Revue Paralia, Volume 3 (2010) pp 5.13-5.24
Keywords: ANEMOC, Mediterranean Sea, Sea State, Hindcast, Wave atlas, Sea State Atlas, TOMAWAC

Constitution of a numerical wave Data-Base along the French Mediterranean coasts through hindcast simulations over 1979-2008

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Abstract:
The purpose of this article is the extension of the wave data-base ANEMOC to cover the Western Mediterranean Sea through numerical hindcast simulations with the third generation spectral wave model TOMAWAC over the 1979-2008 period. Wind-fields used for these simulations come from the U.S. Climate Diagnostics Center of the National Oceanic and Atmospheric Administration (CDC-NOAA) reanalysis (version 2). The model is calibrated with satellite altimeter and wave buoy data. The statistical analysis of these hindcast simulations allows to estimate the average and severe wave conditions over the Mediterranean Sea.

Received 1st June 2010, accepted 18 November 2010, available online 6 December 2010.
Translated version not certified, published under the responsibility of the article authors.

How to cite the original paper:
MORELLATO D., BENOIT M. (2010). *Constitution d'une base de données d'états de mer le long des côtes françaises méditerranéennes par simulations rétrospectives couvrant la période 1979-2008*. Revue Paralia, Vol. 3, pp 5.1–5.12.
DOI:10.5150/revue-paralia.2010.005 (disponible en ligne – http://www.paralia.fr – available online)

1. Introduction

Over the recent years, CETMEF (Centre d'Etudes Techniques Maritimes Et Fluviales) and EDF R&D LNHE (Laboratoire National d'Hydraulique et Environnement de Electicité de France Recherche et Développement) have been collaborating to build through numerical hindcast simulations a continuous data-base of wave conditions covering the North-East part of the Atlantic Ocean, the English Channel and the North Sea, with a refined resolution along the French coasts of the Atlantic Ocean and the English Channel (e.g. BENOIT & LAFON, 2004, BENOIT *et al.*, 2008). This data-base, called ANEMOC, covers a period of time from 1979/01/01 to 2002/08/31. Some of the data obtained during this project are available online: *http://anemoc.cetmef.developpement-durable.gouv.fr*. Among other applications, this data-base has been used to build charts for average and extreme wave conditions (LAFON & BENOIT, 2006). The present study follows the same lines in terms of objectives, methodology and deliverables. It focuses on the Western Mediterranean Sea, with particular interest for the Southern European coasts (France, Spain and Italy).

2. Description of the numerical model used

2.1 The third-generation spectral wave code TOMAWAC

The simulations are performed with the third generation spectral wave model TOMAWAC (BENOIT *et al.* 1996), which is part of the TELEMAC hydro-informatics suite, developed at EDF-LNHE. TOMAWAC solves the wave action density balance equation (e.g. BRETHERTON & GARRET, 1969, KOMEN *et al.*, 1994) and models the evolution (in space and time) of the directional wave spectrum, under unsteady wind forcing. It takes into account the input of energy from the wind, nonlinear wave-wave interactions, as well as dissipation due to white-capping, bottom friction and depth-induced breaking in shallow-water. A feature of high interest of TOMAWAC for nearshore and coastal applications is the use of unstructured spatial grids, which allows to refine the mesh in areas of complex bathymetry and irregular shoreline. The model has already been validated for the hindcast of several real storms (BENOIT *et al.*, 1996, AELBRECHT *et al.*, 1998).

For this project, a numerical grid has been set up with a variable spatial resolution over the Mediterranean Sea (see next section). The wave spectrum grid uses 21 frequencies with a logarithmic scale with $\Delta f/f=0.122$ (between 0.04 Hz and 0.4 Hz) and 36 directions (constant angular resolution of 10 deg.). Output time-step for the results is 1 h. The model is run with steady-state water levels (corresponding to mean tidal level) and without current effects, although the code may deal with unsteady currents and water levels. Coupled runs with the TELEMAC-2D flow model allowing to study the interactions between waves, tides and storm surges will be addressed in a future phase of this project (ANEMOC 2).

2.2 The Mediterranean wave model

The model covers the Mediterranean Sea (30°N to 45°N in latitude and 6°W to 36 E in longitude), with a grid of variable mesh size, from about 2-3 km along French coasts and 6-10 km along Spanish and Italian coasts to a maximum resolution of 0.5° over the rest of the domain. The spatial grid comprises 8770 nodes and 16192 triangles (figure 1). No wave spectra are imposed at the boundaries of this model: all the wave energy is generated inside the domain. Shallow-water processes (refraction, shoaling, bottom friction and breaking) are considered in this model. The computational time-step is 4 min and the required CPU time to model a whole year is about 7 days on a basic PC. Bathymetric data has been obtained from ETOPO 1 (AMANTE & EAKINS, 2009, *http://www.ngdc.noaa.gov/mgg/global/global.html)*, and from the French Oceanographic Service (SHOM) with a high resolution along the French coasts (figure 1).

