EUROWAVES
Integration of data from many sources in a user-friendly software package for calculation of wave statistics in European coastal waters.

by

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Introduction

In the absence of long term wave data collected at a coastal site of interest, the calculation of wave statistics at a coastal site requires various data sets to be assembled, including temporally and spatially long term representative directional wave data offshore of the site, as well as bathymetric and coastline data. Further, a suitable wave model is required, which is capable of modelling the transfer of the offshore conditions to the site, incorporating the relevant shallow water wave phenomena. EUROWAVES simplifies the modelling of wave conditions in coastal waters by integrating the following under a single software package for all European waters:

- High quality long term wave data offshore of all European coasts derived from the integration of wave model data from operational and hindcast runs of the WAM model at the European Centre for Medium-Range Weather Forecasts (ECMWF), together with high precision satellite altimeter data and buoy data from 13 European countries.
- European-wide bathymetric data from US Navy's Digital Bathymetric Data Base (DBDB-V)
- European-wide coastline data from the GMT High Resolution Coastline Database (GMT-HRCD).
- Two shallow water wave models: SWAN (Simulating Waves Nearshore), a state-of-the-art third generation wave model and VENICE, a traditional backward ray-tracing model.
- Sophisticated offshore and nearshore wave statistics toolbox.
- A geographic module allowing the user to easily zoom in to the area of interest on geographic maps, displaying bathymetry and coastline, together with tools to assist the user in setting up the wave model grid.

In addition, in recognition that the user may have access to more accurate wave and/or bathymetric data, EUROWAVES also provides a facility for user input.

EUROWAVES is a MAST project and is financed in part by the Commission of the European Communities and runs to November 2000. In this paper we describe the design, implementation and testing of all parts of the EUROWAVES package. More information about the project is available from the project Web Site (http://www.oceanor.no/eurowaves).

European-wide offshore data

The area of interest covered by Eurowaves includes the entire European coastline from the Barents Sea in the North along the Atlantic rim south to Spain and including Iceland and all the major Atlantic islands (Faeroes, Azores, Canaries, etc.). Further, the North and Irish Seas and the Baltic are included as are the entire Mediterranean (including the coasts of North Africa and the Middle East) and, finally, the Black Sea.

In the construction of the Eurowaves offshore data base, three types of wave data have been integrated. These are a) In-situ measurements; b) Satellite measurements; and c) Wave model simulations. We will briefly discuss the data used, their characteristics and the integration in the following.

In-situ data

Unfortunately, there is no co-ordinated European-wide wave data collection paralleling the network operated by NOAA in the US. Neither is there a central repository and/or inventory of European wave measurements. Most European countries have, however, over the years, carried out data collection from buoys and offshore installations for different purposes, with responsibility for data banking resting within the individual countries. Through a network of contacts, available in-situ wave measurements have been sought from throughout Europe. Agreement has been reached with holders of wave data in 13 countries, and a total of 116 individual site specific data sets have been received. Despite the success in obtaining measured data, there are few offshore data sets and even fewer data sets with measurements simultaneously in deep and shallow water. Offshore data sets (in particular, directional measurements) are valuable for validating the wave model data, whereas simultaneous offshore-nearshore data sets are very useful in validating the entire Eurowaves methodology.

Satellite data

The back-scattered signal from satellite altimeters, when properly interpreted, can provide significant wave height measurements close to the accuracy of a buoy from an orbit of typically 1,000 km. (see, for example, Krogstad and Barstow, 1999). Measurements are provided each second, whilst the satellite flies over a repeat net of ground tracks at about 6 km/s. This provides enormous amounts of wave data worldwide, and with, at present, a steady flow of new data from 3 or more operational satellites, millions of new observations are becoming available each month. Altimeter measurements have been performed during 1985-1989 (US Navy's Geosat), from 1991 by ESA's ERS-1 and ERS-2 satellites, and from the US/French Topex/Poseidon mission since 1992. Algorithms for the correct interpretation of the back-scattered radar return pulse have been gradually improved (Krogstad and Barstow, 1999). The resultant accuracy can be seen in the satellite – buoy comparison shown in Figure 1. For the following reasons, satellite altimeter data are most valuable in offshore waters: a) the distance between adjacent repeat tracks, which is typically greater than 100 km. for Topex is generally much larger than the scale of spatial variability in coastal locations; b) the along track resolution of around 6 km. is also rather large in many cases with respect to spatial variability near the coast and c) the first few observations by satellite altimeters when passing from land to sea are often poor quality. In offshore waters, on the other hand the satellite altimeter is well suited either for providing significant wave height statistics directly or, increasingly, for validating wave model data sets. For example, Oceanor have for the last 10 years used Geosat and Topex/Poseidon measurements to validate and correct data from the UK Met. Office global wave model archive (Barstow and Krogstad, 1999). The same approach has been used in Eurowaves to validate the WAM and BSH model data throughout Europe.

