Monster Rogue Waves
Written by Greg Bjerg on October 28th, 2006 at 2:51 am
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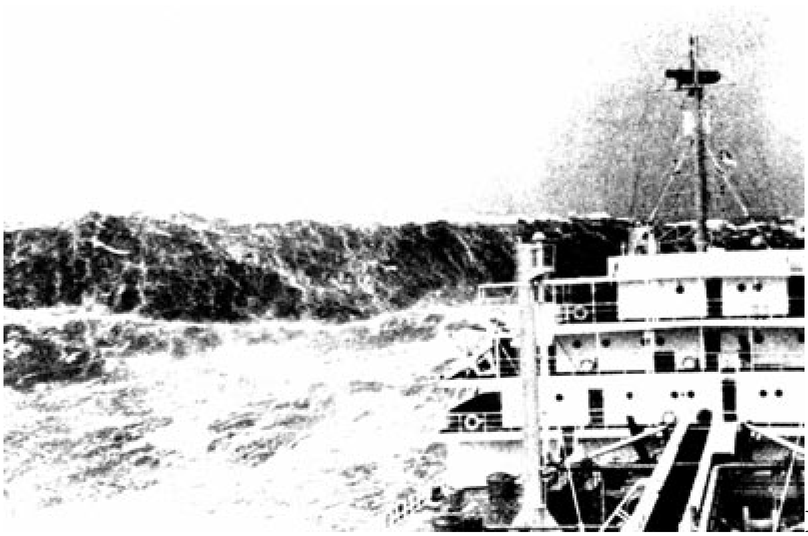
Executive summary: rogue waves (>15m high) turn out to be not as rare as thought before, especially in North Atlantic and off the Namibia coast (both known ship graveyards). "During a three-week study in 2001, radar scanning detected ten monster waves in a 1.5 million square kilometer area."


Giant waves breaking on the deck of the oil freighter Esso Languedoc. For centuries sailors have been telling stories of encountering monstrous ocean waves which tower over one hundred feet in the air and toss ships about like corks. Historically oceanographers have discounted these reports as tall tales– the embellished stories of mariners with too much time at sea. But in the last eleven years scientists have discovered strong evidence indicating that such massive rogue waves do exist. The phenomenon has become the subject of recent scientific study, but their origin remains a mystery of the deep.

About one ship is lost every week in the world's oceans, mostly due to poor seamanship or severe weather. But it now seems likely that at least a small percentage of sea disappearances are due to encounters with these destructive waves. Over the years experienced captains have made very credible reports of meeting behemoth waves which appear spontaneously, cause extensive damage to their ships, and shrug back into the sea just as mysteriously as they had appeared. One account describes the appearance of a giant wave trough which onlookers likened to a "hole in the sea", followed by a twelve-story-tall "wall of water." To further compound the mystery, some such waves have been said to appear mid-ocean, and often in calm weather.

On the open sea, waves can commonly reach seven meters in height; or even up to fifteen in extreme weather. In contrast, some reported rogue waves have exceeded thirty meters in height. Curiously, rogue waves are often seen traveling against the prevailing current and wave directions; and unlike a tsunami, rogue waves are localized and very short-lived. Most modern merchant vessels are designed to withstand about fifteen tons of pressure per square meter, but these unusual waves exert a pressure of about one hundred tons per square meter. Needless to say, a rogue wave means big trouble for any ship it meets.

