Ocean Engineering 107 (2015) 45–53

Contents lists available at ScienceDirect

Ocean Engineering

journal homepage: www.elsevier.com/locate/oceaneng

Directional analysis of sea storms

V. Laface [a,b], F. Arena [a,*], C. Guedes Soares [b]

[a] Natural Ocean Engineering Laboratory, DICEAM, Mediterranea University, Reggio Calabria, Italy
[b] Centre for Marine Technology and Ocean Engineering (CENTEC), Instituto Superior Tecnico, Universidade de Lisboa, Portugal

ARTICLE INFO

Article history:
Received 24 February 2015
Accepted 19 July 2015
Available online 7 August 2015

Keywords:
Significant wave height
Wave direction
Sea storm

ABSTRACT

The paper deals with the directional analysis of sea storms in the Atlantic and Pacific Oceans and in the Mediterranean Sea. The main focus of the work is to investigate the variability of wave directions during sea storms. The analysis is carried out starting from significant wave height and wave direction time series. At the first stage storms are selected from time series without conditions on wave direction. Subsequently the directional analysis of each storm is performed by considering the wave direction associated to each sea state during the storm. A methodology to classify the "directional storms" pertaining to a certain directional sector is proposed. Finally a technique to determine the main directions of occurrence of the strongest sea storms and the appropriate width of sectors for directional analysis is proposed. Results are useful for different kind of applications such as directional long-term predictions for the design process of angle-dependent structures or for wave energy converter devices.

1. Introduction

A sea storm is a non-stationary process, with the significant wave height, the wave spectrum and the wave direction not constant in time. It may be defined as a sequence of sea states during which the significant wave height exceeds a fixed constant threshold. In general, a storm starts when the significant wave height goes above this threshold and finishes when it falls below it. Following the definition of Boccotti (2000), (see also Arena and Pavone, 2006, 2009), a sea storm is 'a sequence of sea states in which the significant wave height exceeds the threshold h_{crit} and does not fall below it for a continuous time interval greater than 12 h'. The storm threshold h_{crit} depends upon the considered location, and it may be related to the average significant wave height in the given area.

Storms evolve in space and time often changing direction and thus one can choose an Eulerian or a Lagrangian description to model them as discussed by Bernardino et al. (2008). However it is most common to adopt the Eulerian approach, which is the one considered in this paper.

Statistical properties of waves during storms were investigated by Borgman (1970, 1973) who determined the cumulative distribution function of the maximum wave height during a storm in an integral form. This result is very important for the long-term analysis of extreme waves during storms. For example it is the main concept on which the models of the equivalent storms are based (Arena and Pavone, 2006, 2009; Fedele and Arena, 2010; Arena et al., 2013). They enable to associate to each actual storm an equivalent one defined by means of a parameter representative of storm intensity, which is equal to the maximum significant wave height in the actual storm, and a parameter representative of the storm duration, which is determined by imposing that the maximum expected wave height is the same in the actual and equivalent storms. It is important, for several marine applications, to consider directionality during storms to develop criteria for the prediction of extremes values that take into account the wave direction, and enable to determine the long-term statistics for any directional sector. Recently Jonathan and Ewans (2007) developed an approach to establish appropriate directional criteria and an associated omni-directional criterion. Jonathan et al. (2008) showed that a directional extreme model is generally better than a model that ignores directionality and an omni-directional criterion derived from a directional model are more accurate and should be preferred.

In this paper the variability of direction during storm history (which is defined as the significant wave height in time domain during the evolution of the storm) is investigated. Then a criterion to classify "directional storms" pertaining to a certain sector is proposed. Furthermore a methodology for the determination of the center and the width of the directional sector is given. This kind of analysis is useful for several kind of application such as directional long-term predictions, design process of angle-

* Corresponding author. Tel.: +39 3355387968; fax: +39 09651692260.
E-mail address: arena@unirc.it (F. Arena).

