Journal of
Applied & Computational Mathematics

Horikis, J Appl Computat Math 2014, 3:1
DOI: 10.4172/2168-9679.1000e137

Editorial Open Access

Rogue Waves: Extreme Waves of Water and Light

Theodoros P Horikis*

Department of Mathematics, University of Ioannina, Ioannina 45110, Greece

The purpose of this editorial is to introduce the reader to the concept of rogue waves, an extreme wave that can occur in many diverse physical systems ranging from deep water waves and liquid Helium to nonlinear optics and microwave cavities and even in finance. The interested readers are referred to [1-3] where parts of this editorial were taken from. For more detailed information on the mathematical developments of the subject, we refer the reader to a recent review [4]. *Rogue waves* (also known as freak waves, monster waves, killer waves, extreme waves, and abnormal waves) are ocean waves with heights up to thirty meters which have been common elements in stories from people working at sea, as well as in popular fiction. It is not hard to imagine why: being on a small boat in a stormy sea swell and suddenly encountering a wave maybe three times as high as the surrounding waves is a terrifying experience (Figure 1).

Figure 1: The Great Wave of Kanagawa by the Japanese artist Katsushika Hokusai. The Great Wave is considered one the most famous of all Japanese prints.

Figure 2: (Top): The Wilstar after being hit by a rogue wave in the Agulhas current outside South Africa in 1974. (Bottom): More recently, the Norwegian Dream suffered heavy damage while returning to New York from a cruise in 2005.

For centuries, seafarers have told tales of giant waves that can appear without warning on the high seas. These mountainous waves were said to be capable of destroying a vessel (Figure 2) or swallowing it beneath the surface, and then disappearing without the slightest trace. Until recently, these tales were thought to be mythical. In the mid-1990s, however, rogue waves proved very real when recorded for the first time by scientific measurements during an encounter at the *Draupner oil platform* in the North Sea (Figure 3). Although they are elusive and intrinsically difficult to monitor because of their fleeting existences, satellite surveillance has confirmed that rogue waves roam the open oceans, occasionally encountering a ship or sea platform, sometimes with devastating results. It is now believed that a number of infamous maritime disasters were caused by such encounters.

In oceanography, rogue waves are more precisely defined as waves whose height is more than twice the significant wave height, which is itself defined as the mean of the largest third of waves in a wave record. Therefore rogue waves are not necessarily the biggest waves found at sea; they are, rather, surprisingly large waves for a given sea state. The conditions that cause such waves to grow enormously in size are not well understood to this day. Rogue waves are not tsunamis, which are set in motion by earthquakes and travel at high speed, building up as they approach the shore. They seem to occur in deep water or where a number of physical factors such as strong winds and fast currents converge. This has a focusing effect, which can cause a number of waves to join together.

The rarity of these events in the ocean and obvious difficulties in

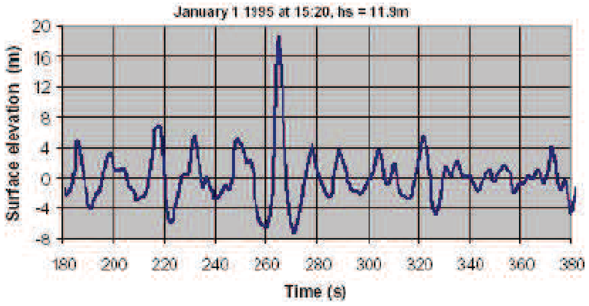

Figure 3: The Draupner wave, a single giant wave measured on New Year's Day 1995, finally confirmed the existence of rogue waves.

