Waves, rogue waves,

Marc Hill/Apex News and Picture Agency/Alamy

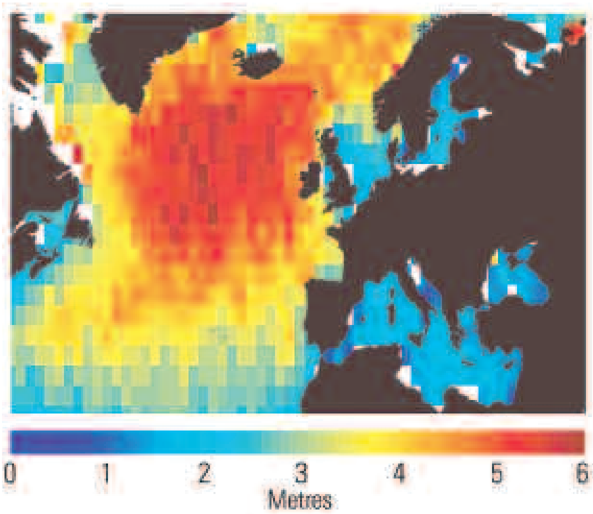
Satellite technology and clever maths can tell us how often to expect rough seas – but they can't yet predict freak waves. Peter Challenor explains.

In 1978, the year I joined NERC, the QE2 encountered a severe storm in the North Atlantic. One wave was so high it broke the bridge windows. Had she encountered the 50-year storm? Since then, there have been a series of similar incidents. The QE2 herself was damaged again in 1995, by a wave 29m high. So how many 50-year storms have there been? How are the individual waves that caused the damage formed? How common are they?

Wind-driven waves aren't as powerful as the tsunamis we've heard so much about recently, but they are still damaging. In 1998 the marine insurance industry lost $2.65 billion due to bad weather – about a third of the total losses for the year. And between January 1995 and April 1998, 1120 ships were lost in storms at sea. You may remember the Spanish trawler in difficulties west of Scotland in mid-January. If we can predict the waves that ships and offshore structures are likely to encounter, then better design could reduce these losses, and save lives.

Recording wave heights isn't easy though. Until the 1950s, we relied on mariners making visual estimates from ships. Waves on the sea surface are essentially random. This means that we have to use statistics to describe them. When measuring waves, we use the roughness of the sea surface to describe

Average wave height January 1985-97



the overall wave field. The measurement used is the significant wave height (for the mathematically inclined this is defined as four times the standard deviation of the sea surface elevation). This corresponds reasonably well to the wave height a trained observer can estimate.

In the 1950s the National Institute for Oceanography at Wormley (now part of the Southampton Oceanography Centre) invented the shipborne wave recorder. The instrument recorded sea surface height on a paper chart, which was analysed by hand. Shipborne wave recorders let us measure waves over long timescales, and routine measurements started on light vessels and weather ships around the UK in the mid 1960s. Today, data buoys measure waves around the coasts of Europe, North America and Japan. But until recently, away from these coasts, visual observations from merchant ships remained our only information. And away from the shipping lanes there were no data at all. Now, satellites have changed this. For the last decade or so, radar altimeters and synthetic aperture radars (SAR) have provided global coverage, although the spatial resolution is less than ideal.

The standard way of expressing extreme environmental conditions, including sea states, is in terms of how often they are likely to return. A 50-year return value is the significant wave height that is exceeded, on average, every 50 years. This doesn't mean that exceptionally rough seas are separated by 50 year periods. It is possible, but unlikely, that extremes could follow each other in successive years. There is a 67% chance that the 50 year significant wave height will be exceeded in any 50 year period (imagine the chance of getting a 50 in 50 throws of a 50-sided die). When describing unusually rough seas, we normally work with 50 or 100 year return values, although when planning coastal defences, sea levels are worked out for a 1,000 or even 10,000 year return value. The easy way to estimate a 100 year return value would be to observe wave heights for 100,000 years and find the value that was exceeded 1000 times. Unfortunately, we cannot get data sets that long, so we have to resort to some clever statistics – the statistics of extremes. These let us extrapolate our data and allow us to estimate the associated uncertainty. Recently we have built up data sets long enough to let us apply extreme statistics to satellite observations.

By their very nature, rogue waves are rare

So far, I've covered extreme waves or sea states – high values of the significant wave height or 'roughness'. To get an estimate of the highest single wave we are likely to see in a certain length of time we need to convert the 'roughness' into a probability distribution for individual waves. Under the classical theory of random waves, the highest wave in three hours should, on average, be about twice the significant wave height. Lately there has been much discussion in the scientific and popular press about so-called freak or rogue waves. These are individual waves that are much higher than classical theory predicts. In the past when mariners reported very large waves we tended to assume they were unlucky or exaggerating. New mathematical solutions from the physics of waves confirm waves can be much higher than we thought. But these solutions don't tell us how likely the monster waves are.

By their very nature, rogue waves are rare. We need many years of data to search for them, calculate their frequency and understand the conditions in which they are likely to occur. Unfortunately, most wave buoys analyse the data on board and do not transmit raw data, making it impossible to see freak waves. Similarly, the radar altimeter data from satellites cannot observe rogue waves directly. Researchers analysing satellite SAR data have claimed a larger number of high waves than would have been expected from the classical theory. However, these results are controversial as they rely on uncertain assumptions about the radar imaging mechanism. The question is; can we find such waves in real life? On 1 January 1995 a laser wave measurer on the Draupner oilrig in the North Sea measured a single wave 26m high when the surrounding waves were 12m. So it seems we may indeed get freak or rogue waves in nature, but it is still possible that we were just lucky (or unlucky depending on your point of view) and measured a very rare event.

Rogue waves remain an enigma. We know that they are a solution to our hydrodynamic equations but as yet we have no theory that combines the random nature of the sea surface with the hydrodynamics. Without such a theory, we need more data. But to look at rare events we need vast quantities of data – it could take a long time to produce enough to give unequivocal results.

and statistics

*Peter Challenor is an oceanographer at the Southampton Oceanography Centre, Empress Dock, Southampton, Hants SO14 3ZH.
Tel: 023-80596413, email: P.Challenor@soc.soton.ac.uk*