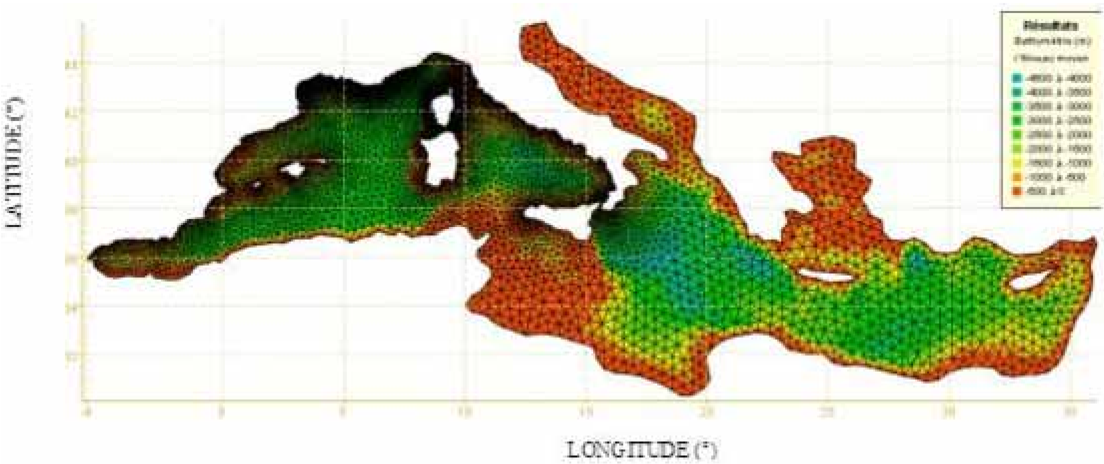

Figure 1. Computational mesh used for the wave simulations with TOMAWAC.

2.3 Wind fields used

The wave model is forced with wind-fields from the NOAA/NCEP reanalysis (version 2), provided by the NOAA/OAR/ESRL PSD, Boulder, Colorado, USA, available on Internet (*http://www.esrl.noaa.gov/psd/*, KANAMITSU *et al.*, 2002). We use the two components of U_{10} (the mean speed at 10 m above sea level) provided every 6 hours over a global Gaussian grid T62 which mesh size is about 1.875 degrees. These data are linearly interpolated in space and in time on the computational grid.

The model is used to hindcast sea-state conditions over a period of 30 years from 1979/01/01 to 2008/12/31.

3. Calibration and comparison phases

In order to calibrate the numerical model we used significant wave heights H_{mo} measured with radar altimetry (QUEFFEULOU & CROIZÉ-FILLON, 2009) from 1992 to 2008. The ground tracks of the set of satellites selected for this calibration (ERS1, ERS2, ENVISAT, TOPEX, POSEIDON, JASON and GFO) on the Western Mediterranean Sea are represented in figure 2.

