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WORLDWAVES : HIGH QUALITY COASTAL AND OFFSHORE WAVE DATA WITHIN MINUTES FOR ANY GLOBAL SITE

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ABSTRACT

There has been a growing demand for reliable information on the wave conditions, in particular at coastal sites, as a result of increased utilisation of the coastal zone to a multitude of activities including various shoreline developments related to transportation, tourism, fish farming and recently wind and wave energy industries. This trend is likely to continue. Reliable data is also needed with respect to the management and protection of these often fragile environments. Many of those concerned with these wave-impacted environments still use antiquated data sources, usually from offshore waters as, in the absence of long term wave data collected at the site of interest, the calculation of reliable wave statistics at a coastal site is a complicated, time consuming and expensive business, requiring various data sets to be assembled. WORLDWAVES simplifies and speeds up the modelling of wave conditions in coastal waters by integrating the following under a single Matlab toolbox: High quality long-term wave data offshore all global coasts; worldwide bathymetric and coastline data; SWAN and backward raytracing wave models; sophisticated offshore and nearshore wave statistics toolboxes with tabular and graphical presentations, including a facility to export ASCII time series data at offshore or inshore locations; a geographic module with easy zooming to any area worldwide; tools to set up model grids and display and edit bathymetry and coastline; a facility for the import of user offshore data and export of inshore time series data. In this paper we describe the design and implementation of WorldWaves including the fusion of satellite, model and buoy wave and wind data in the global offshore database and the new raytracing model.

KEYWORDS: Ocean waves; wave model; satellite altimeter; Matlab toolbox; shallow water; atlas; buoy.

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. In 2001, OCEANOR launched the Eurowaves MATLAB Toolbox (Barstow et al., 2000), a software package integrating, for all European waters, all the necessary data and tools to allow the user to quickly (in a matter of minutes) to make provisional calculations of the long-term wave conditions at any coastal site along the European coastlines. It also contains all the tools to carry out more in-depth wave modelling. Eurowaves was developed under the MAST project Eurowaves, contract no.

MAST3 - CT97 –109 with partial support from the European Commission.

Recognising that all the data sources used in Eurowaves were also available globally, it was early recognized that a global extension to Eurowaves would be a desirable further development. In late 2001, OCEANOR were approached by a consortium of dredging companies (SSB[1]) in the Netherlands. SSB were interested in developing a software package which was capable of making better estimates of wave conditions (ideally, time series of wave height, period and direction) at coastal sites worldwide as input to a simulation program for the workability of dredgers, used mainly in connection with tendering work. Up to that point, offshore statistics from available on-line satellite data and offline wave atlases were the main sources consulted in the absence of in-situ wave measurements.

In the following pages, we describe the development of the main components of WorldWaves in turn. The software package is illustrated by a case study at Ensenada in Mexico.

GLOBAL OFFSHORE WAVE DATABASE

The WorldWaves package had to be capable of calculating wave conditions along any coast, i.e., coasts of North and South America (including the Gulf of Mexico), Europe (including the Mediterranean, the North Sea, the Baltic, the Black Sea and the Atlantic Islands), Africa, the near East (including the Gulf and the Caspian), the Far East (Malaysia, Indonesia, the Philippines, the South China Sea and Gulf of Thailand, Japan, China, Taiwan and Russia), Australasia and the Pacific Islands. In the construction of the WorldWaves offshore database, three types of wave data are being integrated using similar methodology to that adopted successfully in the Eurowaves project. These are a) In-situ measurements; b) Satellite measurements; and c) Wave model simulations. The model data is used as the primary source of wave data as it is available globally and contains all the necessary information for the offshore wave and wind input in the required time series format. The model data are quality controlled and validated and bias is corrected relative to the satellite and in-situ data.

In-situ data

In offshore waters around the world, long-term buoy wave measurement networks are still relatively few and far between. Networks with directional measurements (directional information is essential for coastal prediction) are even scarcer.

[1] SSB (Stichting Speurwerk Baggertechniek) is an organization carrying out joint research and development for the 3 major Dutch dredging companies Van Oord, Boskalis and Ballast Ham.

The most important networks are

a) The NOAA-NDBC buoy networks in the US (covering East and West coasts of the USA, the Gulf of Mexico and the Hawaiian Islands), in addition to the more recent Canadian network. Unfortunately, only one of these buoys currently measures wave direction.

b) The Indian National Data Buoy Programme (see http://www.niot.ernet.in/ndbp/index.html) which is currently probably the largest national program with deep ocean directional buoys used as a standard.

c) National networks in Spain, Greece, France and Italy although most buoys are rather too close to the coast to be of major value in developing our offshore wave database.

d) Long term measurements carried out in Norwegian waters and the North Sea for the offshore industry, although long term buoy data sets were mostly measured in the 1980s and early 1990s and are not concurrent with the model data.

