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

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Abstract: The demand for reliable information on wave conditions, in particular at coastal sites, is increasing as a result of the increased utilisation of the coastal zone to a multitude of activities (e.g. shoreline developments related to transportation, oil and gas industries, wave energy industries, etc). 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 considerably simplifies the modelling of wave conditions in coastal waters, resulting in more timely data, at a lower cost and at the same time retaining a high reliability. In this paper, we describe the development of WorldWaves. The offshore wave database is described in some detail, including the validation of the long-term model data against satellite and buoy data around the world. The software is illustrated by a case study in the northern area of New Zealand.

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

INTRODUCTION

The calculation of reliable wave statistics at a coastal site is a complicated, time consuming and expensive business, requiring (in the common absence of long term wave data at the site of interest) various data sets to be assembled. This includes: i) temporal long-term representative directional wave data offshore of the site; ii) bathymetric and coastline data; and iii) a suitable well-calibrated wave model, capable of modelling the transfer of the offshore conditions to the site.

WorldWaves considerably simplifies the modelling of wave conditions in coastal waters, resulting in more timely data, at a lower cost and at the same time retaining a high reliability. In WorldWaves, the following are integrated under a single Matlab toolbox:

- High quality long-term wave data offshore all global 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 and buoy data from many locations worldwide.
- Global bathymetric data from US Navy's new Digital Bathymetric Data Base (DBDBV - v4.0).
- Global 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 a traditional backward ray-tracing model.
- 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 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.
- A bathymetry editing tool allowing easy editing and/or replacement of the bathymetric data if the user has access to better information.
- A facility allowing users to easily import their own offshore wave data.

WorldWaves builds on experience from the earlier EC financed projects Weratlas[1] and Eurowaves[2] as well as the OCEANOR World Wave Atlas[3] product. Following on from the conclusions of the Eurowaves project, it was found that the offshore database, which is needed to feed into the shallow water wave models, should be constructed by fusing numerical wave model data with satellite and buoy data. Various global and regional wave model databases were considered and validation was carried out relative to ground truth from buoys and satellite altimeters. This lead to the selection of the ECMWF WAM data products which showed superior accuracy exhibiting both low bias and low scatter relative to the reference data. By the end of the project, an offshore database of 10 years (with values every 6 hour) will be available along all global coasts. The ECMWF data also have the advantage that they can be extended to up to 23-year series on a case-to-case basis if required. Reference buoy data are only available at a limited number of locations and mostly from developed countries. However, satellite data are available globally, and our validation of these data against buoy data has shown that their accuracy for significant wave height (*Hs*) is close to that of the buoy data, they can thus be treated as ground truth. The Topex/Poseidon mission continues to gather high quality wave and wind data over 10 years after its launch. Global Topex data have been quality controlled and calibrated to form the main reference for the wave model wave and wind data. Following the selection of coastal wave model points to be included in the package, co-located model and altimeter datasets are derived for all possible grid points and regression analyses from these datasets forms the basis for the calibration of the model data worldwide. All ocean basins are included in the final database, including the Mediterranean, the North Sea, the Baltic, the Black Sea and the Gulf of Mexico.

Further developments are also being carried out in connection with the EC research project EnviWave[4]. This project is co-funded by the EC's Energy, Environment and Sustainable Development Programme. Amongst other developments, this project will allow the integration of wave data from the European EnviSat and Jason (Topex Follow-on) remote sensing satellites with the WorldWaves product (one of the main demonstration areas will be the Indian sub-continent).

In the following pages we describe the development of the main components of WorldWaves. The software package is illustrated by a case study in the northern area of New Zealand.

1 http://www.ineti.pt/proj/weratlas/product_f.html
2 http://www.oceanor.no/projects/eurowaves/index.htm
3 http://www.oceanor.no/products/software/wwa/index.htm
4 http://www.oceanor.no/projects/enviwave/index.htm

GLOBAL OFFSHORE DATABASE

The WorldWaves package had to be capable of calculating wave conditions along any coast worldwide. 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: i) In-situ measurements; ii) Satellite measurements; and iii) Numerical wave model data. The model data are used as the primary source of wave data as these data are available globally and contain 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. The most important networks are: i) the NOAA-NDBC buoy networks in the US, in addition to the more recent Canadian network; ii) the Japanese ODAS buoys in the Pacific, Sea of Japan and East China Sea; iii) the Indian National Data Buoy Programme which is currently probably the largest national program with deep ocean directional buoys used as a standard; iv) the 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; and v) the long term measurements carried out in Norwegian waters and the North Sea for the offshore industry, although long term buoy data sets are mostly from measurements 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. In cases where buoy data do exist, these are (in most cases) the most accurate data for the location in question.

