Rogue waves in the sea: towards the efficient use of remote sensing

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Abstract. Nowadays rogue waves are confirmed to exist in deep and shallow areas of the World Ocean and are registered all over the world. Although there exist hundreds of instrumental rogue wave records, the pool of existing data is insufficient to build reliable statistics and to give a definite answer concerning its nature. Further collecting and analyzing existing data of rogue events can bring us to new ideas of its nature and mechanisms of formation. From this point of view, the remote sensing techniques open a wide range of possibilities for individual wave detection and for validation and verification of observed events. Here we present the statistics of rogue wave observations (verified by satellite data), and draw some conclusions out of it.

Keywords. Rogue waves, World Ocean, altimeter data.

1. Introduction

Rogue waves usually refer to anomalously high ocean waves. Known since historical times under the character of marine legends, rogue waves have been instrumentally confirmed only recently. One of the most famous events is the 25.6 m high «New Year Wave» recorded in the North Sea at the Statoil-operated “Draupner” platform on 1 January, 1995. This very event has triggered advanced studies of ocean rogue waves.

The important breakthrough in understanding of rogue wave dynamics occurred with the development of remote sensing techniques. Space SAR data from satellites (ERS-1, ERS-2 and RADARSAT-1) opened the door for identifying the moving fetch as the origin of rogue waves [1]. Despite its boundedness in space and time (global covering in 1996-1997 and partial in 1992, 1999 – 2002), radar data allowed to locate the highest wave (~25 m, 6 September 1996) during 3 weeks of winter season in the northern hemisphere in the South Atlantic [1]. With the help of altimeter data, in the North Sea, rogue wave groups with extreme wavelength (~400 m) and periods (~25 s) have been recently connected to the organized mesoscale gusts [2].

However, SAR images are indiscrete and some rogue events might be unnoticed. From this perspective it is also reasonable to use methods of remote sensing indirectly over validation of observed rogue events, as it has been done in papers [3, 4]. By doing so, we enlarge temporal limits of use of satellite data and may collect relatively reliable statistics of rogue wave accidents. The results, which come out of this statistics are described in this paper.

2. Methods

The catalogue of rogue events was compiled from the data on extreme and hazardous ocean waves reflected in mass media all over the world. Potential rogue events were revised in terms of their heights with respect to the current wave background using satellite data. The traditional criterion of rogue wave from time-series data suggest that it exceeds at least twice the significant wave height ($H_R/H_S > = 2$). The validity of the event was estimated based on monomission (not combined different satellites) altimeter significant wave heights for Jason-1, Envisat, GFO and T/P provided by [5]. Here and after altimeter significant wave height refer to the average of highest 1/3 of waves over 2° x 2°. If satellite data were not available for required date and time, adjacent values were used. In fact, altimeter data strongly depend on the satellite data calibration and can be different for various satellites over the same area. If several different values of significant wave height were available, the maximum was used. Since maximum wave heights measured by satellites intend to exceed corresponding wave heights from tide series [6, 7], this criterion is introduced as perceptive. Thus, "a huge wave" with the height 1.8 more that ambient significant wave heights was still considered to be rogue. False entries do not satisfy the necessary condition. Possible event imply that available data is not enough to estimate if the phenomenon was rogue or not. However, based on eye-witness reports of the event ("a monster wave"), information about ambient seas (altimeter significant wave height or cited weather conditions) and/or corresponding wave impact (vessel damage or human casualties), it is reasonable to assume that the single wave (or several waves) could have been rogue.

Below we give a few examples, how the selection procedure was organized.

Five people suffered non-life-threatening injuries after a 5-7 ft [1.5–2.1 m] wave hit a 106-ft [32.3 m] boat about 10h20 (local time) 5 miles [8 km] north of Race Point, Cape Cod, USA, on May 16, 2011 [8]. Significant wave height measured by satellites reached H_S = 2–2.2 m in the area [5]. As a result, waves that capsized the boat were of the same magnitude that the ambient seas, Figure 1. Considering this, the event is taken for false.

