Towards a new wave prediction system

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Introduction

Within the last ten years the WAM Cy 4 wave prediction model has become a standard tool for operational wave prediction as well as for research and engineering application. The model is widely distributed and used at about 150 institutions. Even today the program is requested. The availability of high-speed computers and the increasing demands for wave prediction products have let to this large user community of the model code. Quality of wave analysis and forecast continuously improved, mainly due to a much better quality of the forcing wind fields. Only minor changes have been introduced into the model itself. This is a clear indication, that the approach taken ten years ago by the WAM group has been very successful.

Nowadays the important role of surface waves in the earth climate system is generally accepted. Therefore wave modelling has to be really integrated into the system of atmosphere and ocean models. First steps towards the integration have been made e.g. at ECMWF.

The model code distributed today is still the version done in 1991 and does not include any progress made in physic, numeric, and computer technology. The code distribution has created a large user community with a wide range of applications for the model. Therefore new developments of the model has to take into account the progress made in physic, numeric, and computer technology as well as the special demands of the wide user community of the model.

The basic features of the standard WAM CY 4 are summarised in the next chapter. In Chapter 3 a few typical applications will be discussed. The consequences of the future operational availability of 2-dimensional wave spectra will be addressed in chapter 4 followed by an overview of the demands of wave model user in chapter 5. Chapter 6 presents some remarks for the code development. The last chapter gives a summary and an outlook.

The WAM model CY 4

The overall aim of the WAM group was to develop a third generation wave model. Global and regional (basin scale) applications should be possible. State of the art deep and shallow water physics should implemented. The model code should be computer independent.

During the model development a number of compromises had to be done because of the limitation in computer power. For example the non-linear interaction source function had to be approximated by the Discrete Interaction Approximation. The introduction of "grid blocking" is another example. The standard model has the following characteristics and options:

Physics (Shallow or deep water):

- Janssen coupled input source term
- DIA non- linear source term
- White capping dissipation term
- JONSWAP bottom dissipation term

Numerics:

- First order propagation on Cartesian or spherical grid
- Semi implicit integration of source functions

Model input:

- Wind speed and direction at 10m
- Stationary bathymetry
- Stationary current

Grid set-up:

- Grid blocking
- One way nesting to multiple levels
- Fixed special output points for spectra

The model output:

- Limited number of integrated spectral parameters
- Sea – swell separation

Two important updates to the model have been done to improve the model performance:

- Turning of the spectral directions by half of a directional bin width improved the propagation along the grid axis,
- Introduction of a new limiter for the source function integration and change to a fully implicit scheme to achieve a better growth for short fetches.

Special versions of the WAM model have been developed at different institutes. The main changes and extensions are additional output parameter, special nesting techniques and the introduction of sea ice.

During the last decade the main focus of wave model development was for high-resolution shallow water applications. Examples are the SWAN model, the PRO-WAM and the K-Model.

The PRO-WAM is the WAM model but considerable efforts have been done to speed up the model run time, e.g. variable time steps for different frequencies he been introduced and the restriction that the propagation time step must greater than the source function one has been removed. The K- model is based on the WAM propagation but turbulent diffusion has been introduced as the main dissipation process.

Wave model applications

Global wave forecasts are a standard WAM model application. Fig.1 shows as the global distribution of significant wave heights at January 14th, 2000, 00:00UTC from the operational model of the German

Meteorological Office (DWD), which has a resolution of 0.75^0. These data are used to advice shipping and other offshore operators. In addition these global models provide the necessary boundary values for regional high-resolution models. Fig.2 show the map as computed by the operational WAM model at meteorological office of the Sultanate of Oman using boundary values provided by the DWD. The products are used to advise the ships and equally important to provide safety warnings to the local fishing fleet.

