# Wave Data Along Ship Routes in the Mediterranean Sea

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**ABSTRACT**

The calculation of reliable wave statistics for the probabilistic assessment of ship stability requires various data sets to be assembled, including temporal long term representative directional wave and wind data, for a set of geographical points distributed along the route. In the present paper we give a description of the above data available in the Mediterranean Sea, and their exploitation for the long-term probabilistic assessment of ship stability. We also discuss the problems and consequent limitations associated to each source of data.

**Keywords:** *wave data, ship routes, Mediterranean Sea*

## 1. INTRODUCTION

The calculation of reliable wave statistics for the probabilistic assessment of ship stability requires various data sets to be assembled, including temporal long term representative directional wave and wind data, for a set of geographical points distributed along the route. In general, there are four main sources of marine wind and wave data, which can be exploited for deriving long-term wave statistics: visual observations from ships, data measured from buoys or platforms, data measured by remote instruments on board of high altitude satellites, meteorological and wave models operational at the various meteoceanographic centres. The above data have different characteristics expressed as quality, accuracy, errors present in the data, geographical distribution, number of data and missing values. In the present paper we give a description of the above data available in the Mediterranean Sea. We also discuss the problems and consequent limitations associated with each source of data. The above data can also be exploited for the short-term assessment of ship stability by reconstructing wave spectra from integrated parameters along ship routes in the Mediterranean Sea (using, e.g., simple mixture-type models for the directional wave spectrum), and applying the model spectrum to investigate critical events associated with the short-term ship stability.

## 2. WAVE AND WIND DATA SOURCES IN THE MEDITERRANEAN SEA

There are four main sources of marine wind and wave data available to the user: (a) visual observations from ships, (b) data measured from buoys or platforms, (c) data measured by remote instruments on board of high altitude flying satellites, and (d) meteorological and wave models operational at the various meteo-oceanographic centres. The above data have different characteristics expressed as quality, accuracy, errors present in the data, geographical distributions, quantity of data. In the following, we give a brief description of the wave and wind data sources, and the data in the Mediterranean Sea that are available to NTUA. We also list the problems and consequent limitations associated to each source and/or instrument.

## 2.1 Visual Data

Many decades of visual data exist, and a full generation of atlases has been based on this kind of data. Apart from other drawbacks, a major limitation of the visual data is their preferential distribution along the most common maritime routes, and the tendency of ships to avoid the stormy areas, which leads to the derivation of biased statistics. The "Wind and Wave Atlas of the North-Eastern Mediterranean Sea", Athanassoulis & Skarsoulis (1992), prepared by NTUA under the authority of Hellenic Navy General Staff, is based on visual data from the British Meteorological Office, the Greek National Meteorological Service and the U.S. National Climatic Data Center. The observations used for the considered area of North-Eastern Mediterranean Sea come from voluntary ships, collected in the period 1949-1988.

## 2.2 Buoy data

A substantial number of buoys, either non-directional or directional ones, are distributed along the coasts of the Mediterranean Sea. Extended buoy networks exist and operate along the Spanish, French, Italian and Greek coastline and are presented in brief below. Also, some buoys operate in other places along the coasts of Mediterranean Sea, as e.g. the buoy in Cape Arnaoutis, Cyprus ($35^{o}9.16$'N, $32^{o}$,15.88'E), and various buoys along the coasts of Israel and Turkey.

The Spanish buoy network consists of the deep sea and the costal networks, shown in Figures 1a and 1b, respectively. The deep sea network is based on 11 Seawatch (Figure 1a, black circles) and 3 WaveScan (Figure 1a, white circles) buoy stations. The instruments are located at points with depths between 200 and 800 m and measure atmospheric and oceanographic parameters. Measurements are transmitted every hour via satellite to Puertos del Estado (PE) and directly posted to the web site of PE (http:// www.puertos.es).

