Oceanography

Out of the SWAMP to a more certain life on the ocean wave

from Robert Bryan Long

WEATHER forecasting and analysis could be considerably improved by the availability of numerical models that are good enough to define the coupling between meteorology and the waves on the surface of the ocean. Spurred on by this need, by the impending appearance of a new series of satellites that can sense ocean waves, and by the findings of the improbably named SWAMP group, numerical modellers from nine countries and representing 23 institutions have recently formed a coalition in order to develop a third generation of surface-wave models.

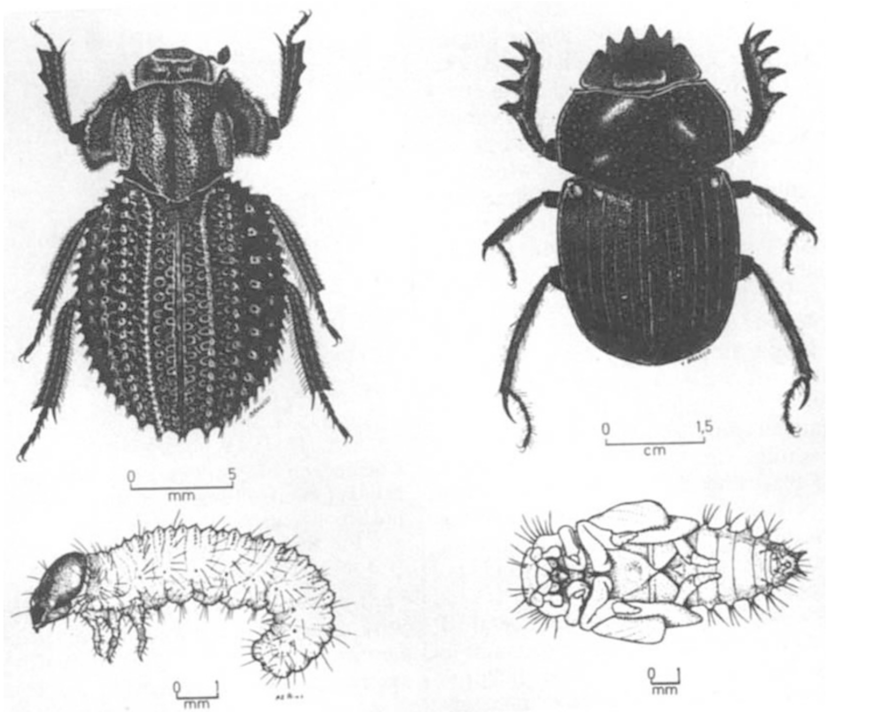
Simulation of the behaviour of the ocean surface under the influence of wind has seen a growing number of applications in recent years. Since 1974, the US Navy has run a northern hemisphere Spectral Ocean Wave Model (SOWM)[1] that provides forecasts for ship routing and other naval activities. A global version of the same system is now being implemented. In Europe, the British Meteorological Office has a regional model (designated BMO)[2] in routine use for the North Sea and the adjacent Atlantic, while in the Netherlands, the GONO model[3], which covers the North Sea and the Norwegian Sea, is run four times a day and provides valuable information in support of the massive Dutch coastal engineering projects. In Norway, a new model developed in the United States has been adopted to provide wave forecasts for the oil industry in the Norwegian Sea. And another dozen or so numerical wave models, which are in advanced stages of development or already in operation, are used either to generate forecasts of ocean wave fields or to produce engineering statistics by hindcasting wave fields for statistically adequate samples of storms.

Several years ago, wave modellers from the United States, Europe and Japan, calling themselves the SWAMP group (Sea WAve Modelling Project), subjected the models from the institutes they represented to a sequence of six different wind-field geometries, each designed to explore a separate aspect of wave prediction (such as fetch-limited and duration-limited growths, the effects of asymmetrical fetch geometries, inhomogeneous and/or non-stationary wind fields, swell generation and propagation). A seventh test used wind fields that simulate stationary and moving hurricanes. The results of that study, soon to be published by Plenum Press in a book tentatively entitled *Ocean Wave Modelling*, indicate that the state of the art is somewhat less than satisfactory.

All current numerical models of wave-prediction are based on computer-generated solutions to a radiative transfer equation describing the balance of processes controlling the evolution of the surface-wave number spectrum. These processes include advection, refraction and a variety of sources and sinks of energy. The principal energy source is the wind, while the principal sink is dissipation due to wave breaking and, in shallow water, to interaction with the sea bed. In addition, the non-linear interaction between waves acts as either a source or a sink for a given wave number. The advection, refraction, and non-linear processes are fully understood from first principles but the atmospheric input and dissipation effects are not well understood and must be modelled empirically. Existing wave models differ according to the set of parameters onto which the radiation balance is projected before being presented to the computer for solution, the particular mix of theory and empiricism used to model the source/sink terms, and in the details of the numerical techniques employed.

The SWAMP group classified existing numerical wave models as first or second generation according to their treatment of linear effects. First generation models, of which SOWM is an example, omit the non-linear term in the radiation balance (or model it in such a way that its effect is negligible), leading to an essentially linear formulation in which each wave component independently grows, propagates, saturates and decays. The prototypes of these models were designed before the importance of the weak non-linear interaction between waves was established by the theoretical work of Hasselmann[4] and experiments of the Joint North Sea Wave Project (JONSWAP)[5]. Second generation models incorporate the non-linear interaction in some form. In principle, the non-linear effects can be exactly computed, but the calculation is so time consuming that it has, until recently, seemed impossible to make it an integral part of a full, three-dimensional (2-space and time) wave model. (One of the SWAMP models, optimistically called EXACT-NL, explicitly computes the non-linear interaction but only for one-dimensional problems, such as simple fetch-limited or duration-limited growth.)

Although there are wide variations in the parameters used to incorporate non-linear interactions into second generation models in the SWAMP study, in every case they include some kind of external constraints on the permitted shapes of the wind-sea portion of the spectrum, where the non-linear transfer is known to be important. These constraints force the wind-sea spectra



A selection of the scarabid dung beetles of South Africa described by A.J. Prins in the *Annals of the South African Museum* 94, 203; 1984. Top left, *Trox horridus;* top right: *Nenteuchus probuscideus;* bottom, larva and pupa of *Trox rhyparoides*.

Correction

In the article "Draughtsmen of the constellations" by David W. Hughes (*Nature* 20/27 December, p.697), 0^0 on line 10 should have been $(90 - \theta)^0$, 0^0 on lines 13 and 64 (twice) should have been θ^0, longitude on line 25 should have been latitude, each ∓ should have been ±, and ~ was omitted before 125BC on line 19.