Refined Source Terms in WAVEWATCH III with Wave Breaking and Sea Spray Forecasts

Michael L. Banner
School of Mathematics and Statistics, The University of New South Wales, Sydney 2052, Australia
Tel : (+61-2) 9385-7071 fax: (+61-2) 9385-7123 email: m.banner@unsw.edu.au

Russel P. Morison
School of Mathematics and Statistics, The University of New South Wales, Sydney 2052, Australia;
Tel : (+61-2) 9385-7064 fax: (+61-2) 9385-7123 email: r.morison@unsw.edu.au

Award Number: N00014-10-1-0390

LONG-TERM GOALS

Several U.S. Federal Agencies operate wind wave prediction models for a variety of mission specific purposes. Much of the basic science contained in the physics core of these models is over a decade old, and incorporating recent research advances over the last decade will significantly upgrade the model physics. A major goal is to produce a refined set of source and sink terms for the wind input, dissipation and breaking, nonlinear wave-wave interaction, bottom friction, wave-mud interaction, wave-current interaction as well as sea spray flux. These should perform demonstrably better across a range of environments and conditions than existing packages and include a seamless transition from deep to shallow water outside the surf zone. After careful testing within a comprehensive suite of test bed cases, these refined source terms will be incorporated into the prediction systems operated by these agencies and by the broader wave modelling community.

OBJECTIVES

Our aim to improve the accuracy of ocean wave forecasts over a wide dynamic range of wind speeds out to hurricane conditions, contributing a dissipation source function that adds explicit wave breaking statistics for the wind sea to the forecast products. Allied aims are to effectively decouple swell systems from the wind sea and to provide a framework that allows full coupling to the associated atmospheric and ocean circulation models. As part of this project we aim to refine the parameterization of air-sea and upper ocean fluxes, including wind input and sea spray as well as dissipation, and hence improve marine weather forecasts, particularly in severe conditions.

APPROACH

We have started out using our refined version of the threshold-based spectral dissipation rate source term S_{ds} introduced by Alves and Banner (2003), as described recently in detail by Banner and Morison (2010). This replaces the original Komen-Hasselman integral formulation presently used in most operational models. The performance of this updated source term was investigated in conjunction with a modified Janssen (1991) wind input source term and the ‘exact’ form of the nonlinear source term S_{nl} (Tracy and Resio, 1982) over a very wide range of wind speeds using a broad computational bandwidth for the wave spectrum. This avoided the known spurious effects arising in faster approximate versions for this source term.

A significant issue is the additional wind stress component due to the separated air flow over breaking waves. Our methodology produces breaking wave stress parameterizations linked to computed breaking wave properties, and indicates that this additional wind stress component can be an appreciable fraction of the total wind stress depending on the wind speed and wave age conditions, consistent with observations of Banner (1990). In hurricanes, our calculations suggest it is around one third of the non-breaking wave stress.

Detailed comparisons with results from the ONR FAIRS open ocean data set gathered from FLIP in 2002, where breaking wave observations were made along with measurements of wind stress, wave height and water-side dissipation rate, showed our model results closely reproduced these observations, including the breaking wave properties. We have also tested our model framework over the wind speed range of 6-60 m/s and found the model behaved stably and produced plausible results for both wave and sea surface drag coefficient behaviour.

We are presently engaged in transitioning our model framework to the WaveWatch III environment, using the Exact NL option for the nonlinear source term in our model refinement.

WORK COMPLETED

Our effort in FY10 commenced formally in May 2010. We attended the first NOPP workshop in SFO in July 2010, where strategic plans were discussed and formalized. MLB is now a member of the management committee and Morison has taken on the roles of the UNSW Wiki and subversion coordinator.

As part of our initial modelling effort, we have examined our refined dissipation and input source term performance over a wide wind speed range, and during increasing and decreasing wind events. For the latter, we have concentrated on events where detailed wave observations exist for winds growing, then peaking and decaying. As an initial scenario, we have been assuming the wave field is duration-limited, i.e. no net propagation effects. This assumption will be relaxed after our model framework is transitioned into the WaveWatch III environment.

RESULTS

The standard wave and wind characteristics forecast by our model include: dimensionless wave energy and peak frequency evolution and the directional spectrum. To this, we added: 1-D transect wavenumber spectrum, mean squared slope, wind stress and total water side dissipation rates, as well as wave stress, breaking wave stress, $\Lambda(c)$ and b. Accurately forecasting all of these properties required a critical reassessment of the absolute strength and spectral distribution of the wind input and dissipation rate source terms, as well as their levels relative to the nonlinear spectral transfer source term. This refined model framework when tested over a wide range of wind speeds from light to hurricane strength performed accurately and stably. In addition to the usual wave field parameters, an important indicator is the behaviour as the wind sea ages of the modeled sea surface drag coefficient. This key air-sea interaction quantity represents the normalized momentum flux input from the wind, integrated over all wave scales, including breaking waves, as well as the tangential viscous stress. This is shown in Figure 1. The predicted drag coefficients agree with the observed levels. Most of the measurements are for low to moderate wind speeds, where the model and data are in close correspondence. At hurricane wind speeds, the predicted drag coefficient level agrees surprisingly well with the limited number of drag coefficient observations that have become available only in the last few years (e.g. French et al, 2007).