The Coastal Network, also belonging to Puertos del Estado, is providing real time data in some specific points located at shallow waters. The main objective of the measurements is to complement those of the Deep Sea Network at those locations of special interest for the port operations or wave modelling validation. The buoys employed are scalar Waverider (Figure 1b, black circles) and directional (Figure 1b, white circles). More details about the Spanish network can be found in the web page of PE (http://www.puertos.es)

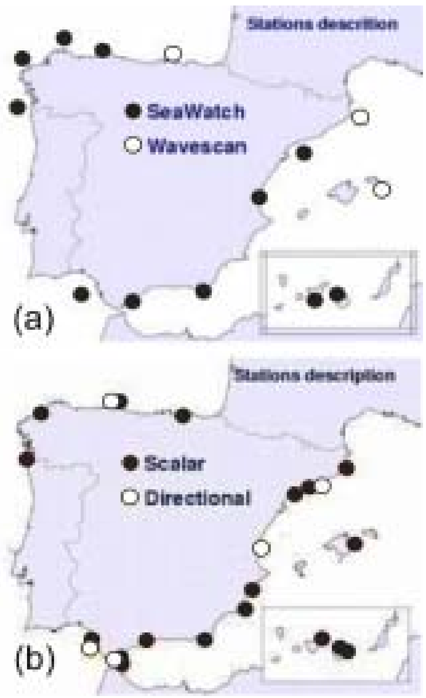



Figure 1: (a) Spanish deep sea buoy network, (b) Spanish coastal buoy network (http://www.puertos.es, Oceanography and Meteorology section).

The French buoy network consists of a

number of coastal and deep sea buoys, shown in Figure 2. In the Mediterranean Sea the two buoys operate owned and maintained by Meteo France: (i) Station 61001 - Nice Buoy, location: 43.40 N 7.80 E (43°23'60" N 7°47'60" E), and (ii) Station 61002 - Lion Buoy 42.10 N 4.70 E (42°6'9" N 4°42'9" E). More details about the French network can be found in the web page of MeteoFrance (http:// http://www.meteofrance.com ). Measurements of these buoys can be accessible on line through the National Data Buoy Center (NDBC, http://www.ndbc.noaa.gov) of the National Oceanic & Atmospheric Administration (NOAA) of U.S.


Figure 2: French buoy network (http://www.ndbc.noaa.gov/Maps/France.shtml).

Figure 3: Italian buoy network (http://www.envirtech.org/ron.htm).

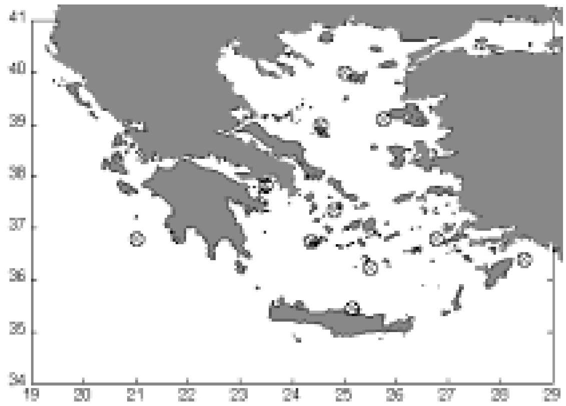



Figure 4: Greek buoy network (http://www.poseidon.ncmr.gr).

The Italian buoy network RON (Rete Ondametrica Nazionale) consists of a number of coastal and deep sea buoys, as shown in Figure 3. The buoy network has been appointed by the Italian Agency for Environmental Protection and Technical Services (APAT) and has been the first real-time updated Network in the Mediterranean Sea. More details about the Italian network can be found in the RON web page (http://www.envirtech.org/ ron.htm).

The Greek buoy network is operating since 1999 in the Aegean Sea, under the supervision of Hellenic National Center for Marine Research (NCMR). The buoy positions are shown in Figure 4. The observation buoys are equipped with sensors that monitor, except of wind speed and direction and wave height, also wave period and mean wave direction, as well as other parameters (such as air-temperature, sea surface salinity and temperature, surface current speed and direction, sea surface dissolved oxygen and others). Details about the Greek buoy network in the Aegean Sea can be found in the NCMR-POSEIDON web page (http://www.poseidon.ncmr.gr/).

In the Mediterranean Sea the buoys represent the most accurate source of information for wave data. The error is estimated in the order of a few percents. The error grows when we move to the highest wave heights, for the tendency of the buoys to slip around the highest crests, leading to an underestimation of the overall wave height. It is obvious that the buoy data are far from being sufficient for characterising larger areas or ship routes in the Mediterranean Sea. The buoys are mostly located very close to the coasts, and thus they are not representative of the conditions in the parts of open sea. Also, a major limitation of many of the buoy datasets is the lack of wind data. The usefulness of buoy data is that they can be used to validate satellite data, covering more extended areas; see Figure 5. Then, the latter can been used to calibrate the data from operational wind and wave models.