Early in the morning three men were washed out to the sea when their boat was struck by a huge wave and capsized several kilometers west of Rarotonga, Cook Islands on February 8, 2011 [9]. The height of hazardous wave was not reported. However, considering strong wave impact in relatively calm waters (H_S = 2.2–2.5 m, [5], see Figure 2), the event is considered as possible.

One died and one was injured when a sudden huge 12–15 ft [3.6–4.6 m] wave hit the bow of a 70–ft [21.3 m] boat (with 4 people aboard) one mile [1.6 km] offshore Virgin Gorda, Virgin Islands on August 16, 2011. The wave smashed the bulletproof glass of the 10-ft-wide windshield. [10, 11]. The destructive wave was estimated to be 3.6-4.6 m given 1.5-1.8 m background waves [5], Figure 3. The height of the single wave and its sudden nature clearly refer to the true rogue event.

3. Results

By using the method described above, we collected relatively reliable statistics of rogue wave accidents and could make adequate conclusions concerning the phenomenon. In particular, during 5 years (2006-2010), 39 events were identified as rogue all over the World Ocean. The inhomogeneous distribution of extreme events is visibly coupled with the ship traffic and mainly covers English-speaking territories, Figure 4. One of key results refer to distinguishing between deep and shallow events by means of modulation instability criterion [12]. It is shown, that the border between deep and shallow events pass through 20 meters, Figure 5. Based on this, deep (h > 20 m) and shallow (h <= 20 m) events are separated. Totally, in 2006-2010 the number of deep-water rogue waves exceeded twice the number of shallow events (26 [66.7%] versus 13 [33.3%] out of 39 classified events). Thus, more than 30% of rogue events are caused by mechanisms different from modulational instability.

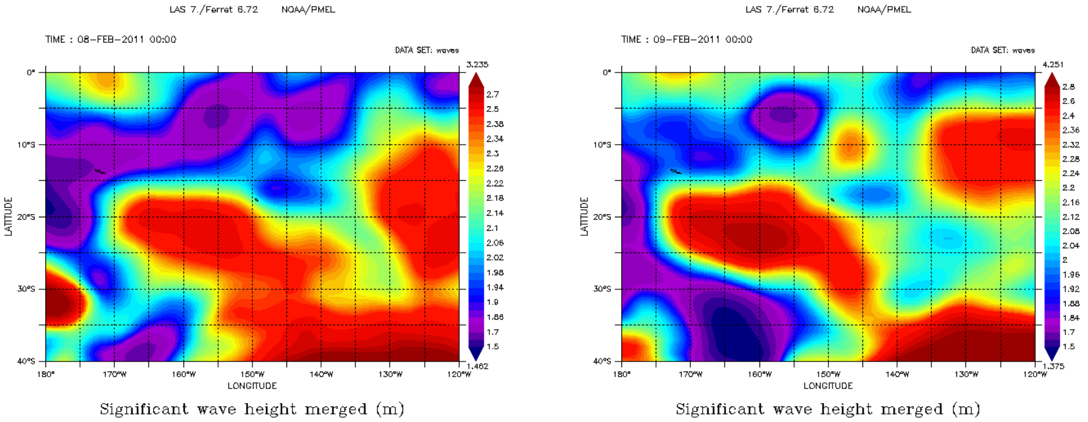

Figure 1. Altimeter significant wave height near of Rarotonga, Cook Islands on February 8-9, 2011 [5].