The buoy data are used primarily for a) validating satellite altimeter and wave model wave heights and b) wave model wave periods and directions. Nevertheless, in cases where buoy data do exist these are in most cases the most accurate data for the location in question and facilities are available in WorldWaves for using these data directly as the offshore input to the shallow water models. In a few cases, simultaneous measurements in deep and shallow water are available and these are very useful in validating the entire WorldWaves 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 made 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. Global long-term satellite altimeter measurements have been performed during 1985-1989 by the US Navy's Geosat and the Geosat-Follow-on mission from 1998, by ESA's ERS-1 (from 1991 to 1996), ERS-2 (1995 - ongoing), EnviSat (launched in 2002), and most importantly for our purposes, the US/French Topex/Poseidon mission from 1992 to 2002. The Topex-Follow-on mission (Jason) was launched in late 2001 and is now being phased in.

Each satellite altimeter has to be validated in order to remove the altimeter-dependent biases on significant wave height and this is generally and most reliably done by comparing with long-term offshore buoy data, although at the beginning of missions cross-validation against other altimeters and wave model data are also used. As we are comparing temporally varying significant wave height data from the buoy with spatially varying data from the satellite it is important that the buoy data are measured in areas where the gradients in significant wave height are rather small, which means in practice moorings far from coasts (ideally, several hundred kilometres) as wave conditions. often vary rather strongly near to coasts both due to geographical sheltering effects, fetch limited wave growth in offshore blowing winds and shallow water effects.

We are mostly concerned here with the Topex satellite altimeter as this mission runs in parallel with the available model data (next section). The other satellite data sets which could have been used are the ERS-1 and ERS-2 missions. However, these data have also been assimilated into the wave model and are therefore not independent of the model data.

Algorithms for the correct interpretation of the back-scattered radar return pulse from satellite altimeters have been gradually improved (see, for example, Krogstad and Barstow, 1999).

For Topex, the original altimeter (Side A) began to degrade around 1996-1997 and the bias increases slowly until the reserve altimeter was turned on in February 1999. For Side A, we use the algorithm due to Challenor and Cotton (1998). For Side B we use the algorithm developed in a recent validation for the period up to June 2002 by Mørk (2002). The resultant accuracy can be seen in the satellite – buoy comparison shown in Figure 1.

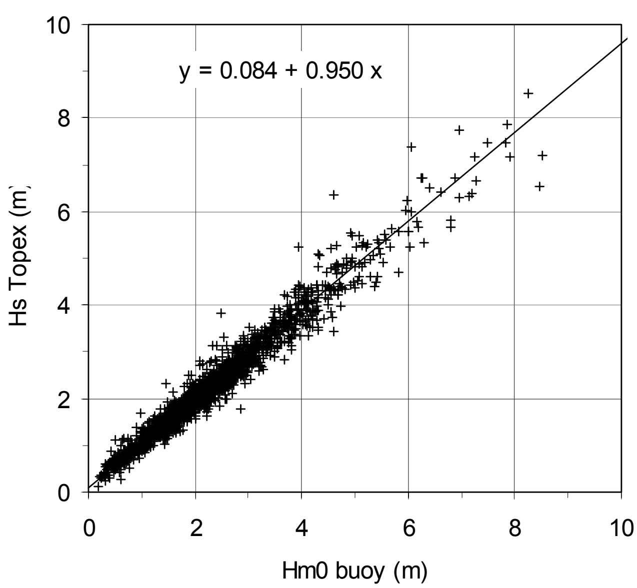

Figure 1. Comparison of significant wave height between the Topex Side B altimeter for 1999-2002 and 13 NOAA buoys; coincident data for Side B (from Mørk, 2002).

All Topex altimeter data globally for 1992 to 2002 have been analysed applying the bias corrections above as well as an automatic data control, removing, for example, unphysical along-track variations in wave height.

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.

In the Eurowaves project, the database from operational runs of the WAM model at the European Centre for Medium-Range Weather Forecasts (ECMWF) was selected as the best available. In the intervening years, in various studies for oil companies and coastal engineering companies, we have had the opportunity to carry out comparisons of the operational WAM data and all other major global wave model databases. In all cases, the WAM data have proven to out-perform the alternatives. Therefore, it was decided to choose the ECMWF database as the main component of the offshore database in WorldWaves.

OCEANOR therefore negotiated an agreement with ECMWF to obtain a 10-year global database for use in WorldWaves as well as general consultancy.

The 10-year database will consist of 6-hourly time series of significant wave height, wave period and direction for both wind sea and swell. As well as wind speed and direction. The following datasets have been transferred to OCEANOR on 57 CDs.:

1. ERA-40 data for 1994 to December 1996. ERA-40 is a global 40-year hindcast project being carried out by ECMWF
(see http://www.ecmwf.int/research/era/Project/index.html)
The first data, for 1994 to 1996 became available and a series of validations carried out by OCEANOR have confirmed the quality of these data. The data are available on a 1.5° lat-lon grid.
2. Operational data for December 1996 to 2002 on a 0.5° lat-lon grid.
3. Operational data for 2003 will be added each month until the 10-year database is complete.

For the Mediterranean, Black Sea and the Baltic, the model was run on an 0.25°grid and data are available on a 0.5° grid for 1992 to 2002.

The WAM wave model (Komen et al., 1994) has been operational at ECMWF since 1992.

Validation and calibration of the WAM data

At the time of writing the global validation of the model data is not complete (this should be finished by late spring 2003). However, we briefly outline the methodology here.