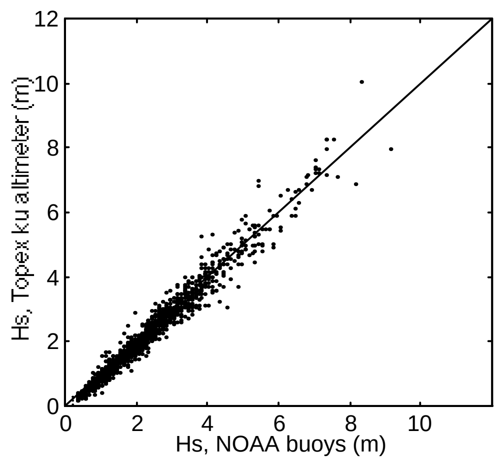

Figure 1. Comparison of significant wave height between the Topex altimeter and NOAA buoys for 1,365 coincident data (from Krogstad and Barstow, 1999).

Wave model data

Nowadays, sophisticated wave models are run operationally at many meteorological centres in Europe and dedicated long-term hindcasts have also been performed. The wave models attempt to replicate the growth, decay and propagation of ocean waves based on input winds over the area in question. In practice, the limiting factor is the accuracy of these input wind fields, to which the wave results are sensitive.

Various sources of wave model data were considered as the primary source of wave data in the construction of the European-wide offshore data in Eurowaves. The final choice was, first, data from the European Centre for Medium-Range Weather Forecasts (ECMWF, Reading, UK), where the WAM wave model (Komen *et al.*, 1994) has been operational since 1992. Data are available at 6 hourly intervals, with a resolution that has been changed in time, from 3 to 1.5 to 0.5 degrees in the open ocean, and from 0.5 to 0.25 degrees in the Mediterranean and the Baltic. In addition, the 1979 – 1993 ECMWF reanalysis (ERA) data set (Gibson et al., 1993) are being considered. For some areas such as the Irish Sea, the English Channel and the Skagerrak, the resolution of the WAM data is not sufficient to give reliable data. In these areas, we are using data from an archive of operational wave model data (HYPA-S model) run by DWD (Deutscher Wetterdienst) held by Bundesamt fuer Seeschiffahrt und Hydrographie(BSH) in Germany. This archive provides wave data from 1991 to 1998 in these latter areas with a grid size of about 30 km. Furher, due to the complete lack of model data in the Black Sea and to the limited extension in time of the model data available for the Baltic, dedicated hindcasts were performed for both these areas at ECMWF. These hindcasts, covering a 7-year period, had a 0.25° resolution and 0.5° for the retrieved fields, and was carried out using the latest version of the WAM wave model.

Each of the model data sets has undergone careful validation throughout the area of interest. The Topex altimeter data has been the major validation data set as it is available close to more or less at all wave model grid points. The altimeter data only provides a validation of the significant wave height, Hs. It turned out that WAM provided good results in the open ocean (see Figure 2a), whereas the model significantly underestimated Hs in the Mediterranean (Figure 2b) and other enclosed basins.