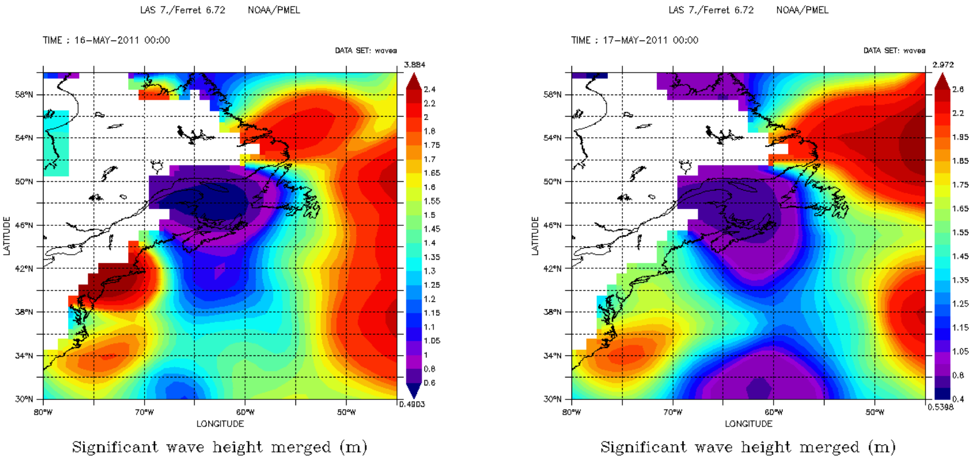

Figure 2. Altimeter significant wave height near Race Point, Cape Code, USA, on May 16-17, 2011 [5].

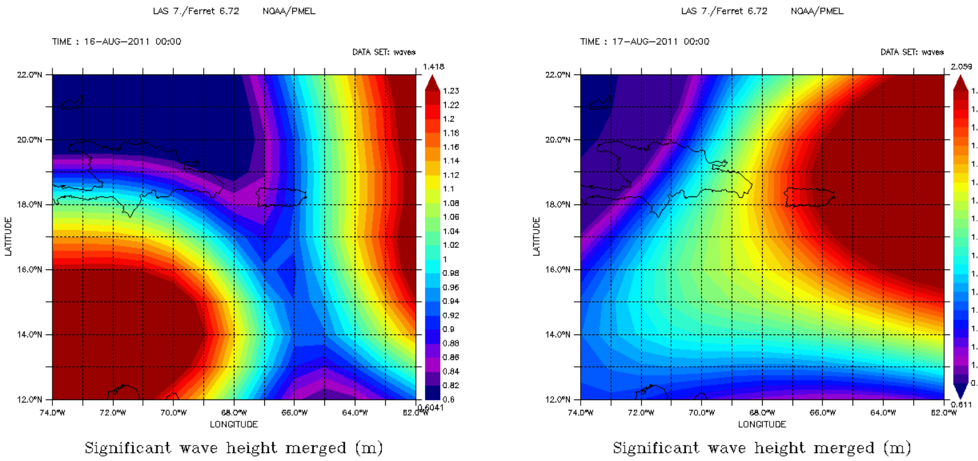

Figure 3. Altimeter significant wave height near Virgin Gorda, Virgin Islands, on August 16-17, 2011 [5].