- Initially, we have selected grid points from the WAM database globally along all coastlines globally at which offshore wave data is required. The initial selection on the 1.5° grid is shown in Figure 2 and includes both continental, oceanic and inland sea coastlines as can be seen.
- The Topex data for the entire mission from 1992-2002 are analysed. The original data have been collected into individual 10x10° square areas. The wave height and wind speed data are corrected to remove bias and are run through a carefully designed automatic data control.
- The closest along-track locations of the Topex mission to each grid point are found and time series of the calibrated Topex wave heights are extracted. Scatter plots are then produced for the matched WAM against Topex significant wave heights. On a regional basis, any year-to-year trends in the accuracy of the WAM data are also investigated.
- For some locations (NOAA buoys and a few others) we are also validating wave heights, periods (and directions), again checking for trends.

The information from the validations is then used to correct and homogenise the wave model data.

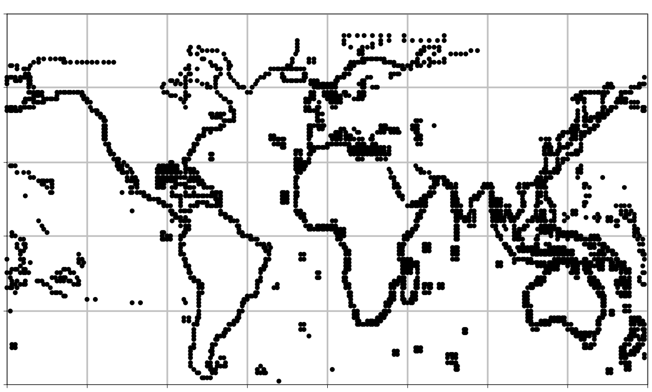

Figure 2. Initial choice of 2654 points from the 1.5 deg grid.

GLOBAL GEOGRAPHICAL DATABASE

In order to carry out the modelling at the inshore location, the user is able to interact with the WorldWaves system, and easily select the location of interest. Starting from a global map, see Figure 3, the user can easily progressively zoom into the continental region of interest, as e.g., shown in Figure 4, for Region III (Africa and the Arabian peninsula). In this way, the user can focus on his/her area of interest, and choose the exact location of his/her interest using the mouse. In order to make this possible, two datasets had to be assembled. First, full bathymetric information and, secondly, an accurate description of the global coastlines was needed.

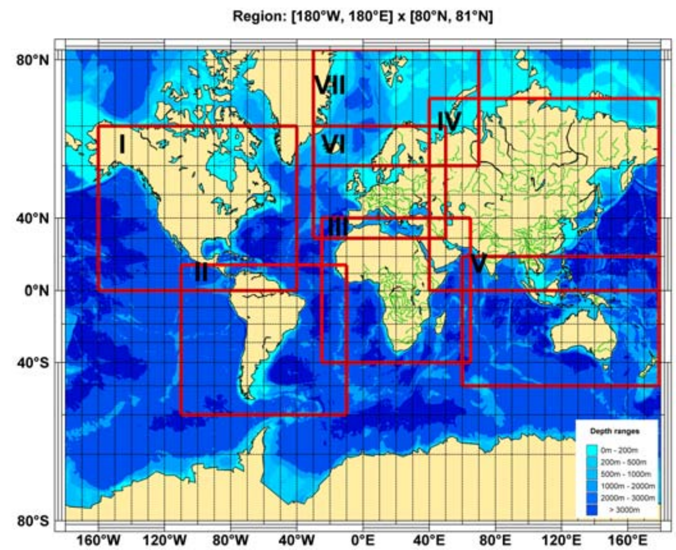

Figure 3. Subdivision of the main (continental) geographical regions.

Global bathymetry

After a careful search of the available data sets, the DBDB-V (version 4.0) database was selected for the bathymetry to be used in WorldWaves. The Digital Bathymetric Database - Variable Resolution (DBDB-V), provides ocean depths at various gridded resolutions. DBDB-V was developed by the Naval Oceanographic Office (NAVOCEANO). Grid resolutions available are 0.5′, 1′, 2′, and 5′ minutes of latitude and longitude. The generation of bathymetric data for the coarser grids (1' and 2' grids) has been based on the digitisation of isobaths from nautical charts at a nominal scale of 1:1,000,000. Digitised isobaths have been put through a gridding routine and, utilising a multi-stage minimum curvature spline algorithm, a single representative depth value has been derived. The generation of bathymetric data for the finer grid (0.5' grid) has been constructed in part by digitising nautical charts at a nominal scale of 1:500,000, and partially by applying specialized interpolating routines to coarser grids. Detailed information can be found in NAVOCEANO (2002). This data set was released in 1996 and was last updated in 2001. 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.