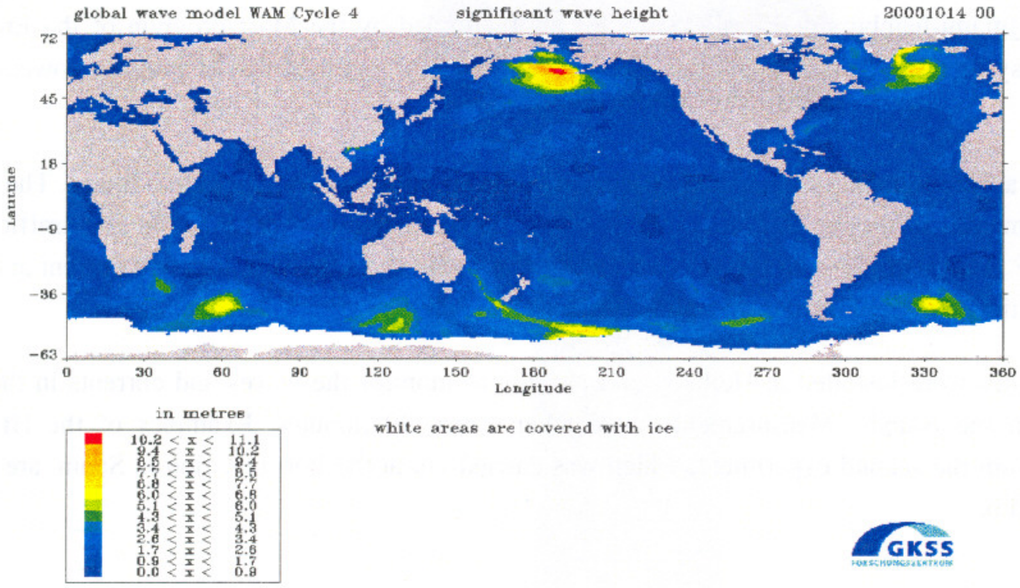

Fig.1: Global map of significant wave height from the wave forecasting system of the German Meteorological Office.

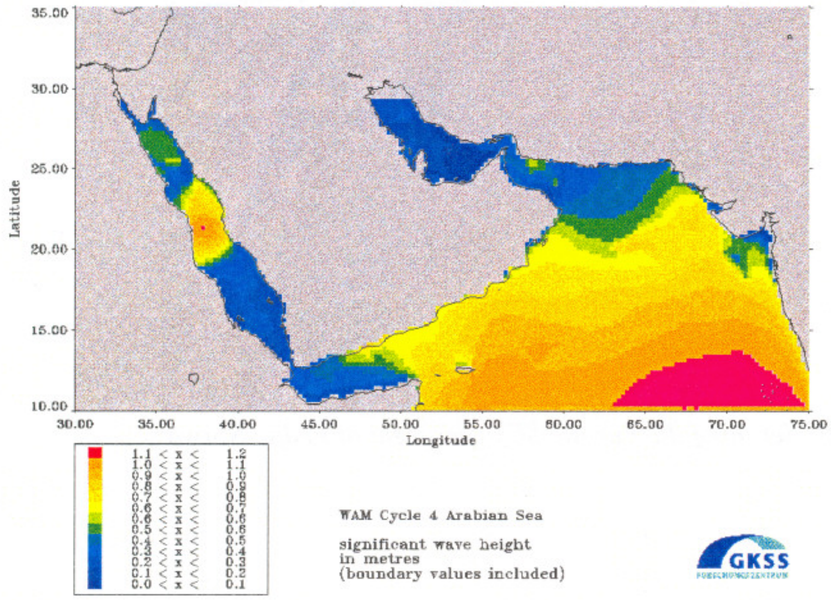

Fig.2: Sig. wave height map of the Arabian Sea from the meteorological office of the Sultanate of Oman

The forecasters, who actually have to issue the information to the public, very well appreciate these products. Nevertheless the information is based on model prediction, which, if at all, include measurements done about 18 to 24 hours earlier. Therefore the personal experience of the forecasters is still very important.

In coastal areas the nowcast and very short forecast of the sea-state is of great importance for the shipping industry, because the typical approach time is a few hours only. In the EuroROSE project (http://ifmaxp1.ifm.uni-hamburg.de/EuroROSE/index.html), funded by the Mast program of the European commission, a system was set-up and demonstrated in two field experiments to provide nowcasts and forecasts.

