The Wave Modelling (WAM) Group, a historical perspective

Gerbrand Komen
Royal Netherlands Meteorological Institute (KNMI), De Bilt, The Netherlands

This paper gives a historic account of the activities of the Wave Modelling Group, established in 1984 on the initiative of Klaus Hasselmann. WAM was triggered by an earlier intercomparison project, the Sea WAve Model intercomparison Project (SWAMP), which will be describe in some detail. From the post-WAM period several highlights will be presented, such as the introduction of global probabilistic wave prediction at ECMWF, progress at BMRC with data assimilation, and recent work at KNMI on decadal variability of the global wave climatology. The number of references has been limited to a minimum, as a more comprehensive bibliography can be found elsewhere (see e.g. in Komen et al., 1994).

Pre SWAMP (<1981)

The basis for modern ocean wave research was laid in the 1950s and 1960s. An important advance was the introduction of the concept of a wave spectrum by Pierson. At the time, this was not yet accompanied by a corresponding dynamical equation describing the evolution of the spectrum. This step was made by Gelci and others who introduced the concept of spectral transport equation. Because of the lack of adequate theories, Gelci was forced to use a purely empirical expression for the net source function governing the rate of change of the wave spectrum. It was only after the new theories of wave generation by Phillips and Miles had been published and the source function for the nonlinear transfer had been derived by Klaus Hasselmann that it was possible to write down the general expression for the source function, consisting of three terms representing the input from the wind, the nonlinear transfer and the dissipation by whitecapping (and bottom friction) - in a form which is still used today.

An experimental milestone was the JONSWAP experiment in the North Sea (published in 1973) in which, among other things, the fetch dependence of the spectral evolution was observed and the concept of self similarity of the spectral shape emerged.

In this same period the availability of computers allowed the development of numerical wave prediction models. Many of these models simply automated older manual methods in which wave heights were computed from wind speed and effective wave age (i.e. dimensional fetch or duration) and in which swell was propagated along rays. An example was KNMI's GONO model, which was primarily developed for swell prediction in the southern North Sea. This and other models were highly tuned but also well-validated by systematic comparison with waverider observations.

SWAMP (1978 - 1984)

Large international wave conferences have always formed milestones in the history of wave research. The above mentioned developments can be traced back, more or less, from the Proceedings of the NATO Air/Sea Interaction Conference in Bandol which was held in 1978. At the time of this conference plans were developed for a Sea WAve Model intercomparison Project (SWAMP). At the following conference in Miami, in 1981 results were presented (SWAMP, 1985). In this project a distinction was made between first generation models, in which nonlinear interactions are neglected, and second generation models which do describe them, but in a simplified parametrized form. Two types of second generation model were distinguished: `coupled hybrid', and `coupled discrete'. In `coupled hybrid' models, such as GONO, the wind sea spectrum, which is strongly controlled by the nonlinear interactions, is assumed to adjust rapidly to a universal quasi-equilibrium form in which only a single scale parameter - normally the wind sea energy - or at the most a second frequency scale parameter need be predicted as slowly varying parameters. The swell, which is not affected by nonlinear interactions, is then treated as a superposition of independent components in the same way as in a first generation model. `Coupled discrete' models retain the traditional discrete spectral representation, but have a parametrization of the nonlinear transfer with limited validity, so that the potential advantage of a more flexible representation of the wind sea spectrum and a uniform representation of the swell-wind-sea transition regime cannot be properly exploited. The SWAMP study compared the results of nine different first and second generation models in simple, hypothetical conditions, such as fetch- and duration-limited growth in a constant wind field, growth in a slanting fetch situation, swell propagation out of a half plane wind field and a diagonal front. Also, the response to a sudden change in wind direction was studied. A final test considered the response of the models to a hurricane wind field. In this last test especially it was found that the models behaved quite differently. For example, the extreme significant wave height ranged between 8 and 25 metres, demonstrating our lack of knowledge. A careful analysis of the tests revealed that much of the discrepancy could be traced to details of parametrizations affecting the spectral behaviour of the models and that differences in predicted wave height could be partly traced back to differences in spectral shape. In reality, wave spectra showed much more variability than was originally assumed in parametric models, and two-dimensional aspects were found to be more important than expected. Therefore a `third generation' model was developed: a full spectral model with an explicit representation for the physical processes relevant for wave evolution and which gives a full two-dimensional description of the sea state.