Satellite data

The back-scattered signal from satellite altimeters, when calibrated and quality controlled, 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. The most important satellite mission for our purposes, as this mission runs in parallel with the available model data, is the US/French Topex/Poseidon from 1992 to 2002. The Topex-Follow-on mission (Jason) was launched in late 2001 and is now being phased in. Within the framework of the EC EnviWave project OCEANOR and NTUA are working on validating both EnviSat and Jason satellite altimeter data.

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. Algorithms for the correct interpretation of the back-scattered radar return pulse from satellite altimeters have been gradually improved (e.g. 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 (2003). The high accuracy is apparent in the satellite – buoy comparisons. 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. In the Eurowaves project, the database from operational runs of the WAM model at the ECMWF was selected as the best available. 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 initially obtain a 10-year global database for use in WorldWaves. The database consists of 6-hourly time series of significant wave height, wave period and direction for both wind-sea and swell. In addition, wind speed and direction are available. The WAM wave model (Komen et al., 1994) has been operational at ECMWF since 1992.

Validation and calibration of the WAM data

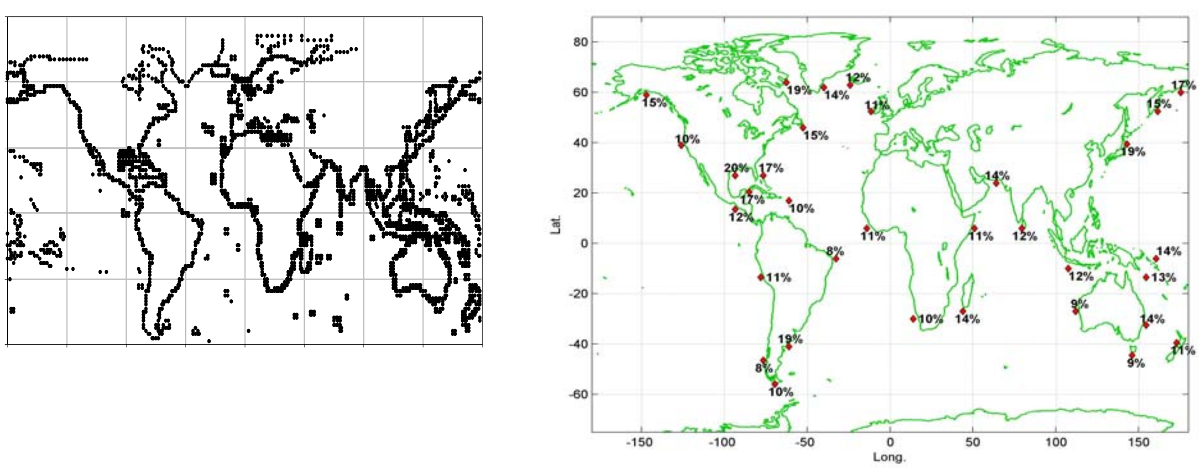


Figure 1. Left: Initial choice of 2654 global points from the 1.5° grid. Right: SI obtained when comparing *Hs* from the Topex satellite altimeter against the WAM model.

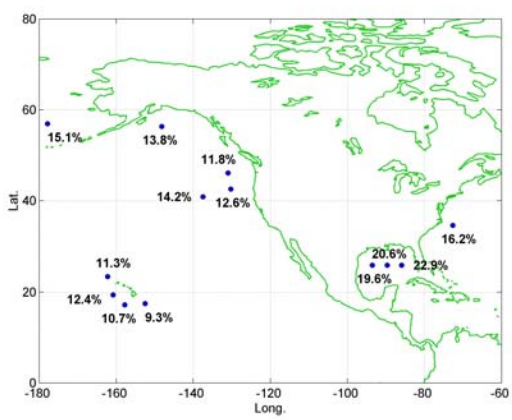
At the time of writing the global validation of the model data is not complete. However, we briefly outline the methodology here. i) Initially, we have selected grid points from the WAM database globally along all coastlines globally at which offshore wave data is required. The initial selection on the 1.5° grid is shown in Figure 1 (left) and includes both continental, oceanic and inland sea coastlines as can be seen; ii) 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; iii) 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. The scatter index[5] (SI) obtained from such plots is displayed for different points around the world in Figure 1 (right). The values, being all between 8 and 20%, reflect the good quality of the WAM model data, On a regional basis, any year-to-year trends in the accuracy of the WAM data are also investigated; iv) For some locations (NOAA buoys and a few others) we are also validating wave heights, periods (and directions), again checking for trends; see Figure 2 (left), for example, where we present SI-values for the intercomparisson of the significant wave height: of some NOA buoys vs. WAM model data.

