Shapes and Statistics of the Rogue Waves Generated by Chaotic Ocean Current

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ABSTRACT

In this study we discuss the shapes and statistics of the rogue (freak) waves emerging due to wave-current interactions. With this purpose, we use a simple governing equation which is a nonlinear Schrödinger equation (NLSE) extended by R. Smith (1976). This extended NLSE accounts for the effects of current gradient on the nonlinear dynamics of the ocean surface near blocking point. Using a split-step scheme we show that the extended NLSE of Smith is unstable against random chaotic perturbation in the current profile. Therefore the monochromatic wave field with unit amplitude turns into a chaotic sea state with many peaks. By comparing the numerical and analytical results, we show that rogue waves due to perturbations in the current profile are in the form of rational rogue wave solutions of the NLSE. We also discuss the effects of magnitude of the chaotic current profile perturbations on the statistics of the rogue wave generation at the ocean surface. The extension term in Smith’s extended NLSE causes phase shifts and it does not change the total energy level of the wave field. Using the methodology adopted in this study, the dynamics of rogue wave occurrence on the ocean surface due to blocking effect of currents can be studied. This enhances the safety of the offshore operations and ocean travel.

KEY WORDS: Rogue waves; nonlinear Schrödinger equation; wave-current interaction; chaotic perturbations.

INTRODUCTION

Rogue (freak) waves are the waves with a height more than 2-2.2 times the significant wave height in the ocean wave field. They present a danger to the safety of marine operations and life and their result can be catastrophic and costly (Kharif and Pelinovsky, 2003; Bayındır, 2015). The understanding of chaotic rogue wave dynamics is a must for the safety of the marine travel and the offshore operations in stormy conditions. There are few known mechanisms in ocean which cause rogue waves formation. These are focusing of the nonlinear wave interactions such as collusion of breathers, frequency modulated wave groups due to geometrical and dispersion effects, atmospheric forcing and wave-current interactions in strong currents.

In this paper we consider the generation of the rogue waves in the strong wave-current interactions regions such as the Agulhas current of the southwest Indian ocean or the Gulf Stream current in the Atlantic ocean (Kharif and Pelinovsky, 2003). With this motivation, we use a simple governing equation first proposed by Smith (1976) which is a nonlinear Schrödinger equation (NLSE). The extended NLSE of Smith accounts for the effects of current gradient on the dynamics of the ocean surface. Implementing a split-step numerical scheme we show that the extended NLSE of Smith is unstable against random chaotic perturbation in the current profile. Therefore the initial monochromatic wave field turns into a chaotic sea state with many apparent peaks at later times. We show that those rogue waves can be described by the rational rogue wave solutions of the NLSE. Additionally we discuss the effects of magnitude of the chaotic current profile perturbations on the statistics of the rogue wave generation. We show that extension term in Smith’s extended NLSE introduces phase shifts to the solutions and it does not alter the total energy of the wave field. Using the methodology discussed in this paper, the dynamics of rogue wave on the ocean surface due to blocking effect of currents can be analyzed which can be used for enhancing the safety of the maritime operations and ocean travel.

ROGUE WAVES IN A CHAOTIC WAVE-CURRENT FIELD

NLSE is widely used in many branches of the applied sciences and engineering. It describes various phenomena including but not limited to pulse propagation in optical fibers, Bose-Einstein condensation, quantum state of a physical system and quantum control just to name a few. It is also possible to model the dynamics of weakly nonlinear deep water ocean waves by the NLSE (Zakharov, 1968). In order to study various dispersion, focusing, nonlinearity and other effects, many modified and extended versions of the NLSE are proposed. In order to examine the effects of the ocean current gradient on the nonlinear wave field dynamics in the vicinity of the blocking point, Smith derived the extended NLSE equation (Smith, 1976; Kharif and Pelinovsky, 2003) in the form

\[ i\psi_t + \alpha \psi_{xx} + \beta |\psi|^2 \psi - \gamma x \frac{dU}{dx} \psi = 0 \]  

(1)

where \( x, t \) is the spatial and temporal variables, \( i \) denotes the imaginary number, \( \alpha, \beta, \gamma \) are constants, \( \psi \) is complex amplitude, \( U \) is the current...