Fig.3 shows the approach area for the main Norwegian crude oil terminals Mongstad and Sturre. The Vessel Traffic Management and Service (VTMS), located at the Island of Fedje, supervises the ship traffic in the area. WERA HF radar stations were set-up on the islands of Fedje and Lingoy to measure current and wave spectra fields in the offshore area marked by the circles.

Two WaMoS sites were installed at Hellisoy and Nordoy to monitor the waves and currents in the main passage between the islands. Measurements were taken every 20 minutes. Examples of the HF radar measurements from the second experiment, which was carried out at the Port of Gijon in Spain, are shown in Figures 4a and b.

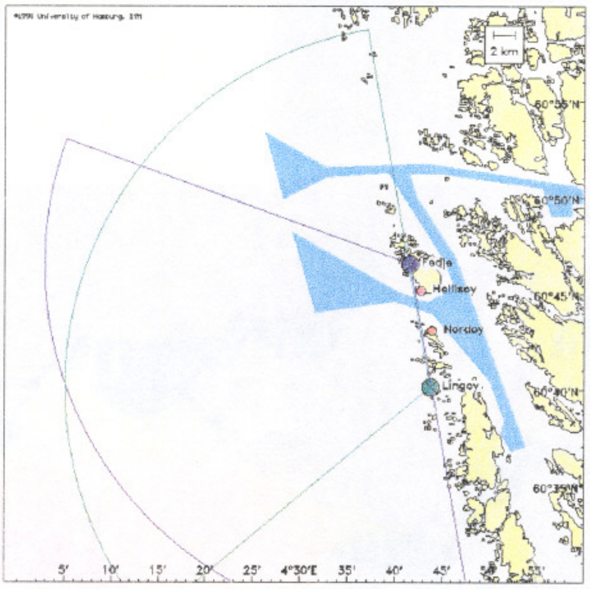

Fig.3: Set-up of the EuroROSE experiment at Fedje, Norway.