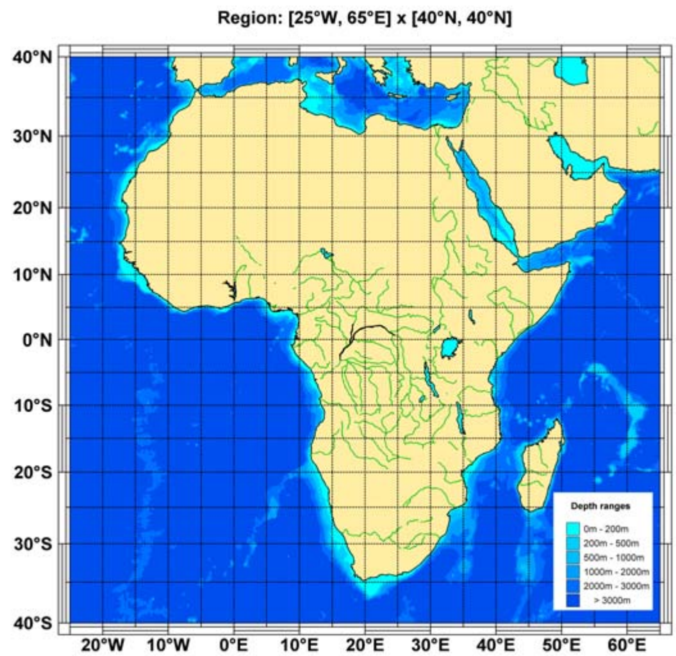

Figure 4. Continental Region III: Africa and the Arabian peninsula

Global Coastline

The database selected for the representation of the global coastline is the GMT Global, Self-consistent, Hierarchical, High-resolution Shoreline Database (GMT - GSHHS) that is available with the public-domain GMT software; see (Wessel and Smith 1996). This database is the only one known that covers the whole globe and is considered in WorldWaves at a working scale of 1:250,000. It contains vector information in a polygon format and is available via anonymous ftp from "ftp://kiawe.soest.hawaii.edu/pub/gmt". The following two well-known, public-domain data sets have been used for its construction:

The World Data Bank II (WDB; also known as the CIA Data Bank), which contains coastlines, lakes, political boundaries, and rivers. These data have an approximate working scale of 1:3,000,000 (scale varies from 1:1,000,000 to 1:4,000,000), meaning the features are considered to be accurately located on maps using that scale or smaller.

The World Vector Shoreline (WVS), which only contains shorelines along the ocean/land interface (i.e., no land-locked bodies of water). The WVS data set is superior to the WDB data set in quality and resolution (its working scale is approximately 1:250,000), but it lacks lakes.

Although not explicitly given, the precision of the WDB data appears to be in the 500-5000m range, while the precision of WVS is an order of magnitude better (Wessel and Smith 1996). The GMT – GSHHS data set is produced using the WVS data when possible and supplementing it with WDB data. The quality of the GMT – GSHHS coastline database fully covers the needs for WorldWaves. The coastline provided by this database passed all quality checks that have been performed within the project. The coastline database, which is derived from detailed satellite images, is 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. Based on the fact that the GMT 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. 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 This results in a marked improvement of the shallow water bathymetry, as e.g., shown in Figure 5.

OFFSHORE-TO-NEARSHORE WAVE TRANSFORMATION

Two coastal wave models have been selected and implemented under the WorldWaves software package. These are the SWAN model (Booij et al., 1999, Ris et al, 1999), the well known third generation shallow water wave model, and a backward ray-tracing model CWAVERAY, developed using MATLAB by NTUA (Belibassakis and Athanassoulis, 2001).

EXAMPLE OF OPERATION

In order to illustrate the way WorldWaves works, we show below a series of screen pictures following a case study for the harbour at Ensenada in Mexico (note that as the offshore model data were not fully calibrated for this example, the results are not optimal. First, Figure 6 shows a large scale map of the area of interest and the offshore grid points at which initially 10 years of data are available at 6 hourly time step (although only 2 years series are used in the examples shown).

The user can easily zoom successively into the location of interest by simply clicking and dragging with the mouse. (Figure 7 shows a closer view of the area of interest. The offshore data to be used as input to the models can be examined statistically and a number of models are available to fit to the data (Figure 8, 9 and 10) In these examples we show the Kernel Density model fit to the data. Monthly and seasonal statistics can also be examined. Figure 11 shows one of the bivariate presentations offered by WorldWaves.

