NEWS & VIEWS

PHOTONICS

Rogue waves surface in light

Dong-Il Yeom and Benjamin J. Eggleton

How do the freak waves that haunt seafarers' nightmares arise? We don't know, is the short answer — but the discovery of a similar phenomenon in optical waves might assist in getting to the bottom of the mystery.

Oceanic rogue waves — monstrous sea waves that form spontaneously and can reach up to 30 metres in height[1,2] — have been held responsible for marine misfortunes ranging from the sudden sinking of seagoing ships to damage to oil platforms. They are not just the stuff of maritime folklore (Fig. 1): recent satellite data have revealed that extraordinarily large waves are in fact far more frequent than statistics would predict. The phenomenon remains poorly understood, and the difficulty of studying rogue waves under controlled conditions makes investigation highly problematic.

Until now, perhaps. On page 1054 of this issue[3], Solli *et al.* detail a series of experiments in a 'nonlinear' optical medium — a photonic crystal fibre — that could enhance our understanding of the physics underlying rogue-wave formation and propagation. The authors claim to have found an optical counterpart of the hydrodynamic rogue wave. It occurs in a system that can be studied in a controlled way using off-the-shelf components, and that delivers results that are readily comparable with well-established theoretical and numerical models.

Solli and colleagues' essential argument is that rogue waves, whether oceanic or optical, are associated with solitons. Generally speaking, solitons are particularly robust solitary wave packets that propagate in a dispersive medium (one in which a wave's speed depends on its wavelength) without becoming distorted. But in the 'noisy' environment of the ocean — where wave noise can result from any number of factors, such as a change in wind direction — or in a specially designed noisy optical system, solitons can also be generated through a process known as modulation instability. In particular, the authors show how this noise seeding, combined with highly nonlinear propagation through the optical fibre, causes the generation of occasional solitons that are very different from normal. These solitons appear as a dramatic intensity spike on top of a low-amplitude background — in other words, as rogue waves.

The authors[3] exploit a nonlinear phenomenon in an optical fibre, known as supercontinuum generation[4], to excite and then study optical rogue waves. In supercontinuum generation, which is a well-understood phenomenon[5], light initially in a narrow band of frequencies is dramatically converted into ultra-broadband light. The effect has been used for applications in many diverse fields — notably in laser-frequency metrology[6], for which half of the 2005 Nobel physics prize was awarded. The noise properties of the broadband spectra have also been investigated in detail, as they are pivotal in assessing potential applications. Research was initially concentrated on the mechanisms by which noise from very short input pulses is transferred to the output spectrum, but it has since spread to cover the full range of possible inputs, from femtosecond pulses right up to continuous light waves[7].