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

GLOBAL GEOGRAPHICAL DATABASE

Global bathymetry and Global Coastline

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. With respect to the coastline, the database selected for its representation is the GMT Global, Self-consistent, Hierarchical, High-resolution Shoreline Database (GMT - GSHHS) that is available with the public-domain GMT software. For more details on these topics see Barstow et al. 2003 and references therein.



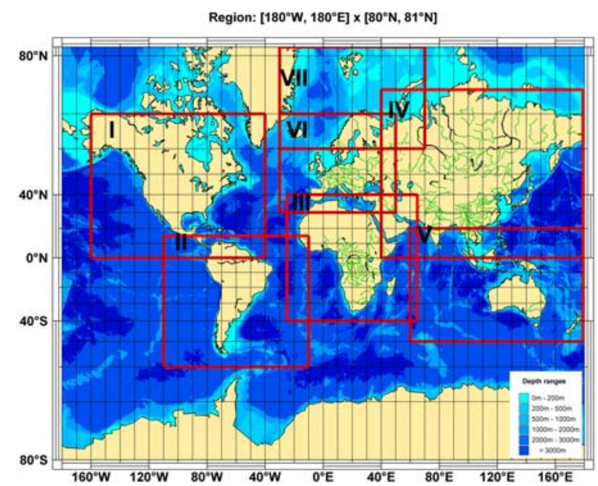


Figure 2. Left: SI obtained when comparing (*Hs*) of some of the NOAA buoys against the WAM model. Right: Subdivision of the main (continental) geographical regions.

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), 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).

A case study in the northern area of New Zealand

To illustrate WorldWaves we carry out a modelling study at a coastal location in the northwest of New Zealand. The modelling session starts by selecting the region of interest; We start by choosing

5 SI is here defined as follows: (standard deviation of the regression)/(mean of the *true*), where *true* in this case means the buoy or satellite.

a geographical region from a global map (Figure 2, right), V in this case. Then we progressively zoom into the area of interest; see Figure 3 (left and right). 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 (Figures 4 and 5). In addition, as shown in Figure 6, it is possible to create statistics for wind-sea and swell separately. We verify that in this location the swell, coming from around 240^o, dominates.

To perform the Offshore-to-Nearshore wave transformation we shall use the SWAN model. The definition of the computational domain, the model parameters and the nearshore target point are shown in Figure 7 (left). The calculated wave field using WorldWaves (single run option), with offshore input data equal to the mean annual wave conditions: Hs = 2.4m, T = 9.7sec (mean wave energy period), and Θ = 250^o (mean wave direction), is presented in Figure 7 (right). Observe that when modelling these input data are assumed to be constant along the border. The calculated directional wave spectrum and wave statistics, at the nearshore target point, are presented in Figure 8, left and right respectively.

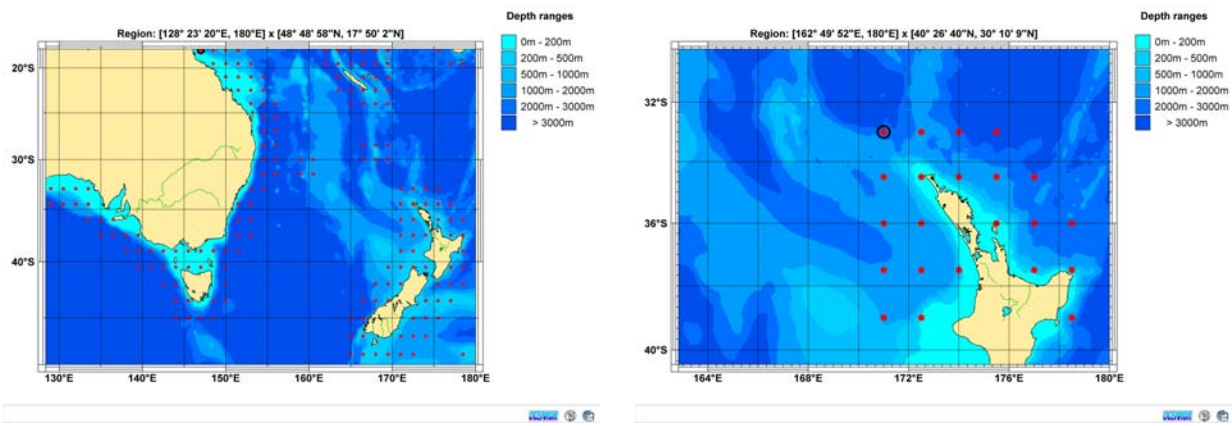


Figure 3. Zooms in the geographical area of New Zealand.

