Source Term Balance for Finite Depth Wind Waves

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LONG-TERM GOAL

The long-term goal is to obtain closure of the energy balance equation for wind wave evolution in finite depth watery means of direct measurement of the main source terms. These source terms represent the basic physical processes required to develop reliable finite depth wave prediction models.

SCIENTIFIC OBJECTIVES

The objectives are to establish a description of the basic sources/sinks of energy responsible for shallow water wind wave evolution, namely dissipation due to both wave breaking and bottom friction, and wind input. Spectral distribution of "white-capping" dissipation has not previously been obtained either experimentally or theoretically, and currently, speculative approaches are used to represent this term in wave models. The natural phenomena determining this term are random, non-linear and related to extreme wave conditions and hence are difficult to evaluate in the field. The other two terms have been the subjects of intensive research during the last three decades, although detailed field observations are rare. There is a qualitative understanding of their behaviour, however, no established quantitative description is available.

APPROACH

An integrated set of measurements in the atmospheric and sub-surface boundary layers as well as on the surface itself has been carried out at the Lake George field experimental site for the last three years, whenever meteorological forecasts were appropriate. In August - September, 1999, the end of the Southern Hemisphere winter and a time of regular cross-lake winds, an intensive observation period

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was conducted. The previous measurements were supplemented by fine-scale measurements of wave-induced air pressure, sub-surface turbulence and bottom boundary layer velocity profiles. This latter experiment, jointly conducted with two American groups, was titled AUSWEX (AUstralian Shallow Water EXperiment).

AUSWEX was followed by two sets of laboratory experiments in the School of Civil Engineering at the Australian Defence Force Academy (ADFA) to improve estimates of the wave energy dissipation due to interaction with the lake bed. Intensity of the field observations was scaled down after AUSWEX, although some super-shallow environment records were obtained. The Lake George field site was closed down and dismantled in September, 2000, thus concluding the three year long period of active observations started in September, 1997. Extensive analysis of the accumulated data has commenced.

Full details of the experimental facility and instrumentation can be found in the 1999 Progress Report. This information is not repeated here.

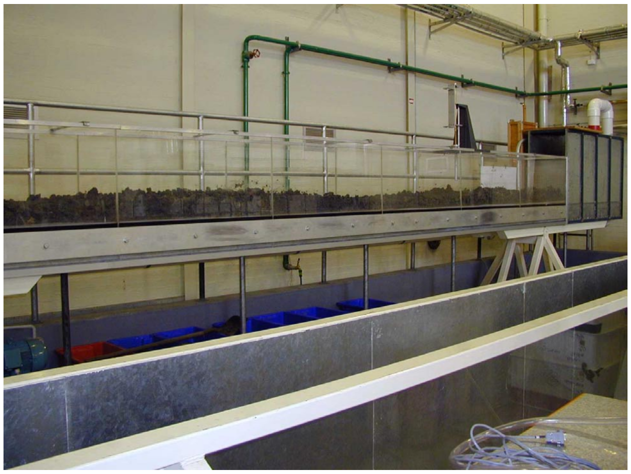
WORK COMPLETED

Data from the Lake George site has now been obtained for three years. A database, containing hundreds of hours of wave, wind, air turbulence, sub-surface currents and turbulence, under-water sound, humidity, air and water temperatures and other records, as well as photographic images of the surface, made during the two years of observations prior to AUSWEX, was prepared, documented and is available on three CDs. About 70 hours of relevant video and hydrophone sound records are available on 24 Super-VHS video tapes.

The joint AUSWEX experiment was carried out from 14 August to18 September, 1999. The data acquired comprise numerous synchronised records by the wave array, anemometer masts, sonic anemometer, three ADVs located at different levels in the water column, video camera, hydrophone, humidity and temperature probes, as well as by the Dopbeam which was traversed to different depths and by the wave follower. The data have been documented and prepared as a data base on four CDs. About 45 hours of video and hydrophone sound records were also recorded.

The two photographs below were taken in the laboratory during the bottom friction experiments. The photo on the left shows a general view of the ADFA flow flume with the Lake George natural bed material. The vertical traversing system used to deploy a high resolution ADV is seen in place on the top of the flume. The second photo shows the surface of the bottom material after ripples had developed due to the action of a strong current. A comprehensive set of photographs showing all facilities and instrumentation at the site, as well as the people, and a video record of the follower in action and a video-sound track of breaking waves, can be viewed on the Lake George Project web site.