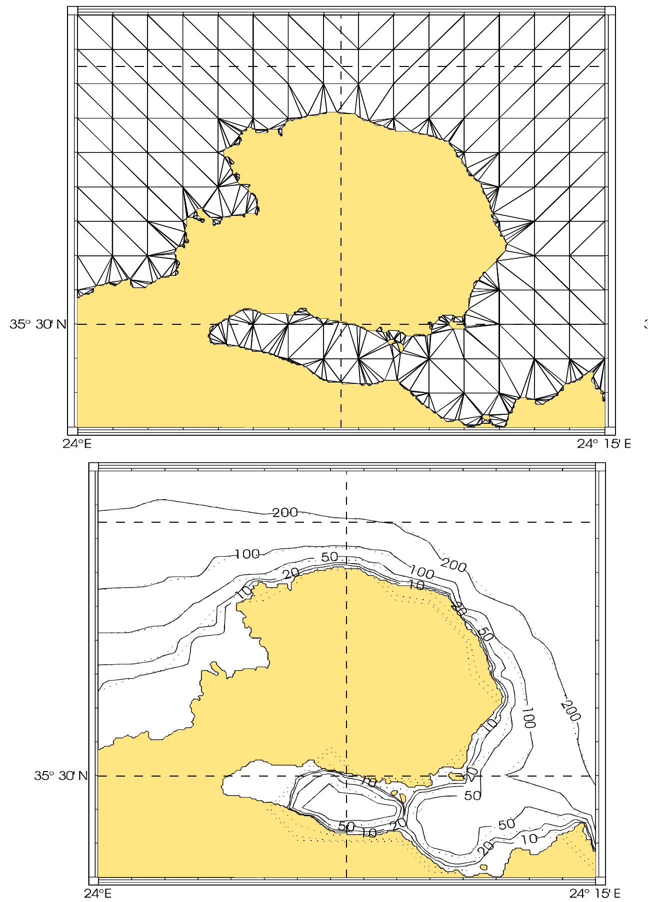

Figure 5 Triangulation of the coastline and bathymetry (above), and the new isobaths obtained by interpolation using the triangulation (below). Dashed lines show the original contours based on the bathymetric data alone, and solid lines show the enhanced bathymetric contours after the correction procedure.

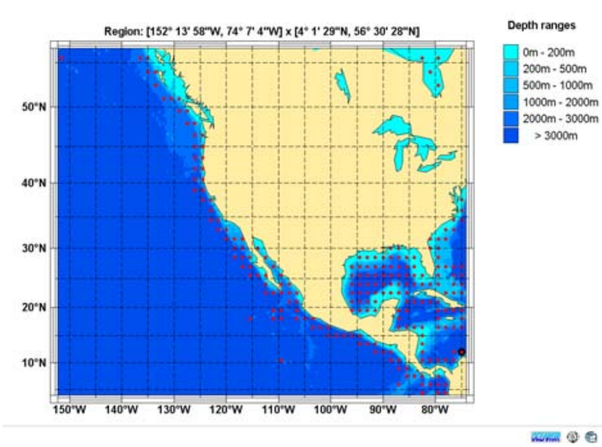

Figure 6. Worldwaves initial offshore data base for Western North America and the Gulf of Mexico

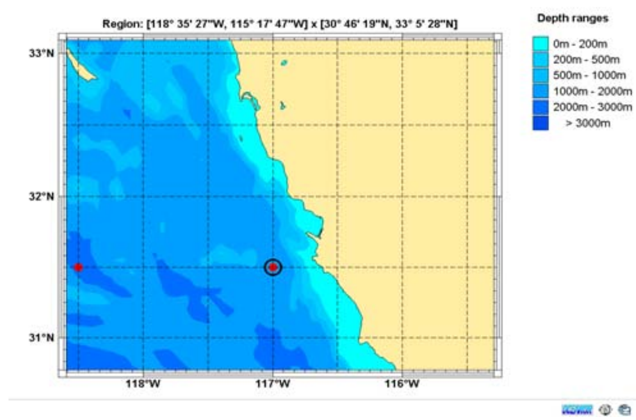

Figure 7. Zooming in to the geographical area of Ensenada, Mexico is performed using the mouse and a click.

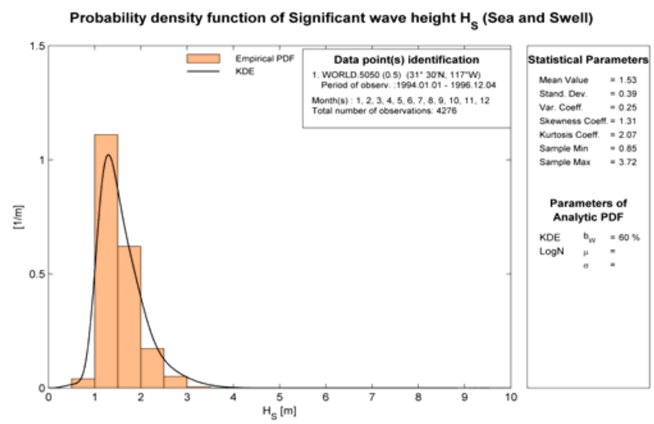

Figure 8. Offshore wave statistics (annual data). Significant wave height at the point (31^o 30'N,117^o W), and the kernel density probability model fit to the data.

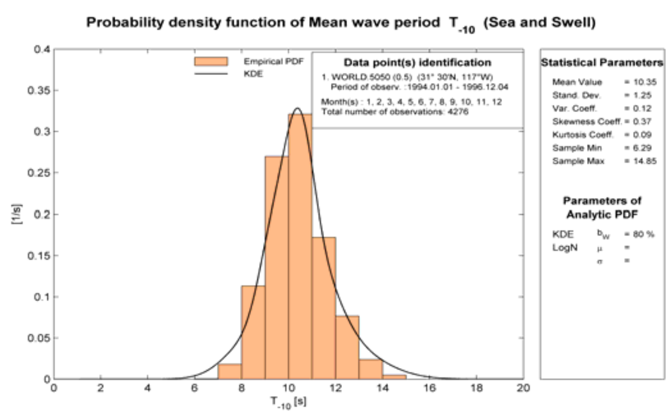

Figure 9. Offshore wave statistics (annual data). Mean wave (energy) period at the point (31^o 30'N, 117^o W) and kernel density probability model