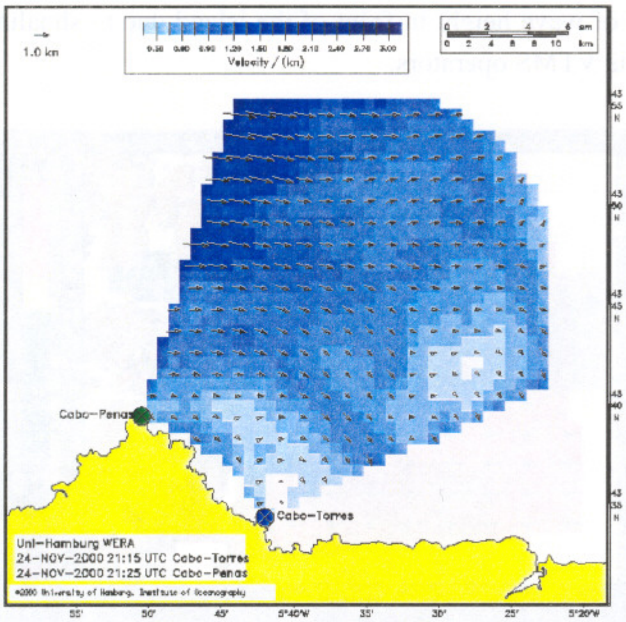

Fig.4a: Current field measured by HF radar during the Gijon experiment

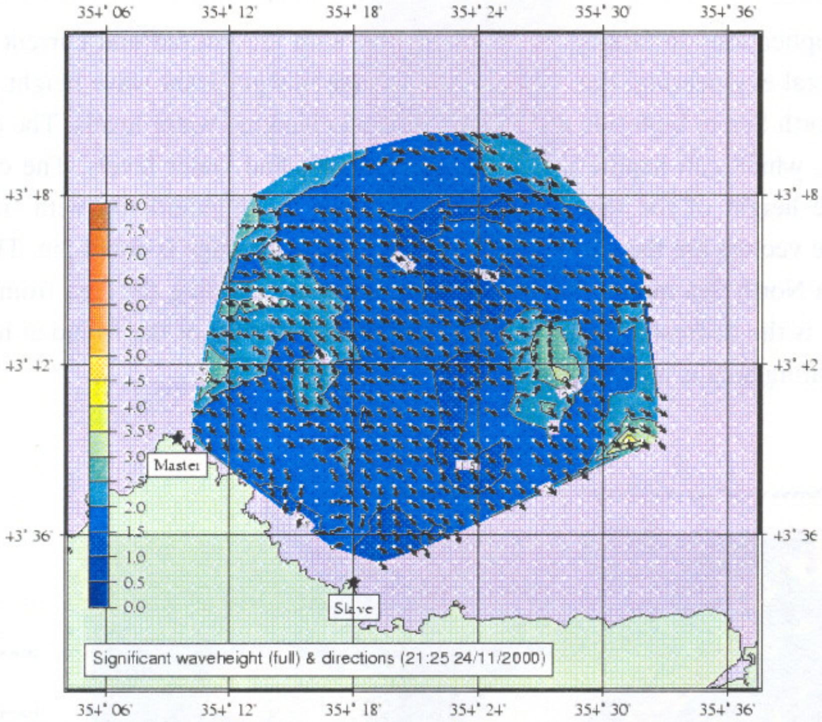

Fig.4b: Sig. wave height and wave direction map from HF radar during the Gijon experiment

These measurements were transferred to the Norwegian Meteorological Office and assimilated into current and wave models for the area. The models were nested into the operational shelf models and the resolution was about 1 km. The assimilation cycle was 20 min and every hour a forecast for the next 6 hours was generated. The analysis and forecast products were transferred back to the VTMS and displayed at the operational centre less than 20 min after the last measurement. Fig.5 shows a typical displayed wave map.

Clearly visible is the increase of wave height in front of the island due to shoaling. This spatial variability was of particular interest for the VTMS operators.

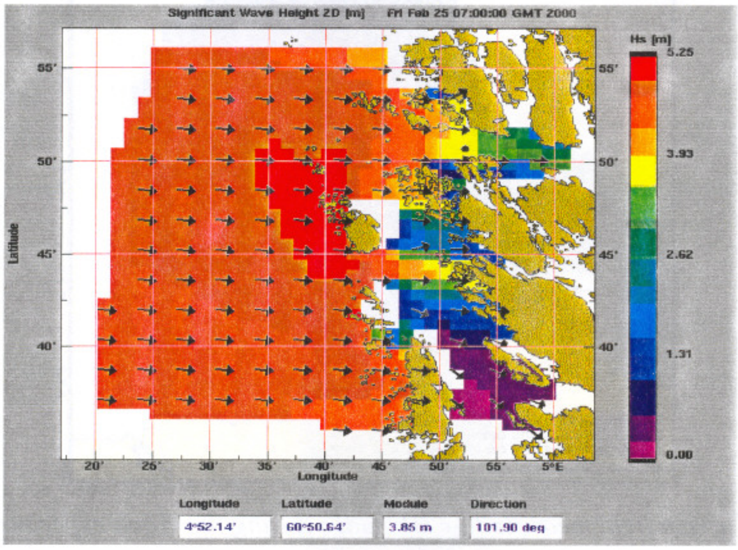

Fig.5: Significant wave height and direction map as displayed in the Fedje VTMS.

For wave model applications in coastal areas interaction with the bottom and current is a very important subject e.g. for coastal engineering. Fig. 6 shows the change in significant wave height around the Island of Helgoland in the North Sea at high tide due to currents and changing water levels. The data are results from the K-Wave model, which can handle non-stationary currents and water levels. The contour lines are the differences in wave height of the non stationary run minus the standard run with fixed bathymetry and without current. The vectors are the currents at high tide. The tidal range is about 2m. The model (resolution 50 m) is nested in a North Sea model. Waves of close to 6m are entering the area from the Northwest. The most striking effect is the decrease of nearly 1m of wave heights west of the island at high tide. The reason is that the main shoaling area is moved closer to the coast.

