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Editorial

Extreme Waves

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1. Introduction

The occurrence of exceptionally large waves in regions of high maritime traffic has severe consequences, ranging from complicating navigation routes to the loss of ships and human lives. This Special Issue on extreme waves compiled ten papers that discuss four broad topics of extreme wave research: storm waves, waves developed under hurricanes and cyclones, waves due to wave-current interaction, and rogue waves. The papers of the Special Issue used several approaches to study extreme waves: remote sensing (radar altimetry and SAR); in situ data; numerical wave modeling, and theoretical methods. The geographical focus was also broad, considering both global scales and regional studies (the Mediterranean Sea and the Agulhas Current region).

2. Extreme Waves and Wave-Current Interaction

Extreme sea states are likely to increase in the future due to climate change, as increases are predicted for both extreme waves, due to stronger cyclone activity [1], and currents, due to the acceleration of the global ocean circulation [2]. This makes the study of wave–current interaction and its role in extreme wave generation an urgent task.

The Agulhas current system is an ideal natural laboratory to study strong wave-current interaction and its impact on extreme waves. In [3] two different approaches of exploring this subject were applied to understand and learn more about the reasons that favor an increase of the wave height when strong currents are present. Based on significant wave height (Hs) composites using SAR data and modeled data, the Hs maxima values were found distributed in the Agulhas Current Retroflection (ACR). Benjamin–Feir index (BFI) composites, a parameter used to characterize the probability of occurrence of extreme waves, show the highest values in the ACR, with high values also observed in the southern border, as occurred with Hs. The results of this study indicate that there is a direct correlation among the Agulhas Current strength, Hs, and the BFI.

3. Rogue Waves

In the Eastern Mediterranean, there is a lack of scientific knowledge regarding sea state characteristics. Different statistical thresholds are examined in [4] or the identification of rogue waves, detecting 99 unique waves south of Israel. Analysis of the detected rogue waves reveals that the majority present a crest to trough symmetry. This finding calls for a re-evaluation of the crest amplitude being equal to or above 1.25 times the significant wave height threshold, which assumes rogue waves carry most of their energy in the crest.

Although rogue waves on the sea surface have been studied intensively, surprisingly, large motions in the interior of the oceans associated with internal waves have not been thoroughly considered. The relevance of rogue events in internal waves is analyzed in [5],

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the numerical robustness of triad rogue modes as well as the connection with the classical problem of Fermi–Pasta–Ulam–Tsingou recurrence is considered. They concluded that rogue waves in one set of triads provided a possible mechanism for significant energy transfer among modes of the internal wave spectrum, in addition to the other known theories, e.g., weak turbulence. Remarkably, Fermi–Pasta–Ulam–Tsingou recurrence types of growth and decay cycles arose, similar to those observed for surface gravity wave groups governed by the cubic nonlinear Schrödinger equation.

The correlation of rogue wave events with marine environmental factors is investigated in [6] in an attempt to validate the predictions of earlier theoretical and modeling analyses. A rogue wave event dataset is contrasted with a control, non-rogue dataset containing a total of nearly 510,000 hourly data segments of surface wave data. The analysis combined the wave records with surface current and wind data from state-of-the-art global coupled models. The study finds particular support for a causal connection between each of the environmental factors and the development of rogue waves. The results suggest that environmental conditions at specific sites, such as seasonal variations in the directional spreading and/or high surface current vorticity, may provide useful signals of greater rogue wave hazards.

The influence of computed wave spectra on statistical wave properties was studied in [7], having the Draupner rogue wave as a reference. This research explored the effects of the wave spectrum—computed using the Discrete Interaction Approximation (DIA) and the Webb–Resio–Tracy (WRT) methods—on statistical wave properties such as skewness and kurtosis in the context of large ocean waves. The results of the numerical simulations suggest that selecting a more computationally expensive WRT method does not affect the statistical values to a great extent. The most noticeable effect is due to the energy dissipation filter that is applied. It is concluded that selecting the WRT or the DIA algorithm for computing the wave spectrum does not lead to major differences in the statistical wave properties.