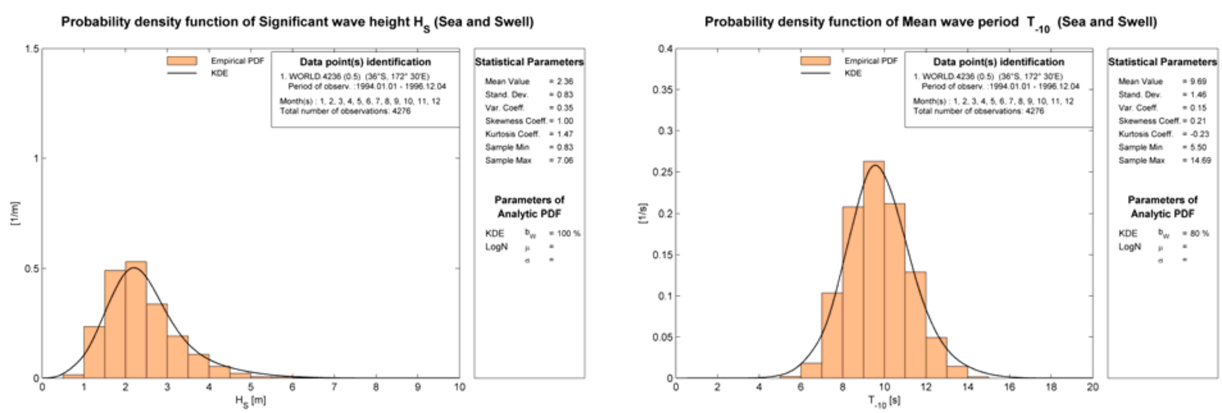


Figure 4. Offshore wave statistics (annual data) at the point (36^o S, 172^o 30’E); Significant wave height (left), mean wave energy period (right) and kernel density probability model.

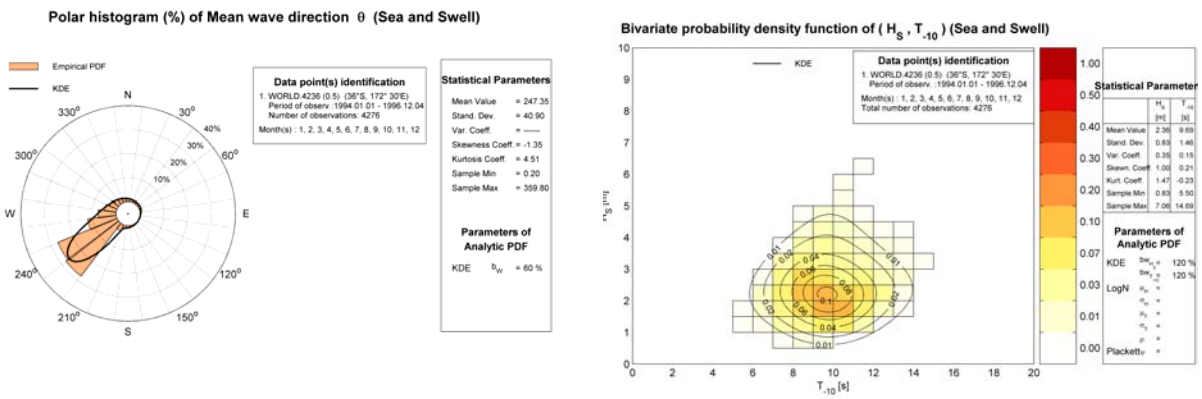


Figure 5. Offshore wave statistics (annual data) at the point (36^o S, 172^o 30'E); Mean wave direction (left), bivariate *Hs*-*T* distribution and density probability model.