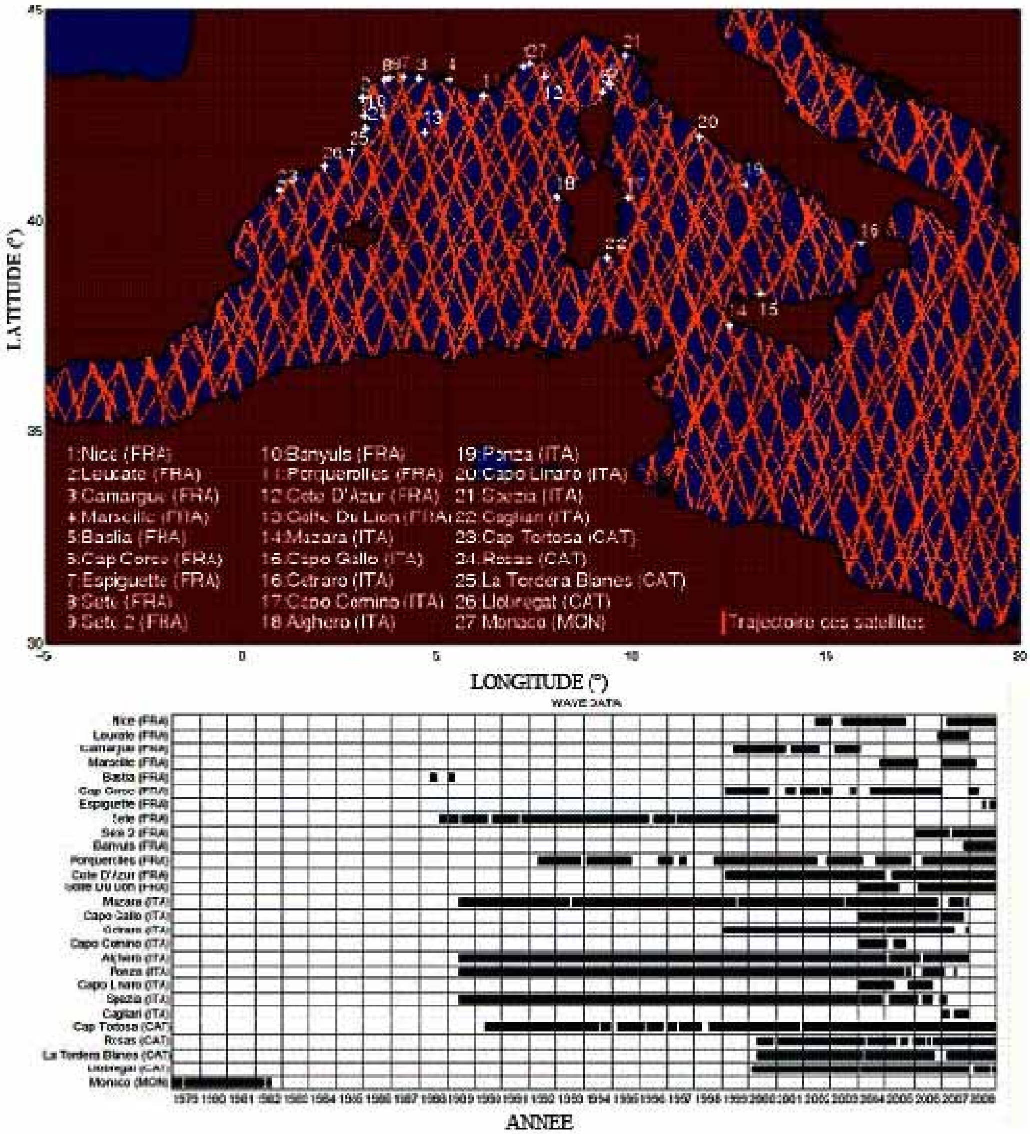

Figure 2. Top : Wave Buoy positions and ground track of satellites; bottom: Periods of measurement of wave buoys used for comparison.

When using the wave model with its default parameters and original wind data coming from the NCEP-2 re-analysis we obtained a mean underestimation of the wave height H_{mo} from 0 to 20% along the Italian and the Spanish coasts and from 0 to 40% along the French coasts. The analysis of the comparisons between the model’s results and the altimeter measurements revealed that the difference varies with the position (x,y) in the Mediterranean Sea and with the wind direction. We then determined a correction coefficient to be applied to the wind velocity depending of the position (x, y) and the wind direction in order to correct the average bias. Justification for this type of correction is supported by the fact that for some fetches, the wind velocity is not well estimated by the atmospheric model due to the presence of mountains and irregular coastlines, taking into account its rather coarse spatial resolution. Finally, we have thus two time-series of results for wave parameters, labeled “original wind” and “modified wind”. The simulation results are compared by using measured wave data from 27 wave buoys located in the Western Mediterranean Sea (see figure 2 for the period of measurement and the position of these buoys). Eleven of these buoys come from the CETMEF CANDHIS database (http://candhis.cetmef.developpement-durable.gouv.fr/), two from METEO-FRANCE, nine from the Italian RON (*Rete ondametrica Nazionale, http://www.envirtech.org/ron.htm)*, four from the Catalan XIOM (*Xarxa d’Instrumentacion Oceanografica I Meteorologica*, *http://www.boiescat.org*) and the last one from Monaco.

The comparison of measured and computed time series of wave parameters (the significant wave height H_{mo}, the mean period T_{m02}, the mean direction, etc) shows that the results are clearly improved when using the "modified wind" (example on figure 3). The NRMSE (Normalized Root Mean Square Error) for all buoys is 40% in the "original wind" case and 30% the "modified wind" case. Figure 4 which represents the distribution of H_{mo} between measures and model for 6 buoys shows this decrease of the NRMSE with the modification of the wind field. In the same way, the slope of the best-fit straight line, passing through the origin, is closer to 1.

The analysis of Q-Q plots (quantile-quantile) (figure 5), which show the correspondence between measured and computed quantiles (from 1% to 99%) of the statistical distribution of H_{mo} over the simulated period, shows also best results of the model with the modification of the wind field.