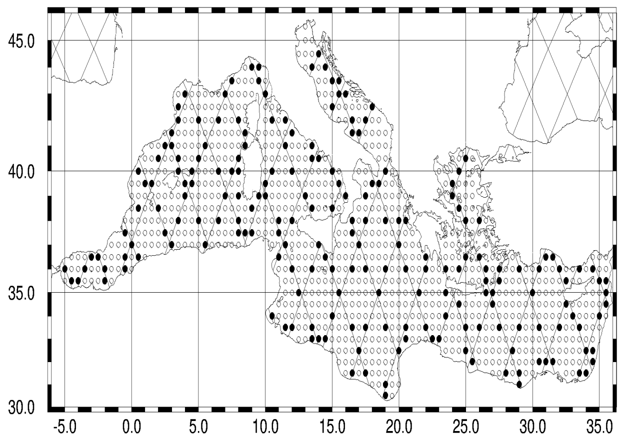



Figure 5: WAM model grid points and TOPEX tracks in the Mediterranean Sea. Filled circles are model points close to satellite tracks used for deriving calibration factors of model data vs. validated satellite data (Barstow *et al*, 2001).

In various recent projects, dealing with the derivation of wave and wind statistical information in coastal areas and in open sea, such as the EUROWAVES project (Barstow *et al*, 2001), WORLDWAVES (Barstow *et al*, 2003a, 2003b) and MEDATLAS project (Athanassoulis *et al*, 2004) the calibrated data, as described above, have been used to derive the statistics for the geographical areas of interest. More details about the validation/calibration procedure can be found in Barstow *et al* (2001, 2003a, 2003b); see also Figure 5.

## 2.3 Satellite data

Satellite radar altimeters provide estimates of the significant wave height and the wind speed (at 10m above the seawater level) along the satellite track (see, e.g., Aage *et al*, 1998). Scatterometers provide the 10m wind vector on the 500km width swath by measuring the radar cross section at different incident angles. In Mediterranean Sea satellite data are available from ERS1, ERS2, TOPEX/Poseidon and ENVISAT. For waves below 1m the error of the altimeter significant wave height is quite big. Also, because of contamination of the signal by land echo, wind and wave data are not accurate close to the coast. More details about the accuracy and problems of Topex altimeter data can be found in Cotton *et al* (1997), Lefevre & Cotton (2001), for ERS data in Queffeulou (1996) and for ENVISAT in Johnsen (2005); see also Athanassoulis *et al* (2004).

## 2.4 Model data

Many different institutions run global atmospheric and wave models, producing daily forecast and analysis worldwide. Because of the multiscale character of the weather/wave phenomena, nested models with much higher resolution are required in order to describe with sufficient accuracy the fields in the inner basins, like the Mediterranean Sea. This is especially true for areas including fine-scale geographical features (islands etc), as for example is the case of the Aegean Sea. Nowadays most (if not all) Meteorological

Offices in Europe use the WAM wave model, Komen *et al* (1994), both for weather forecasting and hindcasting studies.

Model data is the only available data source exhibiting spatial coverage and time extent permitting the derivation of long term wind and wave statistics in the whole Mediterranean Sea. WAM model data can be provided by European Centre for Medium-Range Weather Forecasts (ECMWF, Reading, U.K.) or by the National Met Offices of European countries having association agreements with ECMWF. Two versions of the WAM model have been operational at ECMWF, one for the global ocean and one for the Mediterranean Sea. The wave model for the Mediterranean Sea became operational in July 1992. A 0.5 degree resolution was initially used in both latitude and longitude, for an overall number of about 950 points. The resolution was later increased to 0.25 degree, for an overall almost 4000 points. The original wave model for the Mediterranean Sea included the area between $6^o$ West and $36^o$ East in longitude, and $30^o$ and $46^o$ North in latitude. The area was later extended to include the Baltic Sea. In the Fall of 1998 a much more extended version was made operative.