The data, obtained at the Lake George site, have been actively used for scientific research and some results were presented in papers at the Fourth International Symposium on Air – Sea Gas Transfer in Miami Beach in June, 2000 and at the WISE-7 meeting in Reykjavik in June, 2000, and at a number of seminars. Two papers have been reviewed and are to appear in the Journal of Physical Oceanography (Banner, Babanin, and Young, 2000) and in the Journal of Geophysical Research (Babanin, Young and Banner, 2000).

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RESULTS

As the primary goal of the project is the closure of the energy balance equation, the data analysis has initially concentrated on obtaining the integrated energy balance. This approach allows us to temporarily disregard the non-linear interactions, the only term which was not measured. The objectives of the study are: 1) to provide quantitative estimates of the main terms in finite depth conditions; 2) to verify whether the measured terms satisfy the expected energy balance; 3) to develop techniques to be used in subsequent more complicated analysis of the spectral balance.

Bottom Dissipation

The bottom dissipation term was considered first. As the field measurements in the thin bottom boundary layer proved to be the least accurate, approximately two tons of the Lake George bed material was placed into the flow flume at ADFA, and measurements of the bottom roughness were carried out for a broad range of unidirectional currents. The bottom dissipation rates were obtained using the approach developed by Young and Mirfenderesk, (2000).

The bottom dissipation may have been affected by turbulence induced by breaking waves influencing the bottom boundary layer. The frequency of breaking is significantly enhanced in finite depth environments (Babanin, Young and Banner, 2000), and if the injected turbulence penetrates the boundary layer, the shear stresses and therefore the dissipation rates in the layer can be changed. The effect was investigated in the wave tank at ADFA by generating waves which break at various distances relative to the location of a bottom shear plate, designed to directly measure the bottom stresses. The experiment was scaled to observe the Lake George conditions and the effect was found to be small.

Dependence of the bottom dissipation rate per unit area on the relative depth parameter kd and the wave-bottom interaction parameter H_s / d is shown in Figure 1 (left) based on AUSWEX records. The bottom dissipation study has been completed, and a corresponding journal article is being prepared.

Total Dissipation

The next term considered was the dissipation in the water column. Dissipation rates per unit volume can be conditionally obtained from Kolmogorov sub-intervals of the ADV turbulence spectra. The dissipation rates per unit volume were estimated by integrating the dissipation values provided by the ADVs, located at different depths, for all the AUSWEX records. It was shown that the bottom dissipation is generally rather small (4% of the total dissipation) even for the shallow Lake George conditions. Under extreme conditions, it can become as large as 20% of the total dissipation.

The ADV estimates of the dissipation depend on the unknown advection velocity used to convert frequency spectra to wave number spectra. The traditional approach (Lumley and Terray, 1983) is to use the RMS orbital velocity, however, this can lead to large overestimations (Veron and Melville, 1999). To solve this uncertainty, the Dopbeam records were taken at different levels below the water surface during AUSWEX. The Dopbeam yields wave number spectra directly, and these were calculated by F.Veron and K.Melville of the Scripps Institute of Oceanography. Their dissipation rates demonstrate a steady linear trend between the ADV and Dopbeam estimates. The ratio between these estimates is dependent on both the mean orbital velocity and the relative depth parameter *kd*. In general, the ADV values of the dissipation rates overestimate the reference Dopbeam values by a factor between 1 and 5. This is an important methodical result, since ADV-based estimations are widely adopted.

Wind Input

Approximate total wind input estimates for AUSWEX records were first obtained as $\tau u_* / 2$ (Terray et al, 1983). They matched the total dissipation rates reasonably well, with neither the source nor sink terms revealed systematic error.

Precise estimates of the wind input for AUSWEX data are being carried out based on the wave follower records obtained by Mark Donelan, University of Miami. As can be seen in Figure 1 (right), the device provided good estimates of phase shifts between the surface elevations and wave-induced pressure up to 10 Hz. Reliable estimates of the growth increment γ can also be obtained in a broad frequency range. These results yield estimates of the spectral wind input function (bottom subplot, the pressure readings have not been corrected for the measuring probe height). At present, height attenuation of the induced pressure signal is being considered, which appears to depart from the simple exponential dependence.