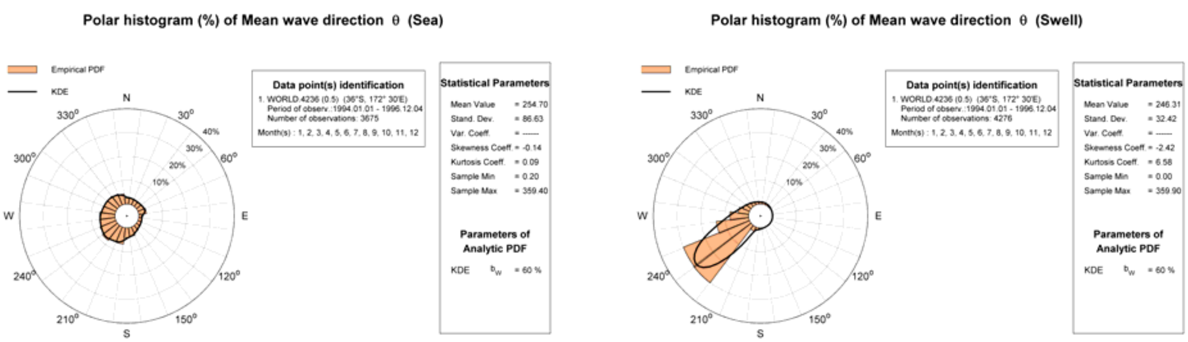


Figure 6. Offshore wave statistics (annual data) at the point (36^o S, 172^o 30'E); Mean wave direction and density probability model: for wind sea (left) and swell (right).

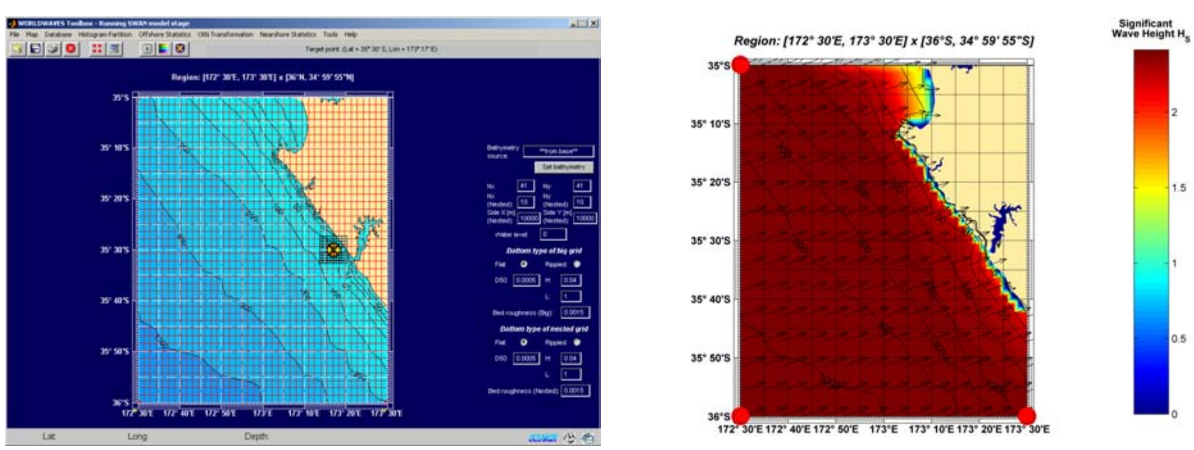


Figure 7. Left: Computational domain for the Offshore-to-Nearshore wave, where the nearshore target point is shown by using a red bullet. Right: Calculated wave field (*Hs*).

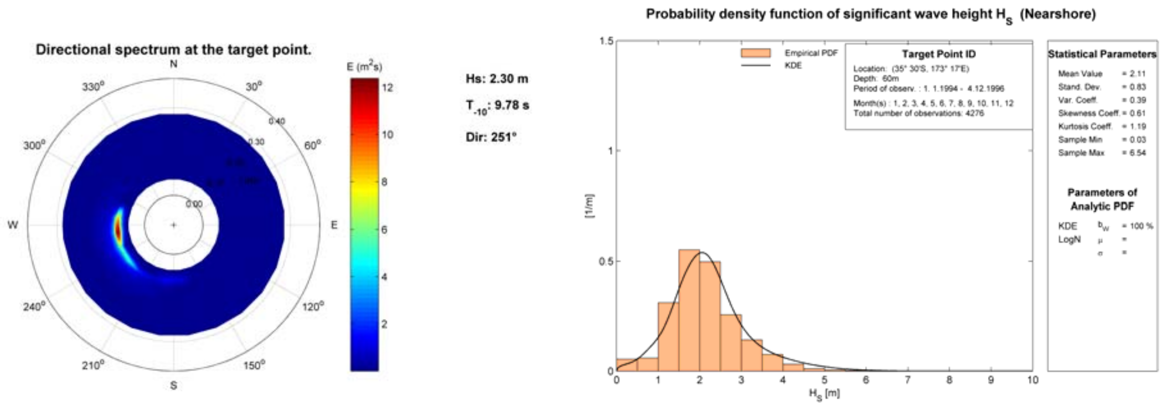


Figure 8. At the target point. Left: Calculated directional wave spectrum. Right: Nearshore wave statistics (annual data), *Hs* and kernel density probability model.

CONCLUSIONS

The WorldWaves software package is the first truly global wave climate package, including for the first time full modelling capabilities for offshore and coastal water locations.

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