WAM (1984 – 1994)

In Miami Klaus Hasselmann invited me to spend a summer in Hamburg. This became the summer of 1983. Klaus and Susanne had developed a code for the four-wave nonlinear interactions and obtained results on the nonlinear energe transfer. I decided to study the energy balance in the fully grown wave spectrum. The idea was that it should be possible to obtain directional information on the wind input and dissipation source term by combining observed directional information and the nonlinear results. What I found was that the balance is very sensitive to details of the directional properties of the wave spectrum, and this turned out to be useful in the construction of a full wave model. However, work went slow in a small team. Therefore, in 1984, Klaus Hasselmann invited a larger group of wave modellers for a one-day meeting in Hamburg. At that meeting - after JONSWAP and SWAMP - he now proposed WAM, de Wave Modelling project, this time under my chairmanship. The establishment of WAM coincided with important developments in satellite observation of ocean waves. SEASAT, in its short life, had proven the concept of detection of ocean waves both with altimeters and radar back scatter. At the start of WAM preparations for GEOSAT and ERS-1 were well under way. From then on, modelling and instrumental development were strongly stimulating each other. The objectives of the WAM group were formulated as follows

- to jointly develop a third-generation wave model, based on a full description of the physical processes governing wave evolution
- to implement a global version of the model and to test medium-range forecasting
- to develop regional versions of the third-generation model to be nested with the global model
- to perform physical studies of wave dynamical processes in order to extend our understanding of wave evolution, where needed, and
- to develop data assimilation techniques which will make it possible to make full use of satellite observations of the sea-state.

In the next ten years all of these objectives were achieved in a large multinational collaboration. Among the results were

- the introduction of improved physics (WAMDI, 1988), in particular two-way coupling between wind and waves
- development and validation of the WAM model in a standard version suitable for real-time and off-line applications, both globally and regional
- an operational version of the model, with data assimilation at ECMWF

In 1986 WAM became a working group under the umbrella of SCOR (the Scientific Committee on Oceanic Research). The annual meetings of WAM were basically open meetings and outreach was an important activity. In 1988 several members of the WAM group organized a very successful Course on Ocean Waves and Tides at the International Centre for Theoretical Physics. WAM effectively ended in 1994 with the publication of Dynamics and Modelling of Ocean Waves (Komen et al, 1994).

Post WAM

The WAM model is still operational at ECMWF. It has undergone several improvements. It now makes part of the ENSEMBLE forecasting system. This is useful for modern shiprouting applications which receive probabilistic information about the wave conditions as an input (Saetra and Bidlot, 2004).

The WAM model was introduced at BMRC in the early 90s. We refer to Diana Greenslade (2004) for a detailed account of the subsequent work. Recently, significant progress was made in the field of data assimilation (Greenslade and Young, 2004).

The WAM model was also part of the model that was used for the recent 40 year reanalysis (ERA-40). KNMI performed a thorough validation and analysis of the ERA-40 wave results. Perhaps one of the most interesting results consists of a reconstruction of the decadal variability of the global wave climate (Caires et al, 2004ab).

References

Caires, S. Sterl, A., G.J. Komen and V. Swail, 2004a. The web-based KNMI/ERA-40 global wave climatology atlas. *Bulletin of the World Meteorologial Organization,* 53(2), pp. 142-146, April 2004. (see also http://www.knmi.nl/onderzk/oceano/waves/era40/index.html)

Caires, S. Sterl, A., G.J. Komen and V. Swail, 2004b. Wave climate and its change - The KNMI/ERA-40 wave atlas. *Clivar Exchanges*, 30, pp. 27-29, June 2004.

Greenslade, D., Marine Forecasting at the Bureau of Meteorology, 2004. See elsewhere in this volume.

Greenslade, D.J.M. and Young, I.R. 2004. Background errors in a global wave model determined from altimeter data. *J. Geophys. Res*. 109, C09007, doi:10.1029/2004JC002324,

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

Komen, G.J., L. Cavaleri, M. Donelan, K. Hasselmann, S. Hasselmann and P.A.E.M. Janssen, 1994. Dynamics and Modelling of Ocean Waves. Cambridge University Press, 532p.

The SWAMP Group: J.H. Allender, T.P. Barnett, L. Bertotti, J. Bruinsma, V.J. Cardone, L. Cavaleri, J. Ephraums, B. Golding, A. Greenwood, J. Guddal, H. Günther, K. Hasselmann, S. Hasselmann, P. Joseph, S. Kawai, G.J. Komen, L. Lawson, H. Linne, R.B. Long, M. Lybanon, E. Maeland, W. Rosenthal, Y. Toba, T. Uji and W.J.P. de Voogt, 1985. Sea Wave Modelling Project (SWAMP), An inter- comparison study of wind wave prediction models, Part 1: Principal results and conclusions, in Ocean Wave Modelling. Plenum Press, 256p.

The WAMDI-group. S. Hasselmann, K. Hasselmann, E. Bauer, P.A.E.M. Janssen, G.J. Komen, L. Bertotti, P. Lionello, A. Guillaume, V.C. Cardone, J.A. Greenwood, M. Reistad, L. Zambresky and J.A. Ewing, 1988. The WAM model - a third generation ocean wave prediction model. *J. Phys. Ocean.* 18, 1775 - 1810.

Saetra, O. and J.-R. Bidlot, 2004: On the potential benefit of using probabilistic forecast for waves and marine winds based on the ECMWF ensemble prediction system. *Weather Forecasting,* **19**, 673-689.