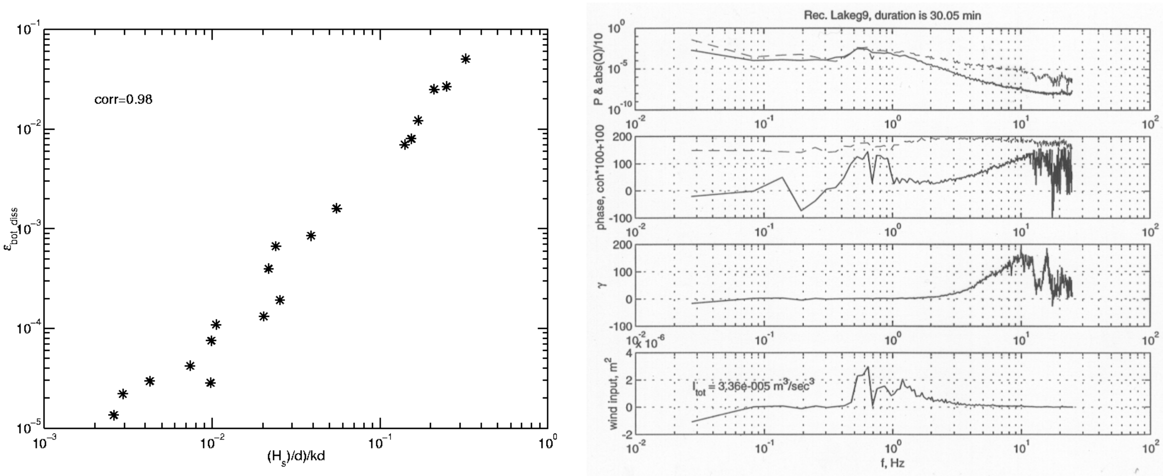

Fig.1. Left: Dependence of the bottom dissipation rate ε_{bot_diss}, [J/(m^2 s)] on dimensionless parameters of the relative depth kd and wave-bottom interaction H_s/d where k is the peak wave number, d is the water depth and H_s is the significant wave height. Right: wave power spectrum (P) and quadrature spectrum (Q) of surface elevation and wave induced pressure (subplot 1, the pressure values were not corrected for the probe elevation); corresponding coherence and phase shifts (subplot 2); fractional growth increment γ (subplot 3); wind input spectrum (subplot 4, not adjusted for the pressure probe elevation)

IMPACT/APPLICATION

Results of the field research and parameterization of the source terms will have potential impact in a number of areas.

1) **Wind Wave Dynamics.** Direct, simultaneous, in situ field measurements of the major source terms together with detailed knowledge of the spectral evolution have not previously been attempted. The results have the potential to provide considerable insight to present understanding of wind wave evolution in finite depth water.

2) **Wave Modelling.** Source terms presently used in finite depth wave prediction models are largely extrapolated from deep water experience. Direct measurement of the source terms in such situations will provide a more appropriate representation for the physical processes in such models. As a result, an enhanced ability to predict nearshore wave conditions should result.

TRANSITIONS

Two groups have used the Lake George facility as a joint effort during AUSWEX, and another two groups intend to use results of the experiment for verification of their theoretical models.

Mark Donelan from the University of Miami installed and successfully operated his wave follower during AUSWEX, is participating in the data processing and will be using the combined data set for analysis of the wind input source function.

Kendall Melville from the Scripps Institute of Oceanography provided his Dopbeam during AUSWEX and is a part of the data processing and investigation team for studies of sub-surface turbulence and total dissipation of wave energy.

Vladimir Makin from the Royal Dutch Meteorological Institute, De Bilt, The Netherlands plans to provide theoretical interpretation using data of observed distributions of mean and wave-induced stresses by means of his wind-wave coupling model.

Linwood Vincent and Donald Resio of CERC are combining the high resolution spectra measured at the Lake George site with other finite depth data to study the detailed form of the finite depth wind wave spectrum.

RELATED PROJECTS

This project is coordinated with the DRI experiments conducted for Duck, North Carolina, and Ian Young, head of this project took part in the field experiment at Duck. As the experimental site provided good control over the environmental parameters, it is hoped the experiment may well fill some of the gaps in the larger scale, open ocean DRI measurements.

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The ONR "Source Term Balance for Finite Depth Wind Waves" Project web-site:
http://www.ce.adfa.edu.au/research/LakeGeorge/web_html.htm