***Corresponding author:** Theodoros P. Horikis, Department of Mathematics, University of Ioannina, Ioannina 45110, Greece, Tel: +30 26510 08268; Fax: +30 26510 08201; E-mail: horikis@uoi.gr

Received January 13, 2014; **Accepted** January 16, 2014; **Published** January 23, 2014

Citation: Horikis TP (2014) Rogue Waves: Extreme Waves of Water and Light. J Appl Computat Math 3: e137. doi:10.4172/2168-9679.1000e137

their systematic characterization restrict the development of theoretical models of the rogue wave generation [5]. Currently four to five competing hypotheses of rogue waves are considered [6,7]. Among them is the nonlinear mechanism of the wave-wave interactions, such as modulation instability. However, no direct evidence in support of this hypothesis has yet been found. Further progress in the rogue wave studies can be made by reinforcing that they constitute a new class of wave phenomena observed in different physics contexts. An ultimate goal of the research into the physics of rogue waves is to establish mechanisms responsible for their generation in order to (a) reliably predict their probability (in engineering applications), (b) generate and control such waves (e.g., in optical fibers), and (c) to avoid or suppress them (in the ocean).

The remaining question is how to model these nonlinear properties. While ocean dynamics in general can be determined from the Navier-Stokes equations, these are extremely complex to solve, but simplified nonlinear wave models based on these equations can be derived. In particular, nonlinear water surface waves can, under suitable conditions, be modeled by a nonlinear Schrödinger equation, giving the evolution of the wave in terms of its amplitude and phase. In this case, a confining potential is created by the wave itself, for which the potential depth depends on the height of the wave. This confinement, or self-interaction, competes with the regular dispersion of the wave, a competition that makes formation of stable waves called solitons possible. This gives rise to some of the remarkable properties of such nonlinear ocean waves.

Interestingly enough, the nonlinear Schrodinger equation not only gives a suitable description of rogue water waves [5,8-11], it is also the standard equation for treating propagation of light pulses in nonlinear optical fibers [12-14], as well as for a multitude of other phenomena, ranging from the dynamics of Bose-Einstein condensates [15] to relativistic laser-plasma interactions [16]. In optical fibers, the material properties are tuned to respond to the intensity of the incoming light to create a self focusing effect, balancing the dispersive spreading of the light wave. This gives rise to optical solitons, light pulses that can cross large distances in a fiber without information loss. Since these light waves are described by the same type of equation as rogue waves, the use of optical systems as analogues of nonlinear water waves has been suggested. Indeed, Solli et al. [17] used this principle to investigate the occurrence of rogue waves in optical systems. They found that initially smooth pulses developed rogue waves due to optical noise, in line with what is to be expected from real rogue waves formed in a random sea swell. In particular, they observed extreme soliton-like pulses that are the optical equivalent of oceanic rogue waves. These rare optical events possess the hallmark phenomenological features of oceanic rogue waves; they are extremely large and seemingly unpredictable, follow unusual L-shaped statistics, occur in a nonlinear medium, and are broadband and temporally steep compared with typical events. On a physical level, the similarities also abound, with modulation instability, solitons, frequency downshifting and higher-order dispersion as striking points of connection. Although the parameters that characterize this optical system are of course very different from those describing waves on the open ocean, the rogue waves generated in the two cases bear some remarkable similarities.

Mathematically speaking, the study of rogue waves in optics has been focused on the so-called Peregrine soliton [18]. Solitons are localized waves arising from nonlinear and dispersive interactions, and are central objects of nonlinear science. The Peregrine soliton is a localized nonlinear structure predicted to exist over 25 years ago, but not so far experimentally observed in any physical system. It is of fundamental significance because it is localized in both time and space, and because it defines the limit of a wide class of solutions to the nonlinear Schrodinger equation [19].

More accurate models, extensions of the single nonlinear Schrodinger equation, have been developed in the literature, such as the Dysthe model (taking into account that the waves may have a broad spectrum) [20], or interacting nonlinear wave models, for which one has a set of coupled nonlinear Schrodinger equations [21]. Such models lend further support to the accuracy of these simple models concerning the evolution of ocean waves into giant waves. In particular, the coupling of two different wave systems shows behavior very reminiscent of a real stormy sea. Thus these simplistic nonlinear descriptions provide important insights into rogue wave formation. However, while the above models show how a given wave system evolves, they do not tell us the suitable initial conditions for such waves to grow from. Moreover, in reality, the state of the sea in which rogue waves form is often highly erratic and turbulent [22-24]. For predictive purposes, such knowledge is of utmost importance, and could help improve our understanding of rogue waves. For further and more detailed information, we refer the interested reader to a recent review.