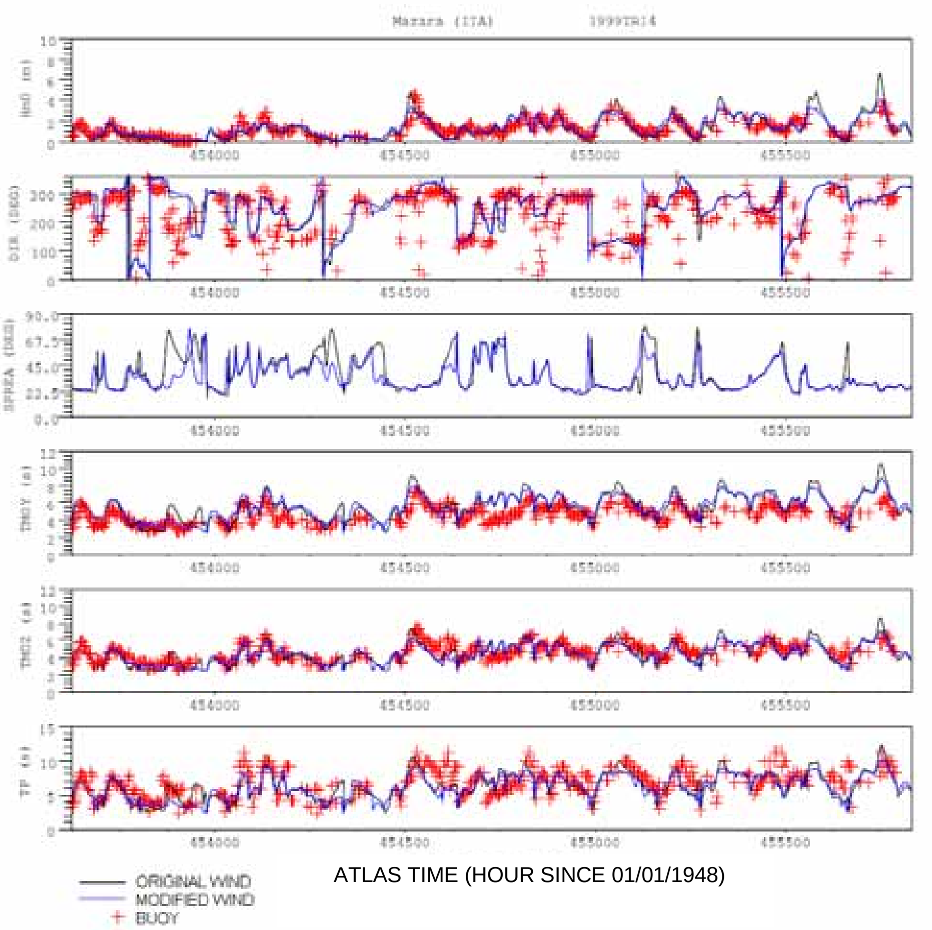

Figure 3. Comparison of model results with buoy data of Mazara for the last quarter of 1999.

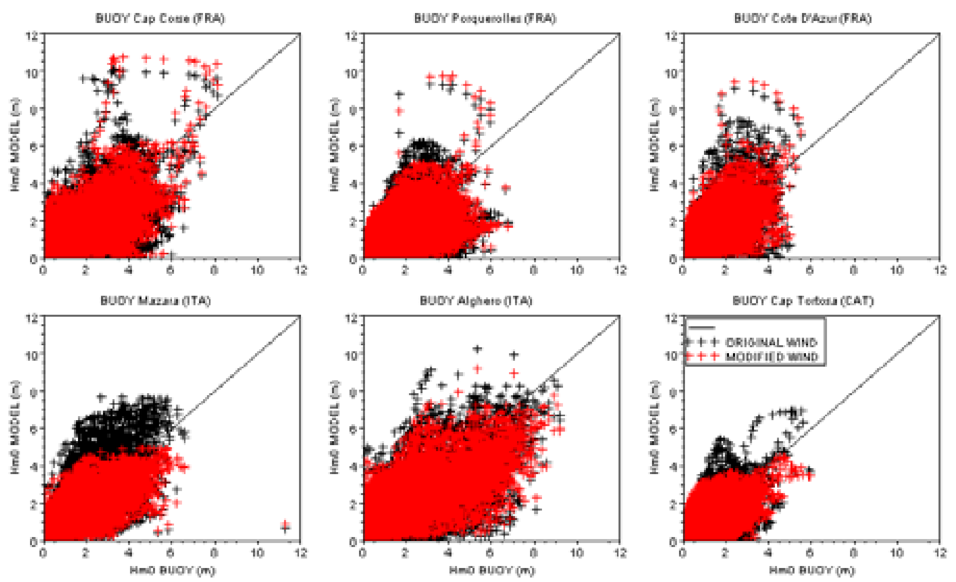

Figure 4. Distribution of H_{mo} between measurements and model for 6 buoys.

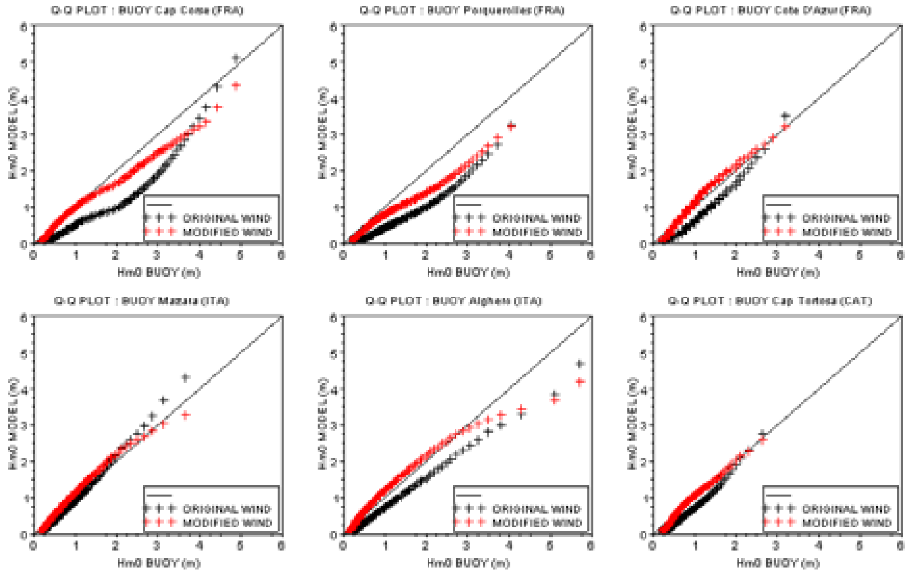

Figure 5. Q-Q (Q1-Q99) plot between measurements and model for 6 buoys.