4. Extreme Waves and Cyclones

Cyclones have a strong effect on the mean sea state [8] and in extreme events [1,9]. In the North Atlantic, for example, very high waves are to be found in the storm track region of the basin [10,11] and the west coast of Europe is regularly exposed to huge swells generated by North Atlantic cyclones that cross the basin from west to east.

Extreme waves generated under cyclones using accurate numerical simulations are investigated in [12]. Tropical cyclones (TC) create a complex surface gravity wave field as a result of the inherently strong temporal and spatial gradients of the wind forcing. This complexity is a significant challenge to models. The study compiles accurate WW3 simulations of six major landfall TCs between 2011–2019. The analysis revealed a general tendency for the wave models to underestimate significant wave height (Hs) around the peak of the TC. Case studies of Hurricanes Sandy and Florence illustrate complex Hs bias patterns, likely resulting from various mechanisms including insufficient resolution, improper wind input and source term parameterization (e.g., drag coefficient), and omission of wave–current interactions. The study shows the challenge of simulating the spatial and temporal variability of TC generated wave fields and demonstrates the value of in situ validation data such as the North Atlantic buoy array.

TC-generated sea states using satellite altimetry data and several operational hindcasts: the US Army Corps of Engineers, National Oceanic and Atmospheric Administration's National Centers for Environmental Prediction Production Hindcast, and the Institut Français de Recherche pour l'exploitation de la Mer (Ifremer) are studied in [13]. This study finds that near the eye of TCs, there exists a pattern of model underestimation in the right sector and overestimation in the left and rear sectors. This pattern holds, albeit modulated, across various intensities, forward translation velocities, and radii of maximum winds; the exceptions being the most intense and smallest storms, where underestimation is more severe and expands to all sectors near the TC eye.

5. The Use of Satellite Altimetry Data and Extreme Waves

Satellite altimetry data have the significant advantage of great spatial coverage. However, many questions remain over the suitability of altimeter data for the representation of extreme sea states and applications in the coastal zone. The limitations of altimeter data to estimate coastal Hs extremes (<10 km from shore) using the European Space Agency Sea State Climate Change Initiative L2P altimeter data product (version 1.1) which consists of near-complete global coverage and a continuous record of 28 years is investigated by [14]. It is used here together with in situ data from moored wave buoys at six sites around the coast of the United States. The limitations of estimating extreme values based on satellite data were quantified and linked to several factors including the impact of data corruption nearshore, the influence of coastline morphology and local wave climate dynamics, and the spatial–temporal sampling achieved by altimeters. The factors combine to lead to considerable underestimation of estimated Hs 10 yr return levels. Sensitivity to these factors is evaluated at specific sites, leading to recommendations about the use of satellite data to estimate extremes and their temporal evolution in coastal environments.

6. Long-Term and Seasonal Trends in Global Wave Height Extremes

Trends in values of 100-year significant wave height are investigated in [15]. To this end, non-stationary extreme value analysis of 41 years (1979–2019) of global ERA5 (European Centre for Medium-Range Weather Forecasts Reanalysis) significant wave height data was undertaken. The investigation shows that there has been a statistically significant increase in the 100-year return value of Hs^{100} over large regions of the Southern Hemisphere. There have also been smaller decreases in Hs^{100} in the Northern Hemisphere, although the related trends are generally not statistically significant. The increases in the Southern Hemisphere are a result of an increase in either the frequency or intensity of winter storms, particularly in the Southern Ocean.

Mediterranean sea-states are studied in [16] to relate the probability of extreme events with different sea state conditions. The study is based on phase-resolving simulations of wave spectra obtained from a WaveWatch III hindcast, using a Higher Order Spectral Method. Statistics of the sea-surface elevation field were produced, calculating crest distributions and the probability of extreme events from the analysis of a long time series of the surface elevation. A good match was found between the distributions of the numerically simulated field and theory, namely Tayfun second- and third-order representations, in contrast with a significant underestimate given by the Rayleigh distribution. Extreme events were found to have an enhanced probability for high mean steepness seas and narrow spectra.

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