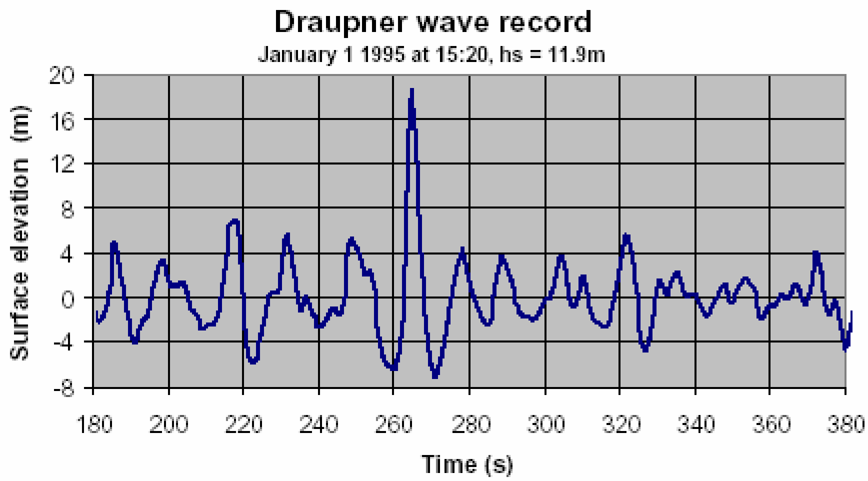


Encounters with rogue waves have been rare but memorable. In 1933 in the North Pacific, the US Navy transport *USS Ramapo* triangulated a rogue wave at thirty-four meters in height. In 1942, the *RMS Queen Mary* was transporting 15,000 US troops to Europe when it was hit by a twenty-three meter wave and nearly capsized. The giant vessel listed by about 52 degrees due to the impact, after which it slowly righted itself.

In 1978, the 37,000-ton *MS Munchen* radioed a garbled distress call from the mid-Atlantic. When rescuers arrived, they found only "a few bits of wreckage," including an unlaunched lifeboat with one of its attachment pins "twisted as though hit by an extreme force." It is now believed that a rogue wave hit the ship, causing it to capsize and sink. No survivors were ever found.

In 1996, the *Queen Elizabeth 2* encountered a rogue wave of twenty-nine meters, which the Captain said "came out of the darkness" and "looked like the White Cliffs of Dover." London newspapers said that the captain situated the vessel to "surf" the wave to avoid being sunk.

Despite these and other encounters with rogue waves, scientists long rejected such claims as unlikely. Anecdotal evidence is often unreliable, so researchers used computer modelling to predict the likelihood of such massive waves. Oceanographers' findings indicated that waves higher than fifteen meters were probably very rare events, occurring perhaps once in 10,000 years. That all changed in 1995 when a freak wave hit the Draupner North Sea oil platform. The oil rig swayed a little, suffering minor damage, but its onboard measuring equipment successfully recorded the wave height at nineteen meters.



More recently, satellite photos and radar imagery have documented the existence of numerous rogue waves, and it turns out that they are far more common than previously thought. During a three-week study in 2001, radar scanning detected ten monster waves in a 1.5 million square kilometer area. Satellites and direct observations have also established that rogue waves can happen anywhere, but they are most numerous in the North Atlantic and off the western shore of South Africa. In spite of their frequency, monster waves rarely meet with sea vessels because they are so short-lived.

The cause of rogue waves is still an area of active research. One theory under investigation cites "constructive interference," which is a result of several smaller waves overlapping in phase, combining to produce one massive wave. Another working hypothesis is based on the "non-linear Schrödinger effect," in which energy is "soaked up" from neighboring waves to create a monster wave. Still other researchers are looking into the possibility that wave energy is being focused by the surrounding environments, or that wind action on the surface is amplifying existing effects.

The phenomenon of freak waves is still a matter of active research, so it is too early to say clearly what the most common causes are or whether they vary from place to place. The areas of highest predictable risk appear to be where a strong current runs counter to the primary direction of travel of the waves; the area near Cape Agulhas off the southern tip of Africa is one such area. However, since this thesis does not explain the existence of all waves that have been detected, several different mechanisms are likely, with localised variation. Suggested mechanisms for freak waves include the following:

- Diffractive focusing by, perhaps, coast shape or seabed shape. In this theory, several smaller wave trains meet in phase. Their crest heights combine to create a freak wave.[5]
- Focusing by currents — Storm forced waves are driven into an opposing current. This results in shortening of wavelength, causing shoaling (i.e., increase in wave height), and oncoming wave trains to compress together into a rogue wave.[5]
- Nonlinear effects — It seems possible to have a freak wave occur by natural, nonlinear processes from a random background of smaller waves.[6] In such a case, it is hypothesised, an unusual, unstable wave type may form which 'sucks'

energy from other waves, growing to a near-vertical monster itself, before becoming too unstable and collapsing shortly after. One simple model for this is a wave equation known as the nonlinear Schrödinger equation (NLS), in which a normal and perfectly accountable (by the standard linear model) wave begins to 'soak' energy from the waves immediately fore and aft, reducing them to minor ripples compared to other waves. Such a monster, and the abyssal trough commonly seen before and after it, may last only for some minutes before either breaking, or reducing in size again. The NLS is only valid in deep water conditions, and in shallow water an alternative such as the Boussinesq equation is used.