References

1. Rogue wave, Wikipedia, the free encyclopedia.
2. A 'Rogue Wave' is large, unexpected, and dangerous. NOAA.
3. Monster Rogue Waves. Damn Interesting.
4. Onoratoa M, Residoric S, Bortolozzoc U, Montinad A, Arecchi FT (2013) Rogue waves and their generating mechanisms in different physical contexts. Phys. Reports 528: 47-89.
5. Shats M, Punzmann H, Xia H (2010) Capillary rogue waves. Phys Rev Lett 104.
6. Slunyaev A, Kharif C, Pelinovsky E (2009) Rogue Waves in the Ocean. Advances in Geophysical and Environmental Mechanics and Mathematics, Spinger.
7. Slunyaev A, Didenkulova I, Pelinovsky E (2011) Rogue waters. Contemp. Physics 52: 571-590.
8. Dysthe K, Krogstad HE, Muller P (2008) Oceanic rogue waves. Annu Rev Fluid Mech 40: 287-310.
9. Muller P, Garrett C, Osborne A (2005) Rogue waves. Oceanography 18: 66-75.
10. Chabchoub A, Hoffmann NP, Akhmediev N (2011) Rogue wave observation in a water wave tank. Phys Rev Lett 106: 204502.
11. Grimshaw R, Pelinovsky E, Taipova T, Sergeeva A (2010) Rogue internal waves in the ocean: Long wave model. Eur Phys J Special Topics 185: 195-208.
12. Pisarchik AN, Jaimes-Re´ategui R, Sevilla-Escoboza R, Huerta-Cuellar G, Taki M (2011) Rogue waves in a multi stable system. Phys Rev Lett 107: 274101.
13. Bonatto C, Jaimes-Reátegui, Barland S, Giudici M, Masoller C, et al, (2011) Deterministic optical rogue waves. Phys Rev Lett 107.
14. Zaviyalov A, Egorov O, Iliew R, Lederer F (2012) Rogue waves in mode-locked fiber lasers. Phys Rev A 85: 013828.
15. Bludov YV, Konotop VV, Akhmediev N (2009) Matter rogue waves. Phys Rev A 80: 033610.
16. Marklund M, Stenflo L (2009) Exciting rogue waves. Physics 2: 86.
17. Solli DR, Ropers C, Koonath P, Jalali B (2007) Optical rogue waves. Nature Letters 450: 1054-1058.
18. Peregrine DH (1983) Water waves, nonlinear Schrodinger equations and their solutions. J Austral Math Soc Ser B 25: 16-43.
19. Kibler B, Fatome J, Finot C, Millot G, Dias F, et al, (2010) The Peregrine soliton in nonlinear fibre optics. Nature Physics 6: 790-795.
20. Dysthe KB (1979) Note on a modification to the nonlinear Schrodinger equation for application to deep water waves. Proc R Soc Lond A 369: 105-114.

21. Onorato M, Osborne AR, Serio M (2006) Modulational instability in crossing sea states: A possible mechanism for the formation of freak waves. Phys Rev Lett 96: 014503.
22. Onorato M, Proment D (2011) Triggering rogue waves in opposing currents. Phys Rev Lett 107: 184502.
23. Onorato M, Osborne AR, Serio M, Bertone S (2001) Freak waves in random oceanic sea states. Phys Rev Lett 86: 5831-5834.
24. Ruban VP (2007) Nonlinear stage of the Benjamin- Feir instability: Three-dimensional coherent structures and rogue waves. Phys Rev Lett 99: 044502.