As has been found during various research projects (e.g. EUROWAVES, MEDATLAS) WAM wave data in the Mediterranean Sea underestimate the significant wave height, in a strongly non-uniform manner. The distribution of the calibration factor, defined as the ratio of the WAM model calculated value and the (satellite) measured value, for the whole Mediterranean Sea, is shown in Figure 6, taken from EUROWAVES project (Barstow *et al*, 2001). As it can be seen in the Northern part of the Mediterranean Sea, the underestimation of $H_S$ is significant (WAM $H_S \approx 40-60\%$ of measured $H_S$). This means that model data can be reliably used only after proper calibration.

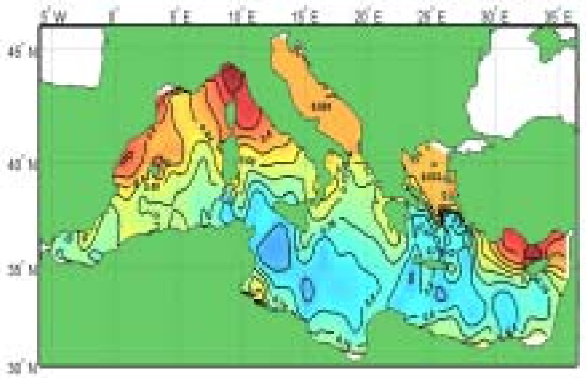


Figure 6: Geographical distribution of $H_S$-calibration factor in the Mediterranean.

## 3. DESCRIPTION OF AVAILABLE WIND AND WAVE DATA IN THE MEDITERRANEAN SEA

A 10-year database is available to NTUA from previous projects, which consists of 6-hourly time series of model wave and wind data from the European Centre for Medium-Range Weather Forecasts (ECMWF). The data are available on a 0.5° regular grid of offshore geographic locations of the Mediterranean Sea area, shown in Figure 7.

These data come from the WAM wave model run at ECMWF and have been calibrated using calibration factors in the Mediterranean Sea, available to NTUA from the EUROWAVES project (Barstow *et al*, 2001). For each geographical location, a 6-hourly timeseries is available spanning the time period from 1/7/1992 to 30/6/2002.

Each record in the time series contains the significant wave height, $H_S$, the energy wave period, $T_{-10}$, the mean wave direction, $Q$, for the total sea spectrum, as well as for the wind sea part and the swell part of the spectrum, and in addition contains the peak period, $T_P$, the wind speed (at 10 m height), $W_{10,SP}$ and the wind direction, $W_{10,dir}$. On the basis of the above data also time series of useful derived quantities can be obtained, such as the wave slope parameter based on mean energy period ($b_{-10} = 2pH_S / gT_{-10}^2$) and the wave slope parameter based on peak period ($b_p = 2pH_S / gT_p^2$).

Using sophisticated statistical analysis tools developed at NTUA, various univariate, bivariate and directional statistical results (in the form of frequency tables or histograms or probability models fitted to the data) can be obtained from the wind and wave database. For each geographical location of the 0.5° grid, the type of statistical analysis results which are currently available are listed in detail in Tables 1 and 2. Of course, the tables can be extended to include similar type statistical results concerning the wind parameters, combinations As an example we list below various types of data that can be provided, either at specific sea areas or along ship routes in the Mediterranean Sea from the NTUA wind and wave database.

C.1 Histograms (frequency tables) of $H_S$ vs. $T_P$ or $H_S$ vs. $T_{-10}$ associated with the total sea spectrum, on a monthly basis or combination of months or seasons or annually. The typical formats of NTUA ($H_S$ vs. $T_P$) data, for one datapoint in the Mediterranean Sea, are shown in Table 3. It is noted here that various partitions (coarse, medium, fine) of the parameter space (significant wave height, wave period, mean wave direction etc.) are possible, in order to better model the details of the corresponding univariate and multivariate probability distributions and to better fit to the user's needs. As an example, the fine partition is shown in Table 3.

C.2 Same as in C.1, but conditionally with respect to mean wave direction (the corresponding mean wave direction bins are: $0^o, 15^o, \ldots 360^o$).