4. Global results

Once the numerical data-base over the period 1979-2008, calibrated with altimeter data and compared with buoy data, has been built, one can use the time series of wave parameters to produce synthetic charts covering the Mediterranean Sea. Examples are given here for the mean value of the significant wave height (figure 6), the mean wave power (figure 7) and the Q99 value of the significant wave height (i.e. the wave height which is on the average exceeded by 1% of the data) (figure 8).

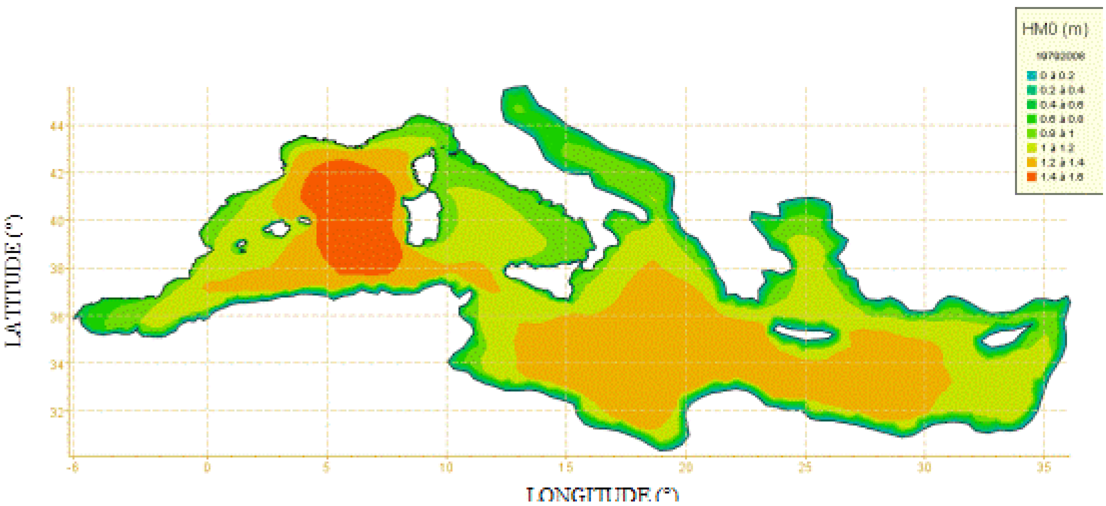

Figure 6. Chart of the mean value of wave height H_{mo} computed over the period 1979-2008.

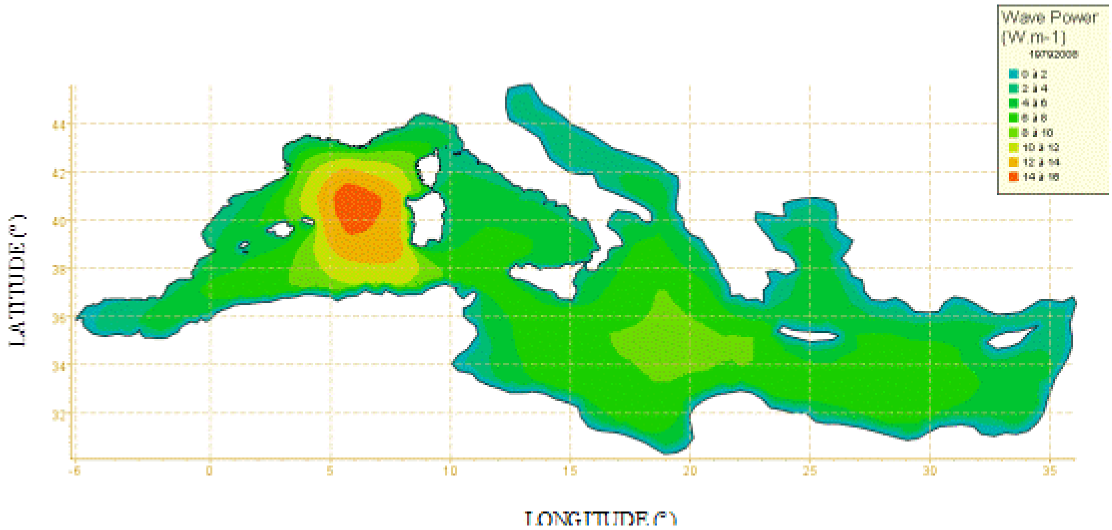

Figure 7. Chart of the mean wave power computed over the period 1979-2008.