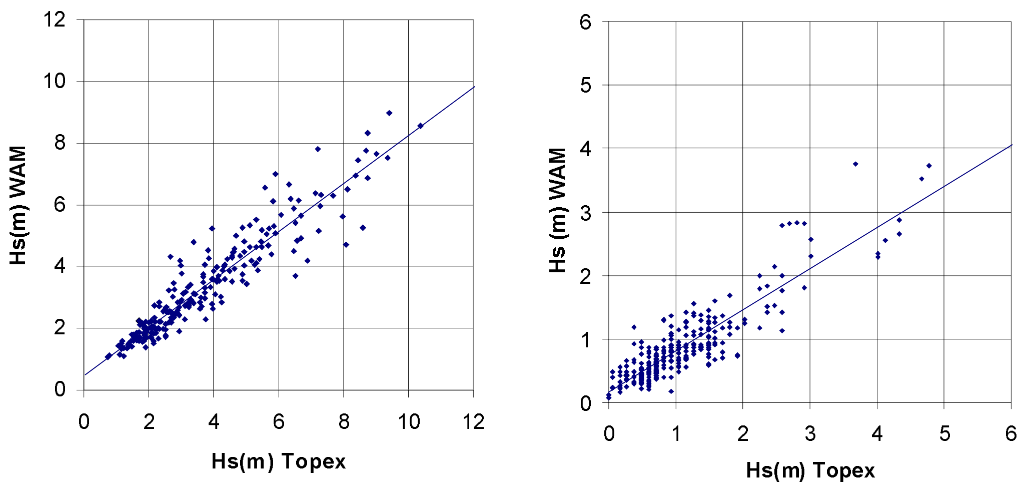

Figure 2. Comparison of significant wave height between WAM model data (y) against altimeter data from Topex for: left) the West of Ireland and right) the Mediterranean off Libya (after Mørk and Barstow, 1998a and 1998b).

Geographical Data

To obtain the final results at the nearshore location, the user is able to interact with the system, and easily indicate the location of interest. Software has been developed which, starting from an overall map of the Eurowaves area, allows the user to zoom progressively into the area of interest, and to choose the exact location using the mouse.

Towards this objective, two pieces of information had to be assembled. First, full bathymetric information and an accurate description of the coastline for the whole Eurowaves area was needed. After a careful search of the available data sets (Athanassoulis et al., 1998), the DBDB-V data base was selected for the bathymetry. This data set was released in 1996 and was last updated in 1998. A new release planned for summer 2000, with some errors discovered in our error checking removed, is hoped to be the final Eurowaves version. It covers the whole area of interest and numerous tests have shown that it is the data set presenting the best overall quality and least compatibility problems with the definition of the coastline. The coastline data were extracted from the GMT High Resolution Coastline Database (GMT-HRCD), released in 1995. It has a working scale of 1:250000, containing vector information in a polygon format.

The coastline database, which is derived from detailed satellite images, is much more accurate than the bathymetry. Close to the coast, in areas rarely mapped by ship soundings, the bathymetric data often seem to have been interpolated from offshore values to some reference point on the land. This can lead to erroneous isobaths close to the coast. A good example is shown in Figure 3a, where there is an overlap of the depth and coastline areas.

Based on the fact that the GMT-HRCD database is the more accurate one of the two, a procedure has been devised to optimise the overall information. Towards this aim, the coastline points are considered as points with zero depth. A triangulation is performed that represents the sea bottom surface (Figure 3b). This enhanced data set is used to obtain, by interpolation, a finer local grid for the examined area, which in turn serves as a basis for estimating the new isolines of constant depth (Figure 3c). This results in a marked improvement of the shallow water bathymetry.

The second piece of software which was required is an interface with the user that, starting from the overall map of Europe, can zoom gradually into the area of interest and allow the user to choose the location after inspecting the detailed local bathymetry, and the geometry of the coast. The user is also allowed to introduce his own local bathymetric information, should he have a more accurate one.