C.3 Histograms (frequency tables) of $H_S$ vs. $T_{-10}$, associated with the wind-sea part of

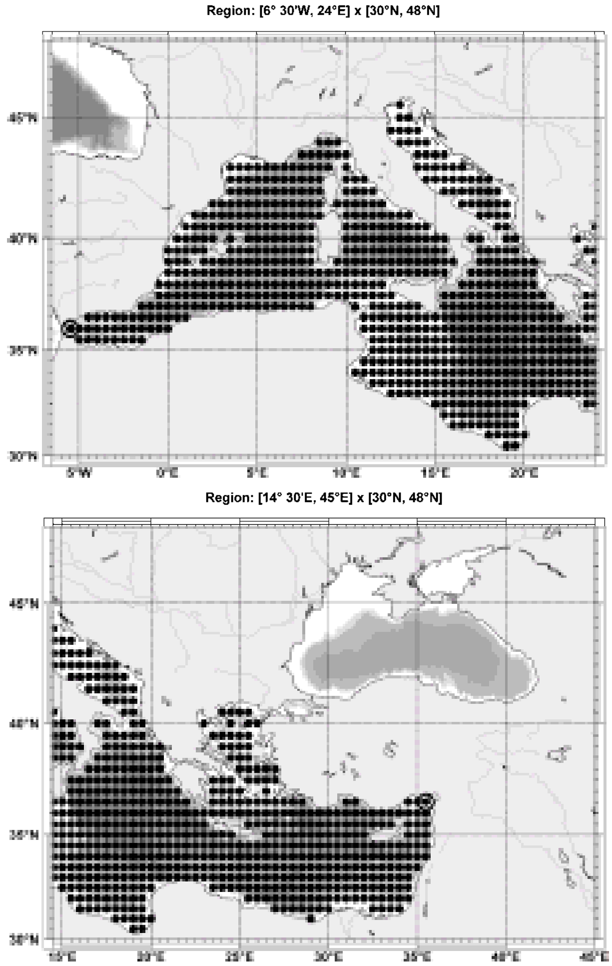



Figure 7: NTUA database: Wind and wave data points in the Mediterranean Sea. The datapoints are shown by using black bullets of wave and wind parameters as well as other derived quantities.

the spectrum, on a monthly basis or combination of months or seasons or annually, at representative points of the 0.5deg grid near the ship route.

C.4 Same as in C.3, but conditionally with respect to mean wave direction

C.5 Histograms (frequency tables) of $H_S$ vs. $T_{-10}$, associated with the swell part of the spectrum on a monthly basis or combination of months or seasons or annually, at representative points of the 0.5deg grid near the ship route.

Table1. Univariate statistics. All the above are available on a monthly basis or combination of months or seasons or annually

| Tables | Graphs |
|---|---|
| Frequency table of $H_S$ [TS[1], WW, SW] | Probability density function of $H_S$ [TS, WW, SW] |
| Frequency table of $T_{-10}$ [TS, WW, SW] | Probability density function of $T_{-10}$ [TS, WW, SW] |
| Frequency table of $T_P$ [TS] | Probability density function of of $T_P$ [TS] |
| Frequency table of $\Theta$ [TS, WW, SW] | Probability density function of $\Theta$ [TS, WW, SW] |
| Frequency table of $\Delta\Theta = \Theta_{WW} - \Theta_{SW}$ | Probability density function of $\Delta\Theta = \Theta_{WW} - \Theta_{SW}$ |
| Frequency table of $b_{-10}$ [TS, WW, SW] | Probability density function of $b_{-10}$ [TS, WW, SW] |
| Frequency table of $b_P$ [TS] | Probability density function of $b_P$ [TS] |

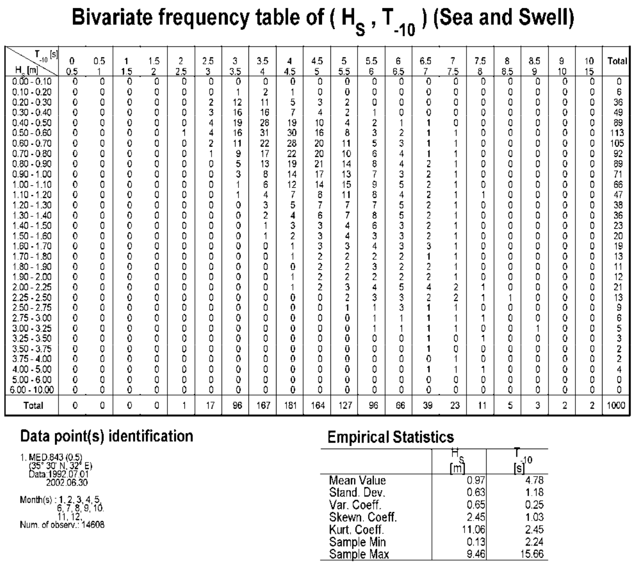
Table 2. Bivariate statistics. All the above are available on a monthly basis or combination of months or seasons or annually.