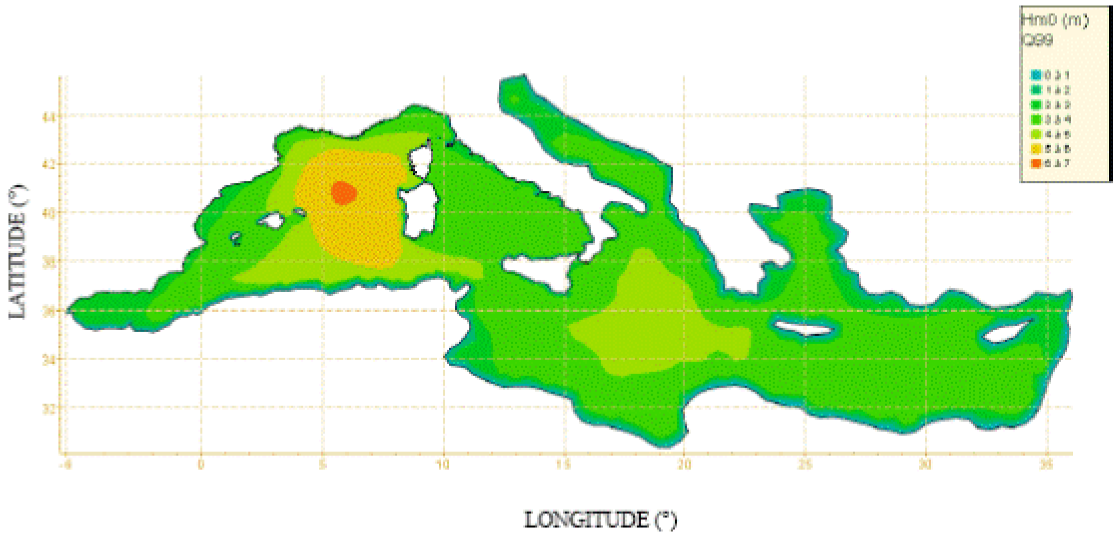

Figure 8. Chart of the Q99 of wave height H_{mo} computed over the period 1979-2008.

5. The new ANEMOC website

The ANEMOC data-base on the Atlantic Ocean, the English Channel, the North Sea and the Mediterranean Sea is now complete in a first version. Part of the results obtained during this work will be available on the present ANEMOC website where 3 levels of data are identified (see figure 9):

- Level 1: Time series of 6 wave parameters with an hourly time-step on 750 sites. (Free for research applications, Non-free for commercial uses) ;
- Level 2: Synthetic charts of mean wave climate (year, summer or winter) on 150 sites (see figure 10), (free) ;
- Level 3: Results of extreme value analysis for H_{mo} on 75 sites, based on POT (Peak-Over Threshold method) (see figure 11), (free).

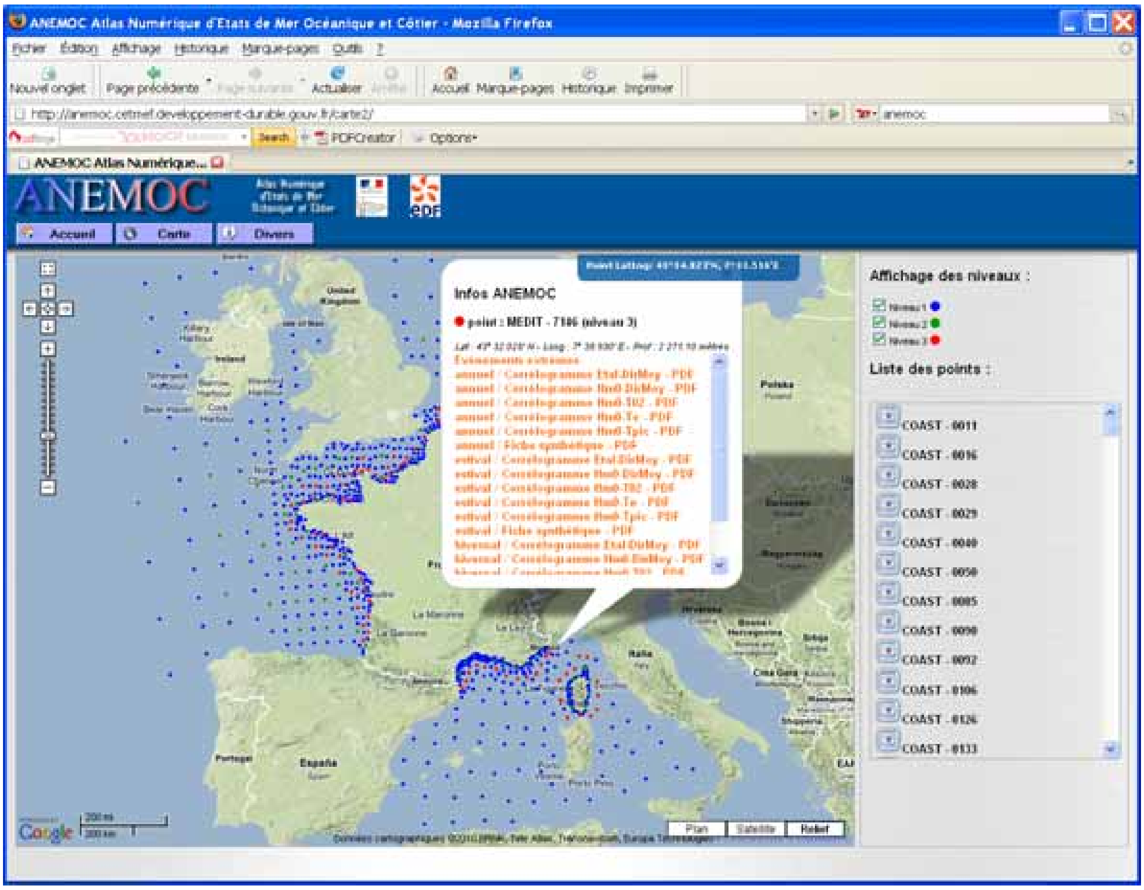

Figure 9. The new ANEMOC website.