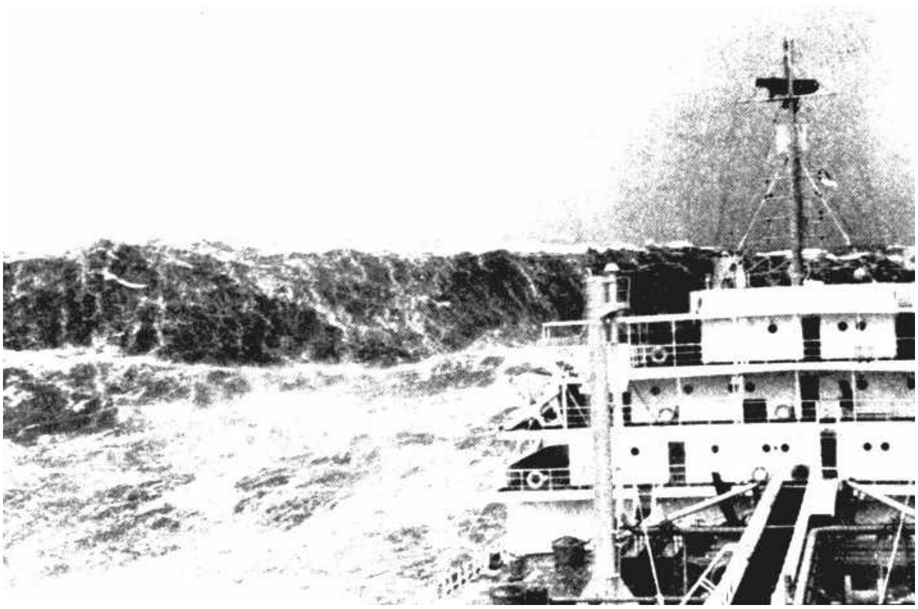
NOAA/NWS

Figure 1 | Science fact. **Oceanic rogue waves are understandably rarely caught on camera. This instance, published in the Fall 1993 issue of *Mariners Weather Log*, was captured around the '100-fathom curve', where the continental shelf drops into the Atlantic abyssal plain in the Bay of Biscay — a known hotspot for extreme waves.**

Until now, however, optical studies have measured the stability of a supercontinuum only indirectly, by measuring noise at radio frequencies or through averaged optical spectra. Solli and colleagues' method allows the statistics of the supercontinuum output spectra to be measured directly; the statistics measured are the distribution of single-pulse properties from a number of pulse trains. The authors use a novel wavelength-to-time transformation technique that temporally stretches a large number of ultrashort pulses by passing them through the dispersive medium. In this way, many random events generated by trains of regular input waves to which noise is added can be measured as they happen (Fig. 2a, overleaf).

The authors could thus show directly that supercontinuum generation intrinsically creates a small number of 'rogue' waves of far greater amplitude than the norm. These events are associated with certain solitons shifting towards longer wavelengths, and the effect appears distinctly in the spectrum as the pulse propagates along the fibre (Fig. 2b). The statistics of these optical rogue solitons are similar to those of oceanic rogue waves: plotting a histogram of the probability of encountering waves of different amplitudes results in a characteristic L-shape, with more high-amplitude events than would be expected