| Tables | Graphs |
|---|---|
| Frequency table of $\left(H_S, T_{-10}\right)$ [TS, WW, SW] | Probability density function of $\left(H_S, T_{-10}\right)$ [TS, WW, SW] |
| Frequency table of $\left(H_S, T_P\right)$ [TS] | Probability density function of $\left(H_S, T_P\right)$ [TS] |
| Frequency table of $\left(H_S, b_{-10}\right)$ [TS, WW, SW] | Probability density function of $\left(H_S, b_{-10}\right)$ [TS, WW, SW] |
| Frequency table of $\left(H_S, b_P\right)$ [TS] | Probability density function of $\left(H_S, b_P\right)$ [TS] |
| Frequency table of $\left(H_S, \Delta\Theta\right)$ | Probability density function of $\left(H_S, \Delta\Theta\right)$ |

[1] Statistics of the various parameters are available for each one of the following three categories of spectra:

TS : Total sea spectum,
WW : Wind sea part of the spectrum,
SW : Swell part of the spectrum.

Table 3. Typical format of $H_S$ vs. $T_{-10}$ data (Image format, fine partition) for one datapoint in the Mediterranean Sea.



**Bivariate frequency table of ( $H_S$ , $T_{-10}$ ) (Sea and Swell)**

| $H_S$ [m] \ $T_{-10}$ [s] | 0 0.5 | 0.5 1 | 1 1.5 | 1.5 2 | 2 2.5 | 2.5 3 | 3 3.5 | 3.5 4 | 4 4.5 | 4.5 5 | 5 5.5 | 5.5 6 | 6 6.5 | 6.5 7 | 7 7.5 | 7.5 8 | 8 8.5 | 8.5 9 | 9 10 | 10 15 | Total |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 0.00 - 0.10 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 0.10 - 0.20 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 2 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 6 |
| 0.20 - 0.30 | 0 | 0 | 0 | 0 | 0 | 2 | 12 | 11 | 5 | 3 | 2 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 36 |
| 0.30 - 0.40 | 0 | 0 | 0 | 0 | 0 | 3 | 16 | 16 | 7 | 4 | 2 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 49 |
| 0.40 - 0.50 | 0 | 0 | 0 | 0 | 0 | 4 | 19 | 28 | 19 | 10 | 4 | 2 | 1 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 89 |
| 0.50 - 0.60 | 0 | 0 | 0 | 0 | 1 | 4 | 16 | 31 | 30 | 16 | 8 | 3 | 2 | 1 | 1 | 0 | 0 | 0 | 0 | 0 | 113 |
| 0.60 - 0.70 | 0 | 0 | 0 | 0 | 0 | 2 | 11 | 22 | 28 | 20 | 11 | 5 | 3 | 1 | 1 | 0 | 0 | 0 | 0 | 0 | 105 |
| 0.70 - 0.80 | 0 | 0 | 0 | 0 | 0 | 1 | 9 | 17 | 22 | 20 | 10 | 6 | 4 | 1 | 1 | 0 | 0 | 0 | 0 | 0 | 92 |
| 0.80 - 0.90 | 0 | 0 | 0 | 0 | 0 | 0 | 5 | 13 | 19 | 21 | 14 | 8 | 4 | 2 | 1 | 0 | 0 | 0 | 0 | 0 | 89 |
| 0.90 - 1.00 | 0 | 0 | 0 | 0 | 0 | 0 | 3 | 8 | 14 | 17 | 13 | 7 | 3 | 2 | 1 | 0 | 0 | 0 | 0 | 0 | 71 |
| 1.00 - 1.10 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 6 | 12 | 14 | 15 | 9 | 5 | 2 | 1 | 0 | 0 | 0 | 0 | 0 | 66 |
| 1.10 - 1.20 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 4 | 7 | 8 | 11 | 8 | 4 | 2 | 1 | 1 | 0 | 0 | 0 | 0 | 47 |
| 1.20 - 1.30 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 3 | 5 | 7 | 7 | 7 | 5 | 2 | 1 | 0 | 0 | 0 | 0 | 0 | 38 |
| 1.30 - 1.40 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 2 | 4 | 6 | 7 | 8 | 5 | 2 | 1 | 0 | 0 | 0 | 0 | 0 | 36 |
| 1.40 - 1.50 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 3 | 3 | 4 | 6 | 3 | 2 | 1 | 0 | 0 | 0 | 0 | 0 | 23 |
| 1.50 - 1.60 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 2 | 3 | 4 | 3 | 3 | 2 | 1 | 0 | 0 | 0 | 0 | 0 | 20 |