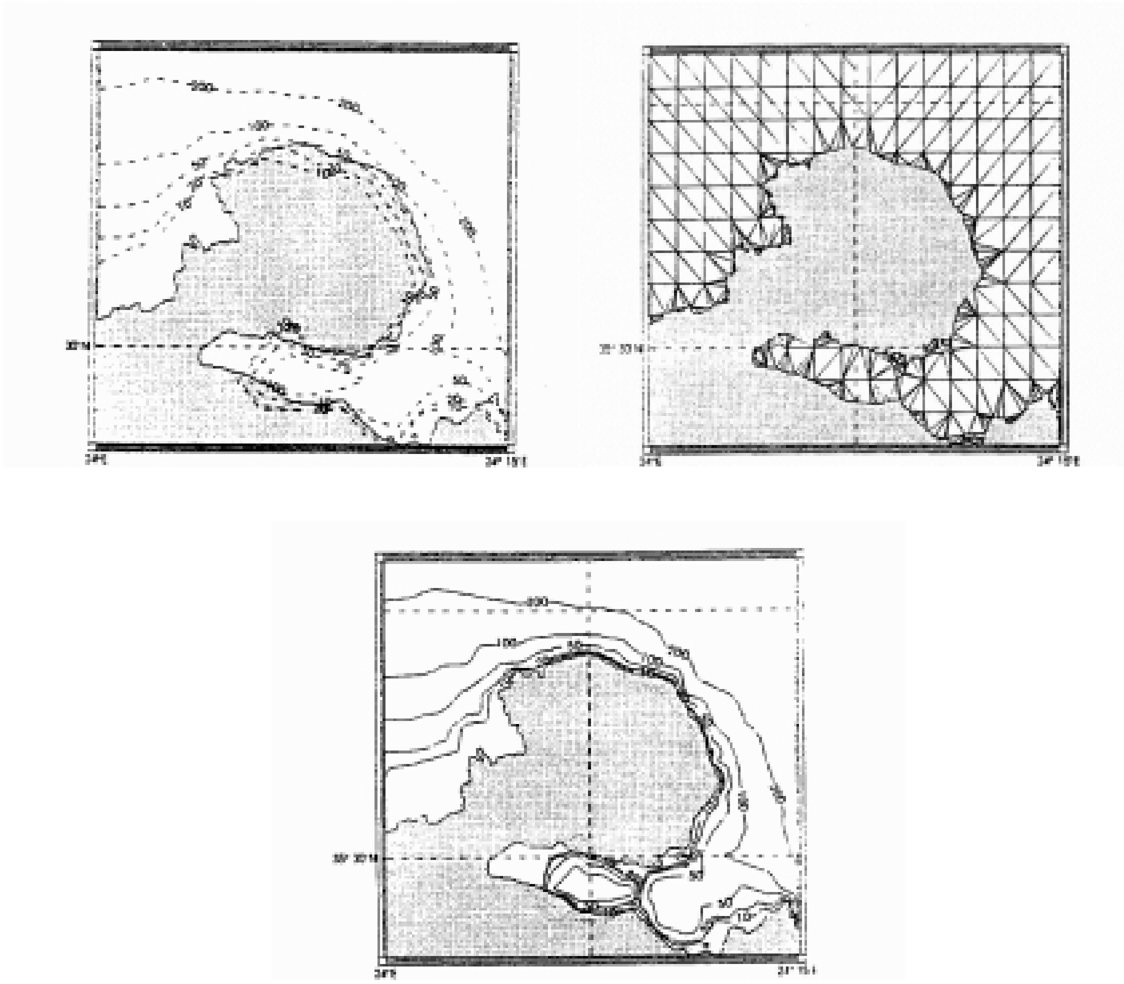

Figure 3. Top left) original isolines and coastline profile; top right) triangulation of the coastline and bathymetric data; bottom) the new isobaths after interpolating from the triangulation.

Offshore-to-Nearshore transformation

Two coastal wave models have been selected and implemented under the Eurowaves software package. These are the SWAN model (Booij et al., 1996), a recently developed third generation shallow water wave model, and VENICE (Cavaleri and Malanotte Rizzoli, 1981), a backward ray-tracing model.

Once the user has selected the area and target point of interest, the offshore wave data is loaded. The user has the option, if he prefers, to specify his own input (for example, in the case when suitable buoy data are available). It is also possible, in order, in particular, to speed up the transformation using the SWAN model to sub-sample the input time series which are nominally 6 hourly. Each 2^nth (n = 0,1,2,3….) record is then transferred to the coast. There are also two different types of run a) Multiple and b) Single run. The multiple run is the transformation of the multi-year time series to the target point, whereas the single run allows the actual wave field to be visualised in the nearshore area according to user input wave conditions.