http://dx.doi.org/10.1016/j.oceaneng.2015.07.027
0029-8018/

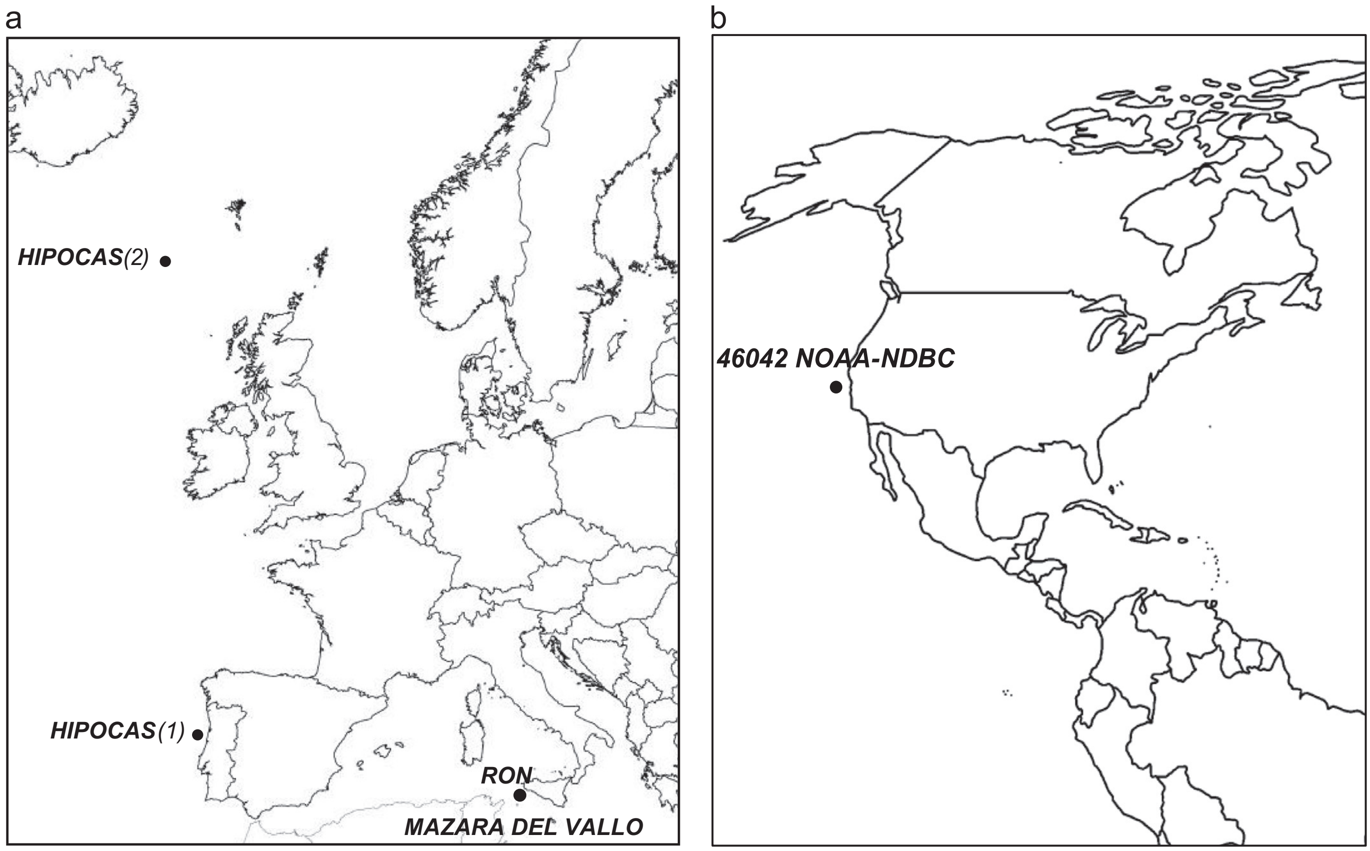

Fig. 1. (a) Locations of the Mazara Del Vallo buoy from Italian RON network and of the two points from HIPOCAS dataset; (b) location of 46042 buoy from NOAA–NDBC (USA).

dependent devices (Arena et al., 2015), but also to check the correct operation of buoys if data of different kind are compared. The results are of interest to those developing extreme wave criteria for design purposes, as these are often on a storm based approach (Tromans and Vanderschuren, 1995). The methodology proposed has been developed by analyzing wave data in locations that are all in essentially extra-tropical regions where the directional variability in a storm (e.g., Ponce de Leon and Guedes Soares, 2014) is much lower than in a region where tropical storms – hurricane and typhoons – dominate. Different conclusions may be found for such locations and the need of criteria based on different assumptions could be required.

2. Sea storms

A sea storm is defined as a sequence of sea states in which the significant wave height H_s exceeds a given threshold. In general, the storm starts when H_s in time domain has an up-crossing related to the given storm threshold and finishes when H_s goes down this threshold.

The Boccotti's (2000) definition of sea storm, given in the previous section, admits that a calm period with significant wave height below the threshold h_{crit} may occur even during the storm evolution.

If this period has duration Δt_{crit} smaller than 12 h there is a single storm, otherwise two different storms (note that this value of Δt_{crit} has been proposed for the Mediterranean Sea and the Atlantic and Pacific Oceans; it may change for different locations). The choice of the storm threshold value is done in relation to the characteristics of the considered location. Boccotti (2000) (see also Arena and Puca (2004); Arena and Pavone, 2006, 2009) proposed a storm threshold related to the average value of significant wave height $\overline{H_s}$ calculated from time series (note that the average is calculated considering the whole time series of H_s). He assumed a storm threshold equal to 1.5 times $\overline{H_s}$, but a higher value, for example 2 or 3 times $\overline{H_s}$ may be assumed. It is worth noting that assuming increasing threshold h_{crit} the number of storms decreases.

Table 1
Average significant wave height $\overline{H_s}$, critical threshold h_{crit} and number of storms with maximum significant wave height $H_{s\ max} \geq 2h_{crit}$.

Location	$\overline{H}_s(m)$	h_{crit} (m)	N°storm ($H_{s\ max} > 2h_{\mathrm{crit}}$)
HIPOCAS(1)	2.40	3.60	137
HIPOCAS(2)	3.51	5.27	227
RON MAZARA	0.97	1.45	232
NDBC 46042	2.21	3.31	34

2.1. Definition of directional sea storm

To define a “directional storm” pertaining to a certain sector $(\vartheta_i \pm \Delta\vartheta)$ the variability of wave direction during the storm has to be investigated. The analysis proposed in this paper (see next section) shows this variability; it is quite high in storm tails (lower sea states), but lower near storm peak (when stronger sea states occur). A directional sea storm may be defined as a sequence of sea states in which the significant wave height exceeds a given threshold h_{crit} and the wave direction is within a given sector $(\vartheta_i \pm \Delta\vartheta)$. Because of the strong variability of wave direction in