6. Perspectives

We are presently working (i) on a more detailed analysis and description of the sea-state parameters (first and second swell, wind-sea, archiving), (ii) on a better modelling of physical processes in the wave model, (iii) on the extension towards shallow water, (iv) on the possible use of meso-scale wind-fields and (v) on data assimilation (altimeter wave heights).

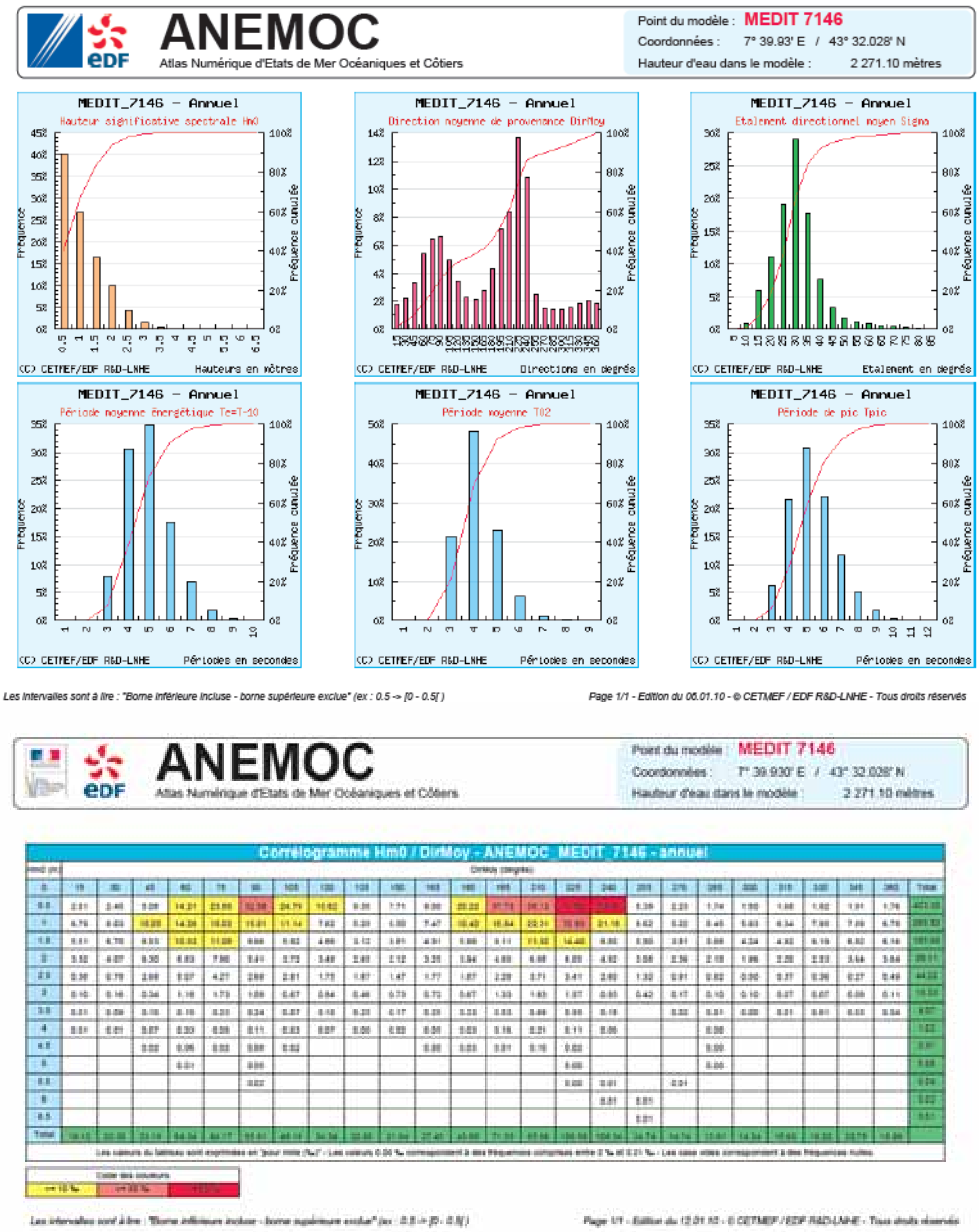

Figure 10. Level 2 data.