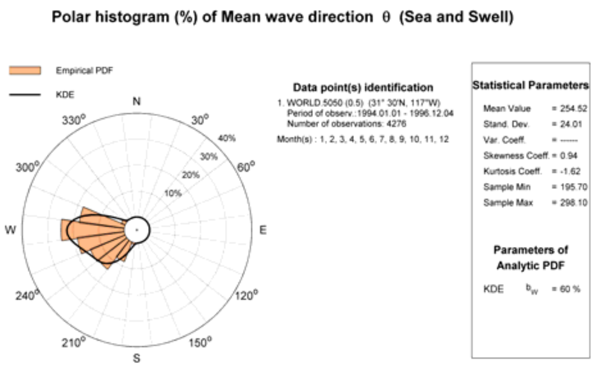

Figure 10. Offshore wave statistics (annual data). Mean wave direction at the point (31^{o} 30'N,117^{o} W) and the kernel density probability model fit.

Setting up the model grid (with nesting is also very easy to do and is also easy to change if the user isn't satisfied with the automatic selection. Various model and bottom parameters can also be modified. (Figure 12). There are two ways of modeling. Either the so-called single run, where the user inputs their own offshore wave data to give contour maps of significant wave height, period and direction (Figure 13) or directional wave spectra at the target point (Figure 14). Carrying out a time series run with either model gives a time series of inshore wave parameters (optionally directional spectra) from which various wave statistics are calculated (Figures 15 to 18).

It is also possible to export the inshore time series data to an ASCII file for the user's own analyses.

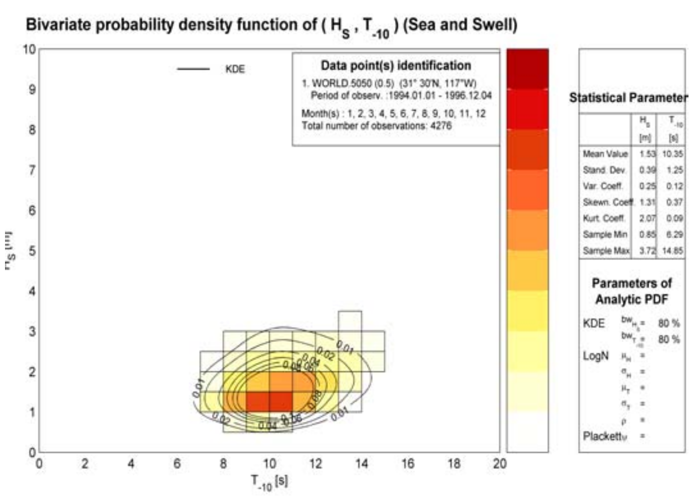

Figure 11. Offshore wave statistics (annual data). Bivariate *Hs-T* distribution at the point (31^{o} 30'N,117^{o} W) and the kernel density bivariate probability model fit.

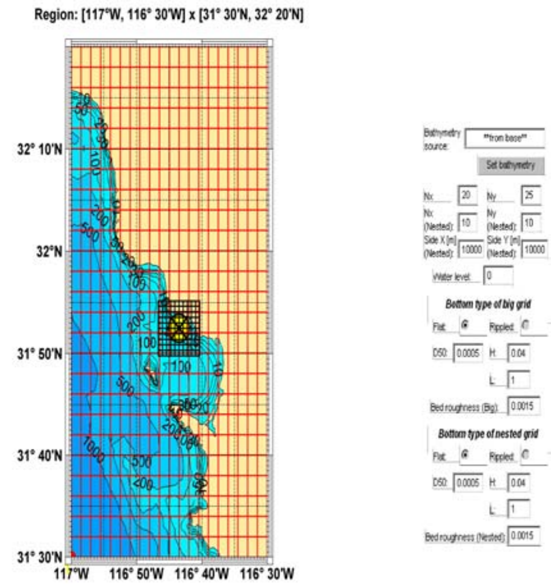

Figure 12. Computational domain and model parameters for Offshore-to-Nearshore wave transformation using SWAN, in the area of Ensenada, Mexico, Puerto de Ensenada. The target point is located at (31^{o}52'30"N, 116^{o}43'30"W), at a depth of h=27m (entrance to Ensenada Port)

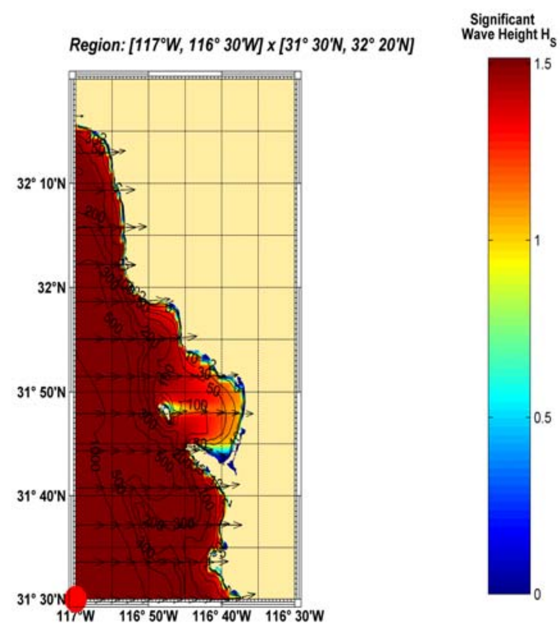

Fig. 13a Calculated wave field (Hs) using WorldWaves single run option with SWAN and offshore input data: Hs=1.5m T=10sec, Θ=270deg (waves from W).

