0012 (CDYoun02), 2001). It is a subject of a separate paper in preparation.

### Whitecapping Dissipation

Results of measurements dissipation of integrated over the spectrum were presented in last year's report (progress report ONR N00014-00-1-0012 (CDYoun02), 2001). In that report, the total energy balance of major source terms is observed was also shown (see also Young and Babanin, 2001).

Measurements of the spectral distribution of wave energy dissipation has historically been an elusive task. In this project, two different approaches were used to obtain the dissipation function based on the Lake George data. Both approaches use techniques of wave breaking detection, developed within the ONR Lake George Project (progress reports ONR N00014-97-1-0234, 1997-2001 and Babanin, Young and Banner (2001)).

*First approach.* Spectrograms were used to identify segments of breaking and non-breaking wave trains. Thus obtained, average power and directional spectra at the peak for breaking and non-breaking waves are shown in Figure 2. After estimating other source terms and the advection term, the difference was attributed to the dissipation due to wave breaking. The difference was obtained as both frequency and directional functions.



**Fig.2. Left: Comparison of frequency spectrum of breaking waves (solid line) and non-breaking waves. The non-breaking wave spectrum is proportionally lower over the entire frequency band. Captions also show very significant differences in skewness, kurtosis and asymmetry between the waves representing each spectrum. Right: Comparison of directional spectrum of breaking waves (solid line) and non-breaking waves at the spectral peak. The non-breaking wave spectrum is substantially narrower.**

*Second approach.* A sensitive acoustic instrumentation was used to identify breaking events and classify them in terms of severity of acoustic impact (this work is done in collaboration with Richard Manasseh and his research group at the CSIRO Division of Thermal & Fluids Engineering, Australia). The distribution of breaking statistics across the spectrum, as well as distribution of acoustic severity, has been obtained. Calibration of the acoustic impact in terms of energy loss due to breaking is planned as a separate laboratory experiment. This, in combination with the breaking statistics across the spectrum, should lead to the frequency function of rate of energy loss due to whitecapping. Combining the *first* and *second* approaches will provide a basis for inferring the frequency-directional function of dissipation. This function will then be used in the modeling tests.

#### *Bottom Dissipation Rate and Non-Linear Interaction Term*

The bottom interaction term was completed last year and is discussed in our previous report (progress report ONR N00014-00-1-0012 (CDYoun02), 2001). The new four-wave non-linear interaction term, developed by Alkyon, The Netherlands, was implemented this year to meet needs of the project.

### **IMPACT/APPLICATION**

*Wave Modeling.* Source terms presently used in finite depth wave prediction models are largely extrapolated from deep water results. The newly proposed terms, particularly the finite depth dissipation function based on physical considerations, will provide a more appropriate representation in such models for the physical processes. As a result, an enhanced ability should result for predicting nearshore wave conditions.

## TRANSITIONS

It is expected that the finite depth dissipation function will find a broad spectrum of applications among members of the WISE group and users of SWAN and other shallow water models.

Mark Donelan of the Rosenstiel School of Marine and Atmospheric Science, University of Miami, Florida is actively participating in the research of the wind input function, utilizing the results for the SHOWEX open-ocean study.

Yehuda Agnon from the Technion University, Israel, is using the project data and results to develop a new triad interaction term for the final version of the model. The purpose of this joint study is to provide a description and parameterization of the three-wave interactions due to not only the resonant non-linear interactions, but also to the influence of the wind input and wave breaking.

Richard Manasseh from the Commonwealth Scientific & Industrial Research Organization (CSIRO), Melbourne, Australia is using the project data and results for testing their acoustic system of detecting breaking events and their severity. He and his research group are also participating in studying spectral distribution of wave breaking properties.

## RELATED PROJECTS

This Project builds upon the successful ONR Lake George Project (N00014-97-1-0234), finished in 2001. The data obtained during the Lake George field experiment, as well as its scientific results, are being extensively used to construct the dissipation function and other source terms in the model under development.

The Project is linked with the ONR CBLAST Project (N00014-00-1-0288, Michael Banner and Lance Leslie are Principal Investigators) on modeling storm spectra. A deep water dissipation function, developed by Michael Banner and his group at The University of New South Wales, Australia, is based on the same physical consideration as the one being developed here.

The Project is coordinated with the SHOWEX Project, sponsored by ONR. Results and data of SHOWEX will be used for further verification of the proposed spectral dissipation function.

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