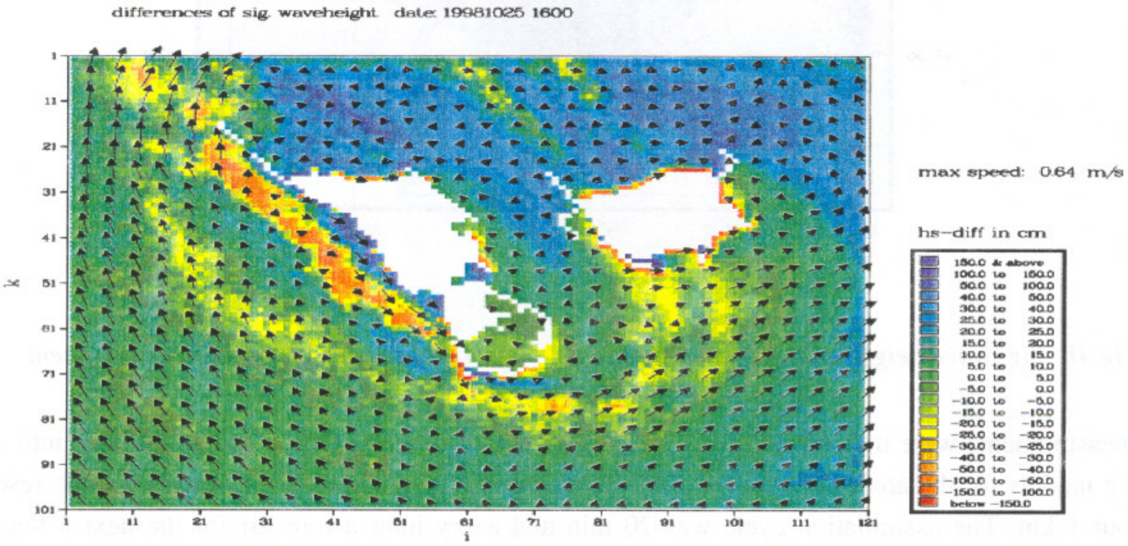

Fig.6: Differences of sig. wave height (contours) and current (vectors) at the Island of Helgoland.

The most used parameter to characterise waves is the significant wave height, which is an average over the highest one-third single waves within a wave record. Little is know about the so called rough or freak waves, single waves or waves groups which are more than two times higher than the significant wave height. These waves are of considerable danger to ships and off-platforms. Fig. 7 gives an impression of these phenomena showing a so-called "white wall". The inlay in the figure is a wave records from the Gorm field in the North Sea, showing a single wave group of 10 m whereas the sig. wave height is about 3m. Only few measurements and statistics exist for these waves. Investigations about ship damages and losses indicate that high-risk areas are parts of the oceans with strong current. The MaxWAVE – project is investigating this problem. Satellite SAR and WaMoS images of the sea-surface and conventional buoy time series data are used to detect these waves and to check the statistics of occurrence. The main aim is to develop prediction and warning criteria. The European Commission funds MaxWAVE and details can be found at the project home page http://w3g.gkss.de/projects/maxwave/ .