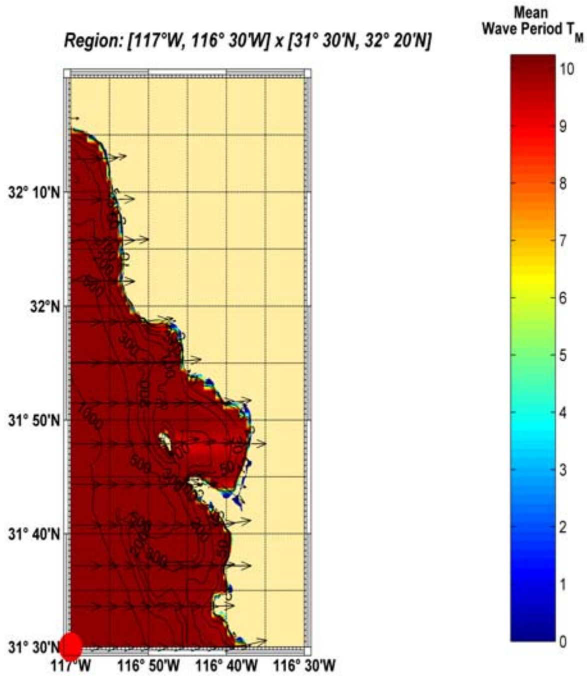

Fig. 13b Calculated wave field (T) using WorldWaves single run option with SWAN and offshore input data: Hs=1.5m T=10sec, Θ=270deg (waves from W).

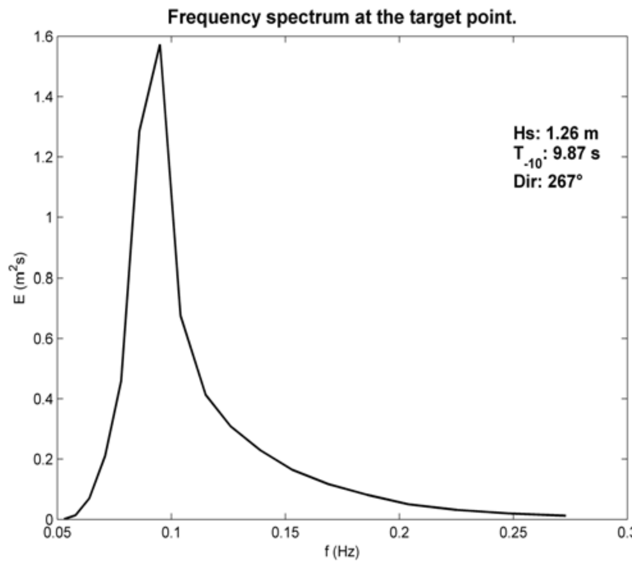

Fig. 14b Calculated frequency spectrum at the target point, using WorldWaves single run option with SWAN and offshore input data: Hs=1.5m T=10sec, Θ=270deg (waves from W). Nearshore spectral parameters: Hs=1.27m, T_{-10}=9.8sec, Θ=267deg.

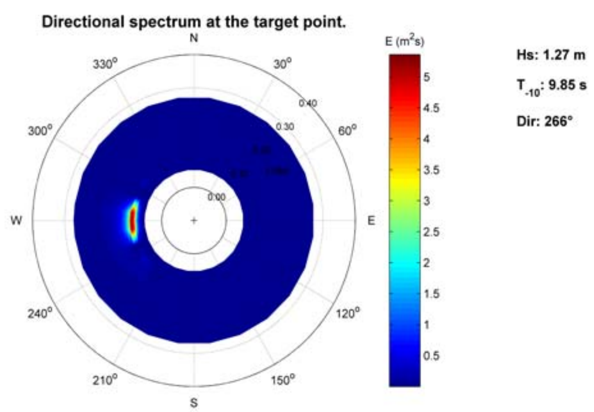

Fig. 14a Calculated directional wave spectrum at the target point, using WorldWaves single run option with SWAN and offshore input data: Hs=1.5m T=10sec, Θ=270deg (waves from W). SWAN grid used in calculations: 60X60points.