- Normal part of the wave spectrum — Rogue waves are not freaks at all but are part of normal wave generation process, albeit a rare extremity.[5]
- Wind waves — While it is unlikely that wind alone can generate a rogue wave, its effect combined with other mechanisms may provide a fuller explanation of freak wave phenomena. As wind blows over the ocean, energy is transferred to the sea surface. Phillips[7] and Miles[8] provide some insight into the problem, though it still remains a tricky one.

The spatio-temporal focusing seen in the NLS equation can also occur when the nonlinearity is removed. In this case, focusing is primarily due to different waves coming into phase, rather than any energy transfer processes. Further analysis of rogue waves using a fully nonlinear model by R.H. Gibbs (2005) brings this mode into question, as it is shown that a typical wavegroup focuses in such a way as to produce a significant wall of water, at the cost of a reduced height.

There are three categories of freak waves:

- "Walls of water" travelling up to 10 km (6.2 mi) through the ocean
- "Three Sisters", groups of three waves[9]
- Single, giant storm waves, building up to fourfold the storm's waves height and collapsing after some seconds[10]

A comprehensive paper describing and illustrating the ways that freak waves could form, complete with layman descriptions, photos and animations, can be found here.

A research group at the Umeå University, Sweden in August 2006 showed that normal stochastic wind driven waves can suddenly give rise to monster waves. The nonlinear evolution of the instabilities was investigated by means of direct simulations of the time-dependent system of nonlinear equations.[11]

Science is necessarily skeptical of things which are beyond our observation, but now that rogue waves are a measurable phenomenon they have been officially upgraded from legend to reality. This recent finding is very telling about how little we really know about our world's oceans, and how many secrets the sea must still hold.

Further Reading:
National Oceanic and Atmospheric Administration (NOAA) Rogue Wave Web Site
BBC Science Web Site on Rogue Waves
University of Oxford report on Draupner Wave event (PDF)
More info on rogue waves, including images and animations

Ship-sinking monster waves revealed by ESA satellites

Rare photo of a rogue wave

21 July 2004

Once dismissed as a nautical myth, freakish ocean waves that rise as tall as ten-storey apartment blocks have been accepted as a leading cause of large ship sinkings. Results from ESA's ERS satellites helped establish the widespread existence of these 'rogue' waves and are now being used to study their origins.

Severe weather has sunk more than 200 supertankers and container ships exceeding 200 metres in length during the last two decades. Rogue waves are believed to be the major cause in many such cases.

Mariners who survived similar encounters have had remarkable stories to tell. In February 1995 the cruiser liner Queen Elizabeth II met a 29-metre high rogue wave during a hurricane in the North Atlantic that Captain Ronald Warwick described as "a great wall of water… it looked as if we were going into the White Cliffs of Dover."

And within the week between February and March 2001 two hardened tourist cruisers – the Bremen and the Caledonian Star – had their bridge windows smashed by 30-metre rogue waves in the South Atlantic, the former ship left drifting without navigation or propulsion for a period of two hours.

Damage done by a rogue wave

"The incidents occurred less than a thousand kilometres apart from each other," said Wolfgang Rosenthal - Senior Scientist with the GKSS Forschungszentrum GmbH research centre, located in Geesthacht in Germany - who has studied rogue waves for years. "All the electronics were switched off on the Bremen as they drifted parallel to the waves, and until they were turned on again the crew were thinking it could have been their last day alive.

"The same phenomenon could have sunk many less lucky vessels: two large ships sink every week on average, but the cause is never studied to the same detail as an air crash. It simply gets put down to 'bad weather'."

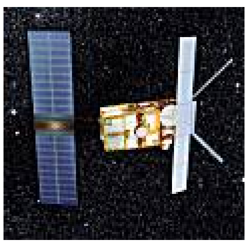
Offshore platforms have also been struck: on 1 January 1995 the Draupner oil rig in the North Sea was hit by a wave whose height was measured by an onboard laser device at 26 metres, with the highest waves around it reaching 12 metres.

Giant wave in Bay of Biscay

Objective radar evidence from this and other platforms – radar data from the North Sea's Goma oilfield recorded 466 rogue wave encounters in 12 years - helped convert previously sceptical scientists, whose statistics showed such large deviations from the surrounding sea state should occur only once every 10000 years.

The fact that rogue waves actually take place relatively frequently had major safety and economic implications, since current ships and offshore platforms are built to withstand maximum wave heights of only 15 metres.

In December 2000 the European Union initiated a scientific project called MaxWave to confirm the widespread occurrence of rogue waves, model how they occur and consider their implications for ship and offshore structure design criteria. And as part of MaxWave, data from ESA's ERS radar satellites were first used to carry out a global rogue wave census.