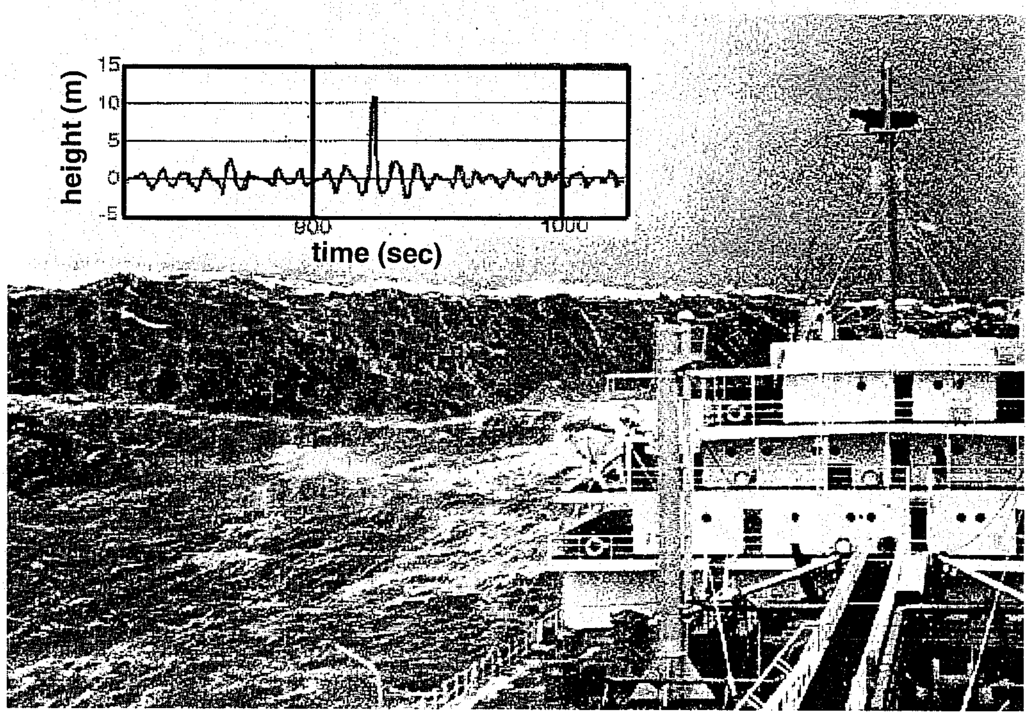

Fig.7: Photo of a rough wave and a wave record showing a very high single wave.

Wave measurements and wave data assimilation

The prognostic variable of the WAM model is the 2-dimensional wave spectrum. From the spectrum a number of integrated parameters, e.g. significant wave height, different wave periods and mean direction, are computed. These integrated parameters are distributed to users and are used for model validation by comparison with wave buoy measurement. The wave data assimilation used in wave models is based on significant wave height measured by altimeter on board of satellites.

The reason for the use of integrated parameters is that measurements of 2-dimensional wave spectra were not available since a few years ago. In the last years large progress was made to measure the 2-dimensional spectra.

The main methods are based on radar techniques. Figure 8 shows the 2-dimensional wave spectrum measured by the WaMoS system, which is based on the x-band radar, used by ships for navigation. Further details are available at http://www.oceanwaves.de.

The extraction of wave information out of satellite SAR images has developed rapidly during the last years and from the ENVISAT satellite high quality 2-dimensional wave spectra are expected next year.

To use the 2-dimensional wave spectra for wave model validation and assimilation it is necessary to develop new comparison statistics and advanced assimilation methods.