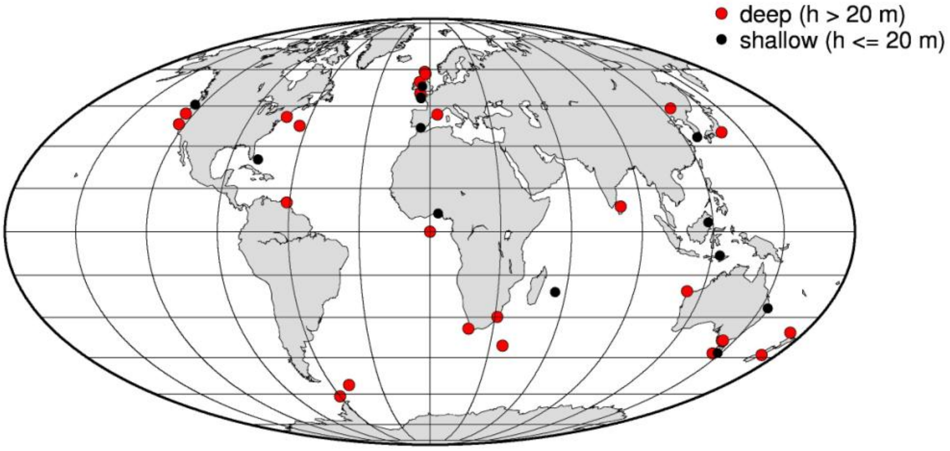

Figure 4. Rogue waves in the World Ocean in 2006-2010 years (only rogue events with known depth are marked); black and red circles correspond to shallow (water depth h <= 20 m) and deep events (h > 20 m), respectively.

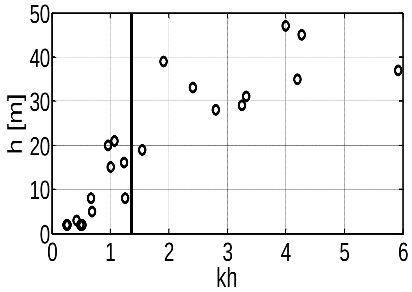

Figure 5. Distribution of rogue waves by applying modulation instability criterion with regard to water depth.

Another conclusion made in [12] is related to the number of waves during one rogue event. It was shown that the number of waves in rogue event increases with the decrease of the water depth. Figure 6 shows the distribution of number of waves in the rogue event for shallow (a) and deep (b) water conditions. It can be seen that the number of rogue events which contain a group of waves of abnormal height (phenomenon called "three sisters") is much larger for shallow (38%) than for deep (12%) water.

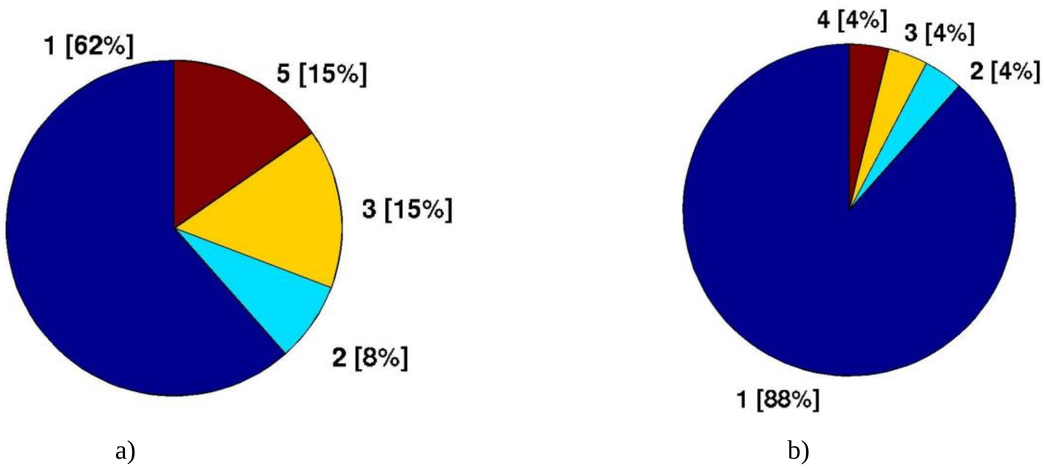

Figure 6. Number of waves in the rogue event: (a) shallow (h <=20 m) and (b) deep water (h > 20 m). Labels indicate number of waves, corresponding percentage is given in brackets.

4. Conclusions

Here we discuss the use of remote sensing techniques for identification and verification of rogue events and present the data of catalogue of rogue events collected from mass media sources and verified by altimeter imagery. These data allow to draw some conclusions of properties of rogue wave phenomenon. It is shown that the contribution of modulational instability mechanism in rogue wave formation for water depths below 20 m is highly unlikely. At the same time, the number of extreme waves in rogue event increases with the decrease of the water depth, so that the phenomenon called "three sisters" is more probable to occur in the shallow region.

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