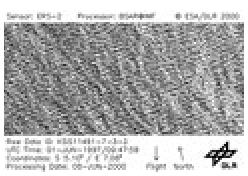


ERS satellite

"Without aerial coverage from radar sensors we had no chance of finding anything," added Rosenthal, who headed the three-year MaxWave project. "All we had to go on was radar data collected from oil platforms. So we were interested in using ERS from the start."

ESA's twin spacecraft ERS-1 and 2 – launched in July 1991 and April 1995 respectively – both have a Synthetic Aperture Radar (SAR) as their main instrument.

The SAR works in several different modes; while over the ocean it works in wave mode, acquiring 10 by 5 km 'imagettes' of the sea surface every 200 km.

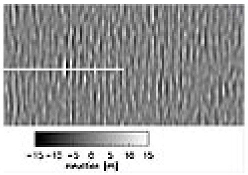


Example of an imagette from ERS-2

These small imagettes are then mathematically transformed into averaged-out breakdowns of wave energy and direction, called ocean-wave spectra. ESA makes these spectra publicly available; they are useful for weather centres to improve the accuracy of their sea forecast models.

"The raw imagettes are not made available, but with their resolution of ten metres we believed they contained a wealth of useful information by themselves," said Rosenthal. "Ocean wave spectra provide mean sea state data but imagettes depict the individual wave heights including the extremes we were interested in.

"ESA provided us with three weeks' worth of data – around 30,000 separate imagettes – selected around the time that the Bremen and Caledonian Star were struck. The images were processed and automatically searched for extreme waves at the German Aerospace Centre (DLR)."



Giant wave detected in ERS-2 imagette data

Despite the relatively brief length of time the data covered, the MaxWave team identified more than ten individual giant waves around the globe above 25 metres in height.

"Having proved they existed, in higher numbers than anyone expected, the next step is to analyse if they can be forecasted," Rosenthal added. "MaxWave formally concluded at the end of last year although two lines of work are carrying on from it – one is to improve ship design by learning how ships are sunk, and the other is to examine more satellite data with a view to analysing if forecasting is possible."

A new research project called WaveAtlas will use two years worth of ERS imagettes to create a worldwide atlas of rogue wave events and carry out statistical analyses. The Principal Investigator is Susanne Lehner, Associate Professor in the Division of Applied Marine Physics at the University of Miami, who also worked on MaxWave while at DLR, with Rosental a co-investigator on the project.

"Looking through the imagettes ends up feeling like flying, because you can follow the sea state along the track of the satellite," Lehner said. "Other features like ice floes, oil slicks and ships are also visible on them, and so there's interest in using them for additional fields of study.

"Only radar satellites can provide the truly global data sampling needed for statistical analysis of the oceans, because they can see through clouds and darkness, unlike their optical counterparts. In stormy weather, radar images are thus the only relevant information available."

So far some patterns have already been found. Rogue waves are often associated with sites where ordinary waves encounter ocean currents and eddies. The strength of the current concentrates the wave energy, forming larger waves – Lehner compares it to an optical lens, concentrating energy in a small area.

Giant wave in a wave tank

This is especially true in the case of the notoriously dangerous Agulhas current off the east coast of South Africa, but rogue wave associations are also found with other currents such as the Gulf Stream in the North Atlantic, interacting with waves coming down from the Labrador Sea.

However the data show rogue waves also occur well away from currents, often occurring in the vicinity of weather fronts and lows. Sustained winds from long-lived storms exceeding 12 hours may enlarge waves moving at an optimum speed in sync with the wind – too quickly and they'd move ahead of the storm and dissipate, too slowly and they would fall behind.

"We know some of the reasons for the rogue waves, but we do not know them all," Rosenthal concluded. The WaveAtlas project is scheduled to continue until the first quarter of 2005.

Related news

- ERS-2 has new role 'nowcasting' Europe's weather
  (http://www.esa.int/esaEO/SEM0V177ESD_index_0.html)

- ESA's orbiting hurricane hunter back in action
  (http://www.esa.int/esaCP/SEMQ1MYV1SD_index_0.html)

In depth

- Wave Atlas on ESA's EO PI Portal (http://esamultimedia.esa.int/docs/linkWaveAtlas.htm)

Related links

- MaxWave (http://w3g.gkss.de/projects/maxwave/)