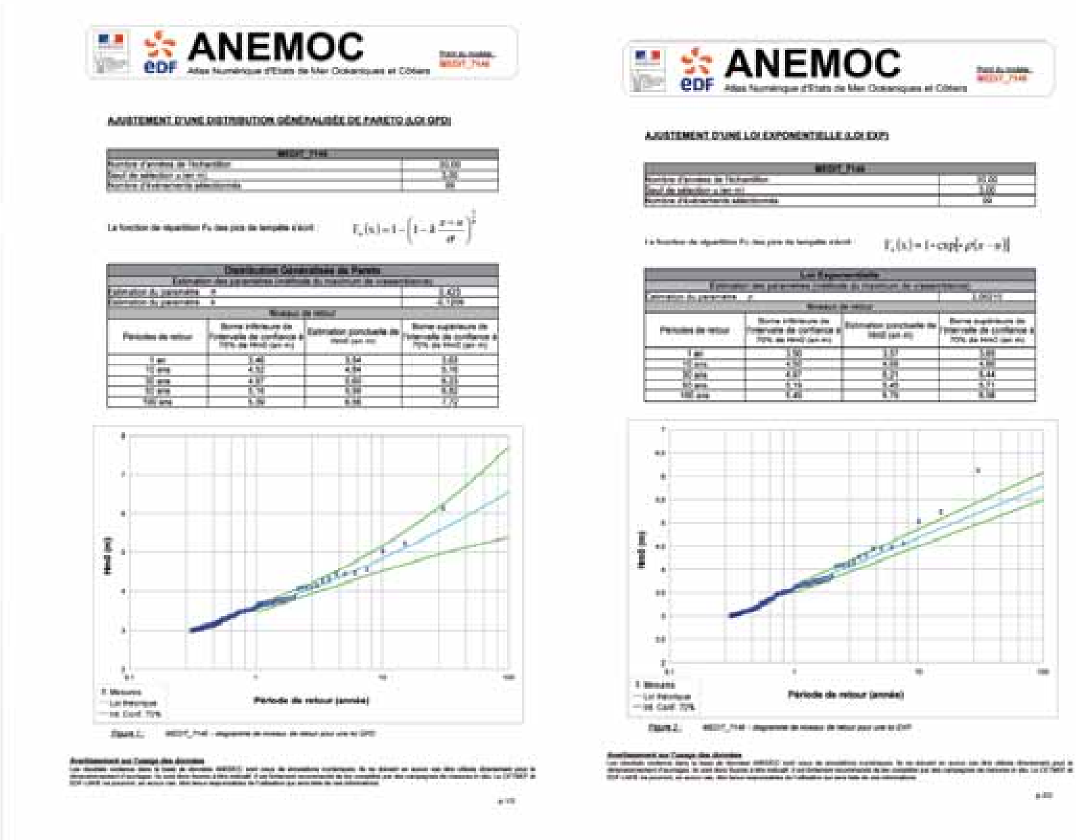

Figure 11. Level 3 data.

7. Acknowledgments

This project is a joint collaboration between EDF-LNHE and CETMEF. We thank Météo-France, XIOM, RON, IFREMER, NOAA and SHOM for access to their data.

8. References

AELBRECHT D., BENOIT M., MARCOS F., GOASGUEN G. (1998). *Prediction of offshore and nearshore storm waves using a third generation spectral wave model*, Proc. 8th Int. Offshore and Polar Eng Conf. (ISOPE), vol. III, pp 71-76.

AMANTE C., EAKINS B.W. (2009). *ETOPO1 1 Arc-Minute Global Relief Model: Procedures, Data Sources and Analysis*. NOAA Technical Memorandum NESDIS NGDC-24, 19 p, March 2009.

BENOIT M., MARCOS F., BECQ F. (1996). *Development of a third generation shallow water wave model with unstructured spatial meshing.* Proc. 25th Int. Conf. on Coastal Eng. (ICCE'1996), Orlando (Floride, USA), pp 465-478.

BENOIT M., LAFON F. (2004). *A nearshore wave atlas along the coasts of France based on the numerical modelling of wave climate over 25 years*. Proc. 29th Int. Conf. on Coastal Eng. (ICCE'2004), Lisbonne (Portugal), pp 714-726.

BENOIT M., LAFON F., GOASGUEN G. (2008). *Constitution et exploitation d'une base de données d'états de mer le long des côtes françaises par simulation numérique sur 23 ans. Base ANEMOC en Atlantique – Manche – Mer du Nord*. European Journal of Env. and Civil Eng., Vol. 12/1-2, pp 35-50. doi:10.3166/ejece.12.35-50

BRETHERTON F.P., GARRET, C.J.R., (1969). *Wavetrains in inhomogenous moving media*. Proc. Roy. Soc. London, Series A, 302, pp 529-554.

KANAMITSU M., EBISUZAKI W., WOOLLEN J., YANG S.-K., HNILO J.J., FIORINO M., POTTER G.L. (2002). *NCEP-DEO AMIP-II Reanalysis (R-2)*1631-1643, Bul. of the Atmos. Met. Soc.

KOMEN G.J., CAVALERI L., DONELAN M., HASSELMANN K., HASSELMANN S., JANSSEN P.A.E.M. (1994). *Dynamics and modelling of ocean waves*. Cambridge Univ. Press, 532 p. doi:10.1017/CBO9780511628955

LAFON F., BENOIT M. (2006). *Estimation of extreme wave conditions from hindcast simulations with application to the wave climate along French coasts*. Proc. 30th Int. Conf. on Coastal Eng. (ICCE'2006), San Diego (Californie, USA), pp 739-751.

QUEFFEULOU P., CROIZE-FILLON D. (2009). *La mesure satellite de hauteur de vague par altimètre. État des lieux, application à la climatologie et à la modélisation des états de mer*. AMA 2009. Les ateliers de modélisation de l'atmosphère, Toulouse, 27-29 janvier 2009.