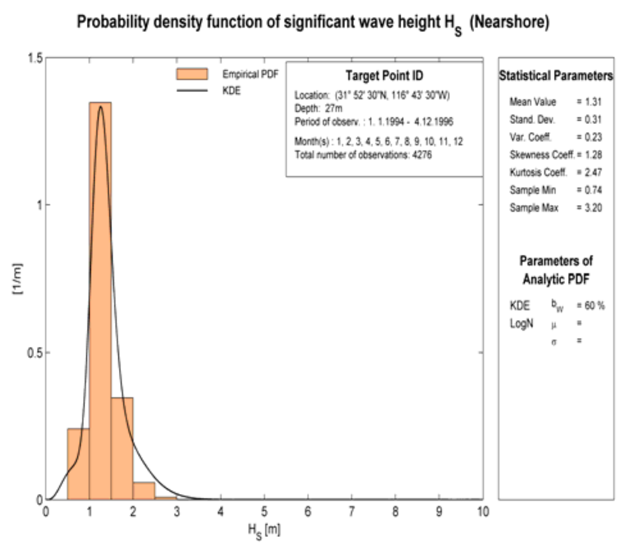

Figure 15. Nearshore wave statistics (annual data). Significant wave height at the target point (31°52'30"N, 116°43'30"W), at a depth h=27m (entrance to Ensenada Port) and the kernel density probability model

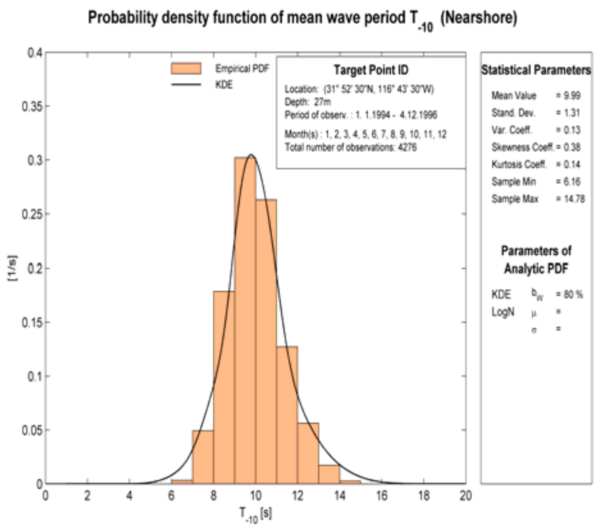

Figure 16. Nearshore wave statistics (annual data). Mean (energy) wave period at the target point located at (31^{o}52'30"N, 116^{o}43'30"W), at a depth h=27m (entrance of Ensenada Port) and kernel density probability model

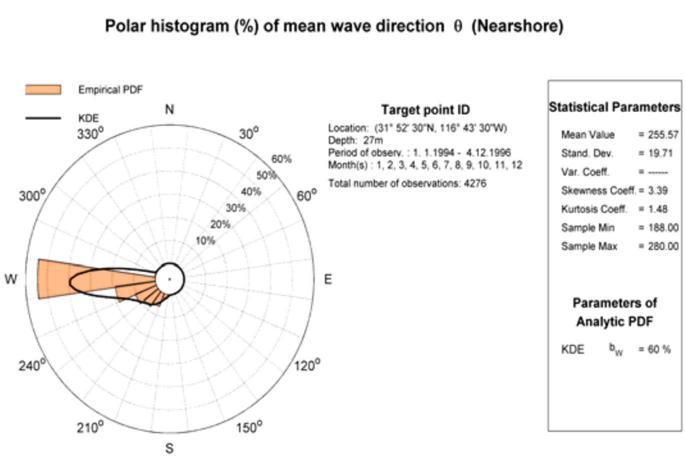

Figure 17. Nearshore wave statistics (annual data). Mean wave direction at the target point (31^{o}52'30"N, 116^{o}43'30"W), at a depth h=27m (entrance of Ensenada Port) and kernel density probability model

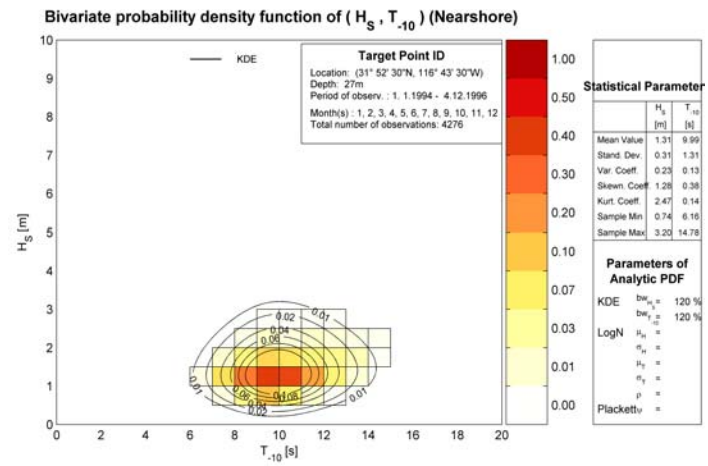

Figure 18. Nearshore wave statistics (annual data). Bivariate Hs-T distribution at ,the target point (31^{o}52'30"N, 116^{o}43'30"W), and the kernel density bivariate probability model

FUTURE PLANS

The WorldWaves software package is the first truly global wave climate package, including for the first time full modelling capability also in coastal waters. Following validation of the whole package during the spring and early summer 2003 against in-situ measurements, it is planned that the package will become available to both scientific and commercial interests. It is expected that both global, regional and country versions of WorldWaves will be available and an educational version is also planned.

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