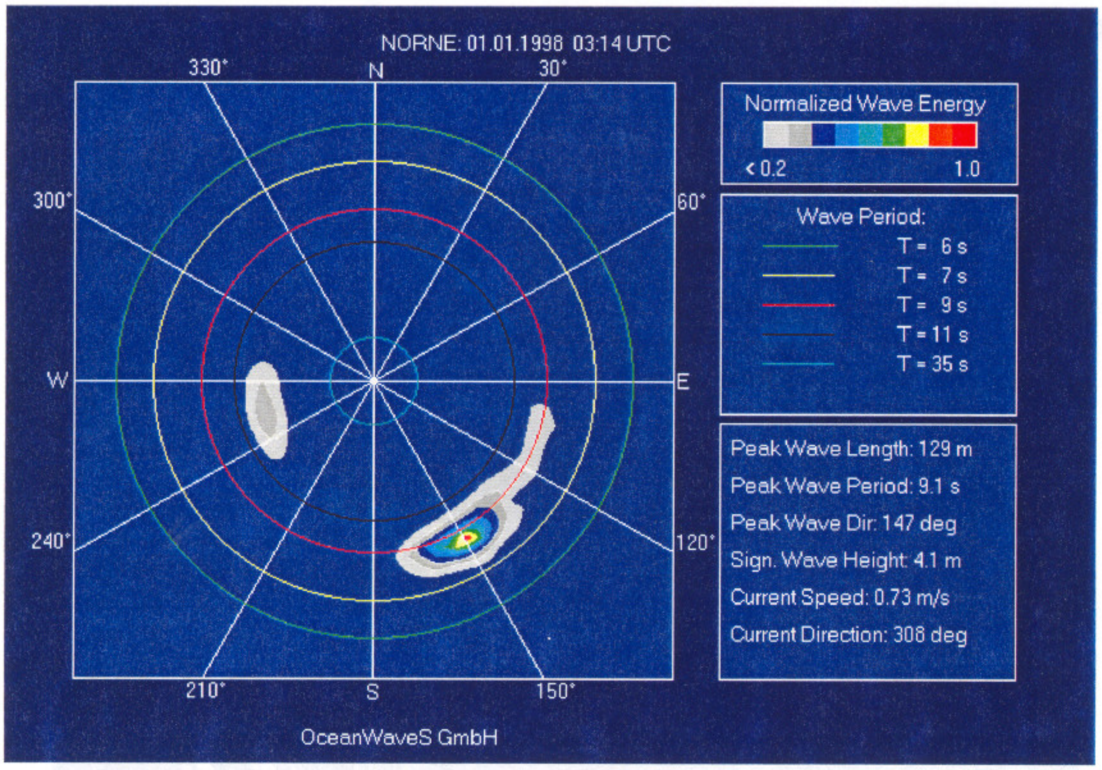

Fig.8: 2-dimensional wave spectrum measured by WaMoS x-band radar.

Wave model user

Originally the WAM model was designed and developed to provide global and regional wave forecast. Typically the model was applied by forecast centres, which had the computer power to run models operationally in quasi real time. Only experience modellers used the code and the application was controlled by wave modelling experts. The success of the model and the increasing computer power has let to a wide distribution of the code. Nowadays the WAM code is used at more than 150 institutions around the world. It is often applied as a "black box" or a special tuning of the model is done to generate wave data for a wide range of special engineering applications.

To serve this new group of model users it is necessary to adapt the model in the following way:

- The model code has to be as flexible as possible to allow application in different areas and scales without code changes.
- Nesting techniques have to be developed further to allow a much more simple model application.
- The model performance in shallow water and for very high resolutions has to be investigated and clear limits for the application scales of the model have to be defined.
- A save application of the model requires a number of advanced consistency checks of which the most important seems to be a strict stability check in the code.
- The range of output variables has to be extended to all parameters, which are used in engineering praxis.
- The effects of non-stationary water depth and currents are considered as an important extension of the model.

Code developments

In general development has to follow the rules, which were already applied for WAM CY 4. The code has to be:

- User friendly
- Easy to maintain
- Flexible
- Adaptable to future needs
- Computer independent

The model was coded in ANSI FORTRAN standard X3.9-1978 and was optimised with respect to memory and time using single processor vector computers. The development of the computer hardware and software over the last ten years allows a number of features, which have to be built into the code to make optimal use of the computers and therefore extent the areas of model applications.

The most limiting factor of the model is the computation time. A multi-processing version of the code, based on standard libraries, seems to be the most effective solution.

A recoding of the model in standard ANSI and ISO FORTRAN 90 will allow optimal use of the multi-processing features and result in a much more flexible code. The module technique will allow applying the same code for all applications.

Summary and outlook

The future development has to incorporate into the model

- Better physics and numerics,
- Non-stationary currents,
- Non-stationary water depth,
- Very high resolution (nesting),
- Assimilation of spectra,
- Advanced wave parameters for the end-user

The model code has to be modernised to follow the developments of computer hardware and software.

The best way to achieve this goal, to build on the experience of ten years of WAM model applications and to take into account the future demands of model users a model development group has to be set-up.

The objectives of the proposed European concerted action 'Shallow Water wave Modelling In Europe (SWAMIE) may serve as a guideline for the way forward.

1. To provide a European network for wave modelling, especially in shallow water, with strong research links to the rest of the world

2. To review the state of the art in shallow water wave modelling and promote best practice

3. To widely disseminate test data and model code

4. To improve the collaboration between the different participating institutes

5. To enable intense participation in problem-specific workshops

6. To identify the requirements (physics, numeric, optimum implementation and evaluation) and limitations for the next generation of spectral wave models

7. To facilitate the initiation of new research into shallow water wave modelling