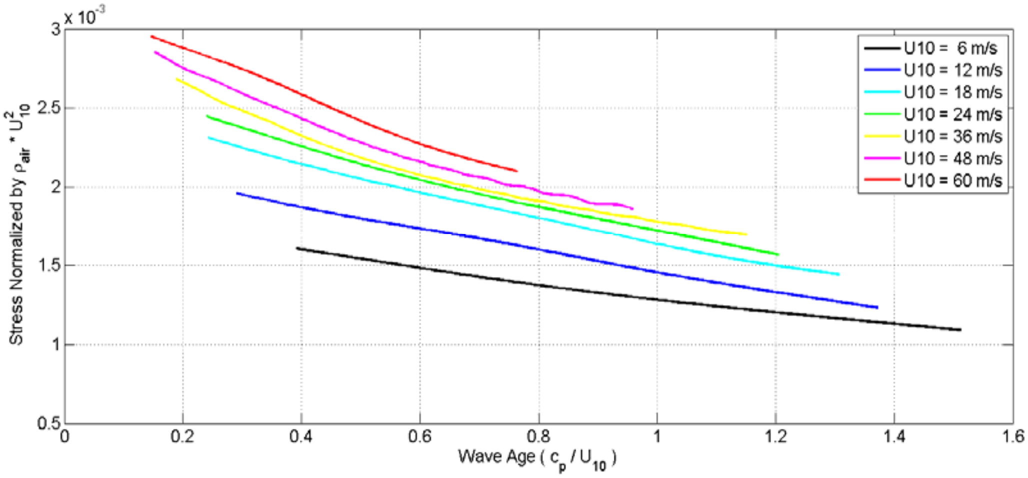

Figure 1. Normalized momentum flux (wind stress) input from the wind integrated over all wave scales, including the tangential viscous stress and additional wind stress due to separation over breaking waves, as a function of the wave age.

IMPACTS and APPLICATIONS

This effort will contribute significantly to the major NOPP goal of upgrading the model physics for wind generated ocean waves, the near-surface winds and upper ocean circulation in the WaveWatch III model environment. The upgraded WaveWatch III model code will be distributed to various Federal agencies for incorporation in their mission-specific systems. The major impact will be more accurate and comprehensive sea state and marine meteorological forecasts from the next generation of operational sea state models.

National Security

Distribution of the upgraded WaveWatch III to the US Navy and Army Corps of Engineers (USACE) should result in improved environmental forecasts of open ocean and coastal zone waves, winds and currents and increase the reliability and safety of naval and USACE operations.

Economic Development

Implementation of the upgraded WaveWatch III by the National Weather Service (NWS), NOAA and other agencies in Department of Commerce should see economic benefits accruing from: improved design criteria for coastal and offshore structures; increased safety during operations; more accurate weather forecasts, especially associated with hurricanes and coastal storms.

Quality of Life

Benefits will arise through improvements in NWS public weather and coastal maritime forecasts, evacuation associated with hurricanes and severe coastal storms, as well as infrastructure protection (e.g. foreshore erosion, coastal property damage and loss).

Science Education and Communication

The improvements in understanding of the physical processes (dynamics and associated fluxes between atmosphere and ocean) derived from this project will be published in the mainstream literature for public dissemination.

TRANSITIONS

This effort will contribute significantly to the major NOPP goal of validating and transitioning the new model physics for wind generated ocean waves, the near-surface winds and upper ocean circulation into the WaveWatch III model environment. The upgraded modeling environment will be distributed to various Federal agencies for incorporation in their mission-specific systems.

National Security

Improved environmental forecasts of open ocean and coastal zone waves, winds and currents should increase the efficiency and safety of Naval operations and Army Corps of Engineers projects.

Economic Development

Utilization of the upgraded modeling systems will lead to improved design criteria and practice for coastal and offshore structures and safety, as well as improved weather forecasts, especially during hurricanes and storms.

Quality of Life

There is a premium on the reliability of public weather and maritime forecasts, for evacuation announcements, infrastructure protection as well as routine day-to-day lifestyle decisions. The envisaged model improvements should enhance present capabilities.

Science Education and Communication

Results from the improved understanding of physical processes (dynamics and associated fluxes between atmosphere and ocean) obtained during this project will be published in the open literature for broad dissemination.

REFERENCES

Alves, J.H and M.L. Banner, 2003: Performance of a saturation-based dissipation source term for wind wave spectral modelling. J. Phys. Oceanogr. 33, 1274-1298.

Banner, M.L., Morison, R.P. Refined source terms in wind wave models with explicit wave breaking prediction. Part I: Model framework and validation against field data. Ocean Modell. (2010), doi:10.1016/j.ocemod.2010.01.002.

French, J.R., W.M. Drennan, J. Zhang, and P.G. Black, 2007: Turbulent fluxes in the hurricane boundary layer. Part I: Momentum flux. J. Atmos. Sci., 64, 1089-1102.

Tracy, B.A. and D.T. Resio (1982) Theory and calculation of the nonlinear energy transfer between sea waves in deep water, WIS Rept 11, US Army Engineers Waterway Experiment Station.