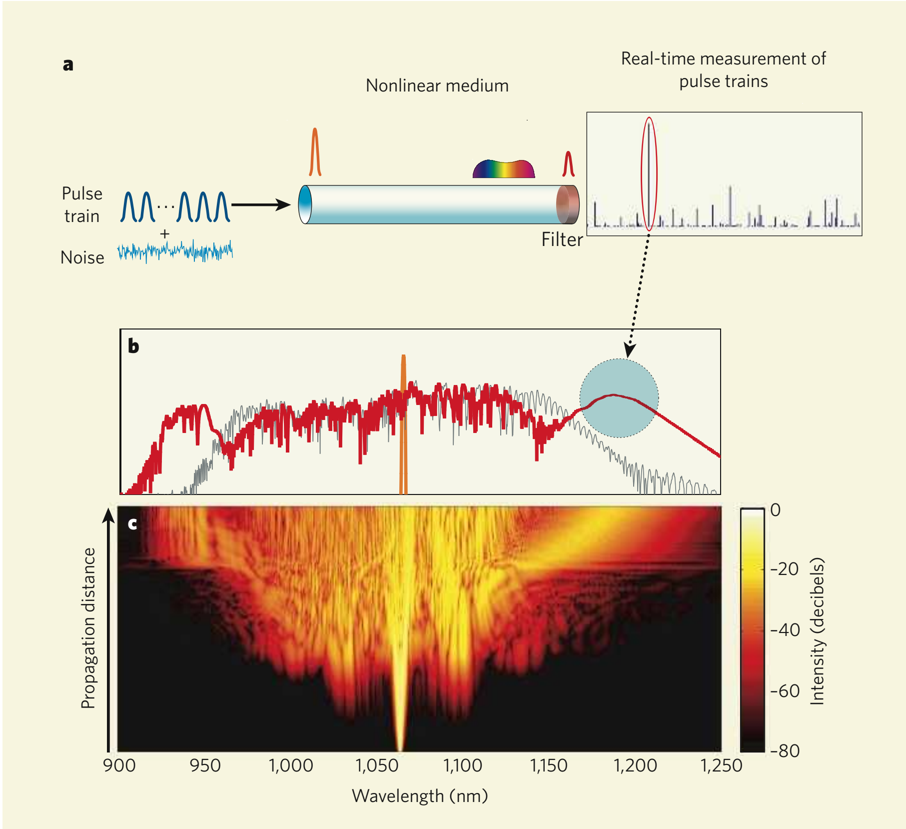

Figure 2 | Rogue generation. a, In Solli and colleagues' optical rogue-wave production[3], noise is added to a smooth wave pulse that is sent through a nonlinear medium (a photonic crystal fibre). In a process known as supercontinuum generation, this narrowband pulse is increased hugely in bandwidth. After spectral filtering, a small number of 'rogue wave' events of statistically abnormal amplitude are found in the real-time measurement of pulse trains. **b,** By following the evolution of supercontinuum generation along the propagation distance in the optical fibre, the authors show that the rogue events correspond to solitary wave packets (solitons) that are shifted to long wavelengths. The orange line represents the spectrum of the (narrowband) input pulse, the grey line that of a normal broadband output pulse, and the red line that of a rogue output pulse. **c,** From bottom to top, the evolution of the spectrum of rogue-wave intensity as the light propagates along the nonlinear medium.

from a conventional gaussian distribution. In addition, optical and oceanic waves both undergo dramatic fluctuations in intensity during their evolution.

Solli *et al.*[3] find supporting evidence for the soliton interpretation from numerical simulations, using the nonlinear Schrödinger equation — a way of representing wave propagation in a medium such as an optical fibre — to model supercontinuum generation. On the strength of these simulations, the authors propose an intimate connection between the initial amplification of input noise and the generation of rogue solitons.

So how do these optical findings help us to understand the generation of rogue ocean waves? Clearly, the noise and propagation environments are hardly identical. On the other hand, nonlinear propagation in optical systems is increasingly giving wider insight into areas as disparate as superfluidity and the science of self-similarity[8,9]. The direct experimental access to the statistics of optical rogue solitons, as well as the ease of 'managing' supercontinuum generation by modifying the optical-fibre geometry[10,11], means that rogue-wave physics is likely to join this list. The next intriguing stage will be to determine the precise degree to which the ideas elucidated by Solli *et al.*[3] transfer to the oceanic context. ■

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50 & 100 YEARS AGO

NATURE

50 YEARS AGO

"Scientists in Society To-day", proposal of a toast of the Royal Society by the Right Hon. The Viscount Hailsham Q.C.

To-night I can be as bold as brass. Although not a scientist, I am at least an 'egghead' by conviction and, I hope, by practice, and I am addressing a society of scientists who are also, always by achievement and almost by definition, 'eggheads'. It is time we got together. 'Eggheads' of the world, unite! We have nothing to lose but our brains. A country neglects its 'eggheads' at its peril. For it is the 'egghead' who is the greatest realist. It is the 'egghead' who invents the *Sputnik*, not the captain of football, nor the winner of the sword of honour, nor the president of the Junior Common Room ... It is a formidable indictment of Western civilization and democracy that 'eggheadedness' is not valued at its proper worth.

From *Nature* 14 December 1957.

100 YEARS AGO

A telegram from Largs states that Lord Kelvin has not been well for more than a fortnight, and has been confined to his bed. His condition on Tuesday night had improved. [But worse news was to follow in the *Nature* issue of 19 December 1907, as will be reported in 100 Years Ago next week.]

ALSO:

A proposal made to the Public Control Committee of the London County Council by Signor D. Maggiora to apply the process of discharging cannon of special construction, known in Austria as weather shooting, "to prevent the formation of fog or to disperse it in the case it is already formed, and also to disperse and destroy all clouds, and to prevent rain, hailstorms, lightning, and thunder," has been under the consideration of the Council. It was referred to the director of the Meteorological Office for report ... As might be expected, Dr. Shaw's report ... is entirely unfavourable.

From *Nature* 12 December 1907.