| 1.60 - 1.70 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 3 | 3 | 4 | 3 | 3 | 1 | 0 | 0 | 0 | 0 | 0 | 19 |
| 1.70 - 1.80 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 2 | 2 | 2 | 2 | 1 | 1 | 0 | 0 | 0 | 0 | 0 | 13 |
| 1.80 - 1.90 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 2 | 2 | 3 | 2 | 2 | 1 | 0 | 0 | 0 | 0 | 0 | 11 |
| 1.90 - 2.00 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 2 | 2 | 2 | 2 | 2 | 1 | 0 | 0 | 0 | 0 | 0 | 12 |
| 2.00 - 2.25 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 2 | 3 | 4 | 5 | 4 | 2 | 1 | 0 | 0 | 0 | 0 | 21 |
| 2.25 - 2.50 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 2 | 3 | 3 | 2 | 2 | 1 | 1 | 0 | 0 | 0 | 13 |
| 2.50 - 2.75 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 1 | 3 | 1 | 1 | 0 | 0 | 0 | 0 | 0 | 9 |
| 2.75 - 3.00 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 1 | 1 | 1 | 1 | 0 | 0 | 0 | 0 | 6 |
| 3.00 - 3.25 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 1 | 1 | 1 | 0 | 0 | 1 | 0 | 0 | 5 |
| 3.25 - 3.50 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 0 | 1 | 0 | 0 | 0 | 0 | 3 |
| 3.50 - 3.75 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 2 |
| 3.75 - 4.00 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 0 | 0 | 0 | 0 | 0 | 2 |
| 4.00 - 5.00 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 1 | 1 | 0 | 0 | 0 | 0 | 4 |
| 5.00 - 6.00 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 6.00 - 10.00 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| Total | 0 | 0 | 0 | 0 | 1 | 17 | 96 | 167 | 181 | 164 | 127 | 96 | 66 | 39 | 23 | 11 | 5 | 3 | 2 | 2 | 1000 |

**Data point(s) identification**

1. MED.843 (0.5)
(35° 30' N, 32° E)
Data:1992.07.01
2002.06.30

Month(s) : 1, 2, 3, 4, 5, 6, 7, 8, 9, 10. 11, 12,
Num. of observ.: 14608

**Empirical Statistics**

| | $H_S$ [m] | $T_{-10}$ [s] |
|---|---|---|
| Mean Value | 0.97 | 4.78 |
| Stand. Dev. | 0.63 | 1.18 |
| Var. Coeff. | 0.65 | 0.25 |
| Skewn. Coeff. | 2.45 | 1.03 |
| Kurt. Coeff. | 11.06 | 2.45 |
| Sample Min | 0.13 | 2.24 |
| Sample Max | 9.46 | 15.66 |

C.6 Same as in C.5, but conditionally with respect to mean wave direction.

C.7 Histograms (frequency tables) of $H_S$ vs. $W_{10,SP}$, on a monthly basis or combination of months or seasons or annually.

## 4. CONCLUSIONS

A description of the wind and wave data available in the Mediterranean Sea is given, and the problems and consequent limitations associated to each source of these data have been discussed as concerns their exploitation for the long-term probabilistic assessment of ship stability.

The above data can also be exploited for the short-term assessment of ship stability by reconstructing wave spectra from integrated parameters. Future work is planned towards: (i) the investigation of simple mixture-type models for modelling the directional wave spectrum along ship routes in the Mediterranean Sea, and (ii) the evaluation of the predictive capability of the model spectrum as concerns critical events associated with the short-term ship stability.

## 5. ACKNOWLEDGMENTS

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