The actual input to the model is, for each time step, a full directional spectrum, which is reconstructed from the 6 available parameters (3 each for wind sea and swell) using suitable forms for the wind sea and swell spectra as well as the directional spreading.

In Eurowaves, it is planned to provide results at least as close as 5 km from the coast and down to five metres depth. This is basically connected to the practical accuracy with which we know the bathymetry close to the *whole* European coastline. If, as mentioned in the previous section, more detailed local information is introduced, the user can move even closer to the coast.

Semi-automatic procedures have been developed to help the user in establishing reasonable model grids with, in the standard run using the Eurowaves wave database, a coarser offshore grid with border forced through at least one data point, and a fine nested grid with the target point at least 5 km from the coast and grid border, as well as at least 10 m water depth. Again, with the user's own input, the package allows modelling closer to the coast.

Other features which should be mentioned are an on-line display of position (lat/lon) and local depth according to the pointer position, an editable bottom friction setting (separately for coarse and fine grids) with both flat and rippled bed options, and a time bar indicating the time elapsed and time to go (particularly useful for the more time consuming runs with the SWAN model).

In order to test the transformation to the coast and to give the user reliable information on the accuracy of the different models, locations representing a typical set of application areas for Eurowaves have been selected for detailed testing and validation. It is here that synchronous measurements in deep and shallow water are valuable, in that knowing the actual wave conditions offshore and inshore we are better able to evaluate the errors and sensitivity of the models to different features.

Tests have been carried out so far at

a) Holderness on the east coast of England in the North Sea

b) Montalto di Castro on the west coast of Italy (similar bathymetry to Holderness, but more or less pure wind sea climate).

c) Figueira da Foz on the west coast of Portugal (swell dominated wave climate with simple bathymetry).

Each of these tests have proven useful in demonstrating particular problems and solutions. For example, the Holderness tests showed the sensitivity of the results to a) parametric vs. spectral input; b) effect of wind etc. (Sclavo and Cavaleri, 1999); the Montalto di Castro case was used for testing the sensitivity to grid resolution, orientation etc. and also clearly showed the importance of local knowledge of the bottom conditions as model errors relative to the local measurements were explainable when it became clear that this area has a bottom covered by seaweed. It should be noted that the Eurowaves software itself is now being used to perform the testing. This has itself made the testing considerably easier and less time consuming than was the case previously.

Wave Statistics

A software module providing the user with a sophisticated set of univariate and bivariate wave statistics for both offshore and target points has also been implemented. This provides probability density functions - pdfs (empirical, as well as lognormal and Kernel Density Estimation models). Univariate pdfs (in tabular and graphical form) can be produced for Hs, mean period (T_m), wave direction, and mean wave slope (also for wind sea and swell parts separately) as well as directional divergence (wind sea minus swell direction). Empirical statistics (mean, standard deviation etc.) are also available. Similarly bivariate analytic and empirical pdfs and statistics are available, for example (Hs, Tm). The monthly means and information on the inter-annual variability are also available for the same parameters.

This package has been intensively tested at a number of locations (Spain, Cyprus and Portugal) where both buoy and model data are available. The buoy data were input as Eurowave offshore points, so that they can be treated by the same software package. The detailed statistical comparisons have revealed various differences between buoy and model data sets and has also allowed the statistical presentations to be optimised for the actual data.

Future plans

The Eurowaves project is due to end in November 2000 and it is expected that the package will be commercially available soon after that. The package should be of interest within many different application areas from coastal and offshore engineering and the shipping industry to wave energy interests and fish farmers. In practice, all the important components being used to construct Eurowaves; i.e., wave model data, satellite altimeter data, bathymetric and coastline data as well as the coastal wave models themselves can be put together for any country or region globally.

Acknowledgements

This work has been carried out under the MAST project Eurowaves, contract no. MAST3 - CT97 –109 with partial support from the European Commission. The authors are also the principal contractors of this project. We would finally like to thank all those, too many to name here, who have provided data to the Eurowaves project.

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