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What conditions led to the Draupner freak wave?

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What conditions led to the Draupner freak wave?

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On 1 January 1995 at 15 UTC, the most famous freak wave to be detected by a measuring instrument was recorded by a downward-looking laser at the North Sea Draupner gas platform. The wave was 25.6 m high, with an 18.5 m crest height (Box A). The significant wave height in the area is estimated to have been almost 12 m. The measurement confirmed the existence of giant rogue waves, which had previously been reported anecdotally by sailors. It prompted a number of studies which aimed to determine the meteorological and wave situation at the time and to provide a physical explanation of the event.

High-resolution retrospective forecasts (hindcasts) recently produced at ECMWF show the evolution of wind, pressure and wave fields on 1 January 1995 in unprecedented detail and shed fresh light on how the Draupner wave event may have come about. They suggest that waves driven by a southward-moving polar low interacted with a substantial local wind-generated wave system to produce the conditions conducive to the observed large rogue wave.

New tools

An overview of studies into the origin of the Draupner wave is given by *Cavaleri et al*. (2016a). A detailed analysis was reported by *Sunde* (1995) and summarised by *Haver* (2004). It is often reported that a depression located over Sweden generated a vigorous north-westerly flow leading to substantial south-east propagating waves covering the whole North Sea. *Adcock et al.* (2011) made use of a dedicated reanalysis based on ERA-Interim reanalysis data. The ERA-Interim system, which uses model cycle 31r2 of ECMWF's Integrated Forecasting System (IFS), was run at an increased resolution (TL799, corresponding to a horizontal grid spacing of about 25 km) to produce a new investigation of the situation. However, the resolution of *Adcock et al.*'s simulation was still too coarse to capture the fine details of the event. A new, highly detailed description of the overall situation not previously available is reported here. It was obtained by hindcasting the meteorological and wave conditions using the current resolution of high-resolution forecasts, TCo1279, corresponding to a horizontal grid spacing of about 9 km (*Hólm et al.*, 2016), with IFS Cycle 41r1 rather than 41r2, which has now been used for the operational introduction of TCo1279.

The Draupner storm was modelled as a series of forecasts starting from initial conditions provided by the dedicated TL799 reanalysis. The model version used in the simulation benefits from all model upgrades between IFS Cycle 31r2, used for ERA-Interim, and IFS Cycle 41r1.

Some wave-related terminology

A

2D wave energy spectrum: The distribution of wave energy both in frequency and direction. This quantity is the prognostic variable of any modern wave model.

1D wave energy spectrum: The 2D wave energy spectrum integrated over all directions.

Crest height: The height between the top of the wave and the undisturbed water surface.

Crossing sea: Sea state with two wave systems travelling at oblique angles.

Significant wave height: Four times the square root of the integral of the wave spectrum. It closely corresponds to the average height of the highest one third of waves.

Swell: A wave system originating from a distant storm and not affected by local winds.

Wave peak period: The reciprocal of the frequency corresponding to the highest value of the 1D wave energy spectrum.

Wind sea: A wind wave system directly generated and affected by local winds.

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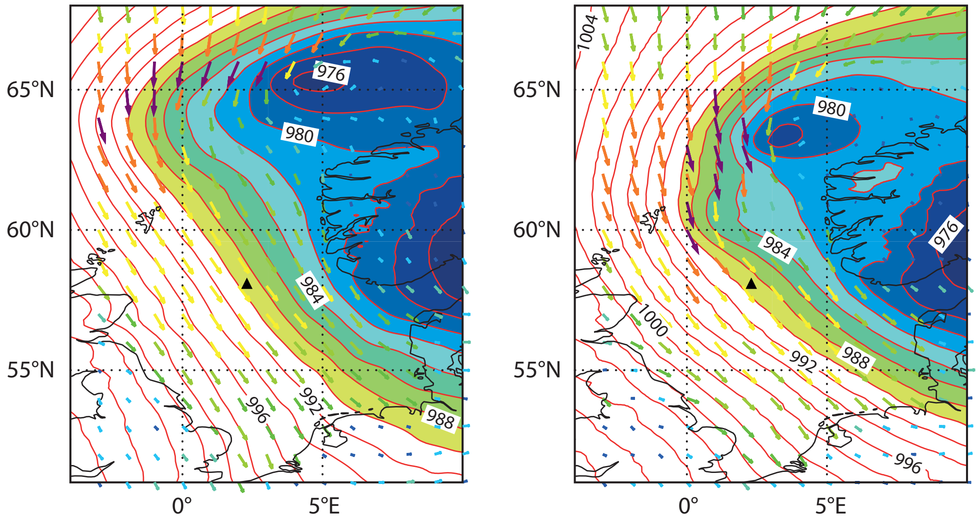
New results

All results reported here have been obtained starting from the analysis valid at 1 January 1995 00 UTC. Figure 1 provides a sequential view of the meteorological conditions on 1 January. A low-pressure system is centred over Sweden. At 00 UTC (Figure 1a), a polar low is clearly visible off the coast of Norway. It brings with it an energetic increased flux of cold air from the north. At Draupner (represented by the black triangle near the centre of each panel), the wind direction is about 315° (i.e. from the northwest). Over the next 12 hours (Figure 1b–c), the polar low moves rapidly southward, with increased wind speeds on its western flank. It reaches the Draupner latitude at about 15 UTC (Figure 1d). In the area of the platform, the 10-metre wind speed at that time exceeds 20 m/s, and the direction is turning more northerly. In the following hours the low keeps moving south and southeast, reaching the Dutch coast close to the German border at about midnight.

a Zero-hour forecast **b** Six-hour forecast



c Twelve-hour forecast **d** Fifteen-hour forecast

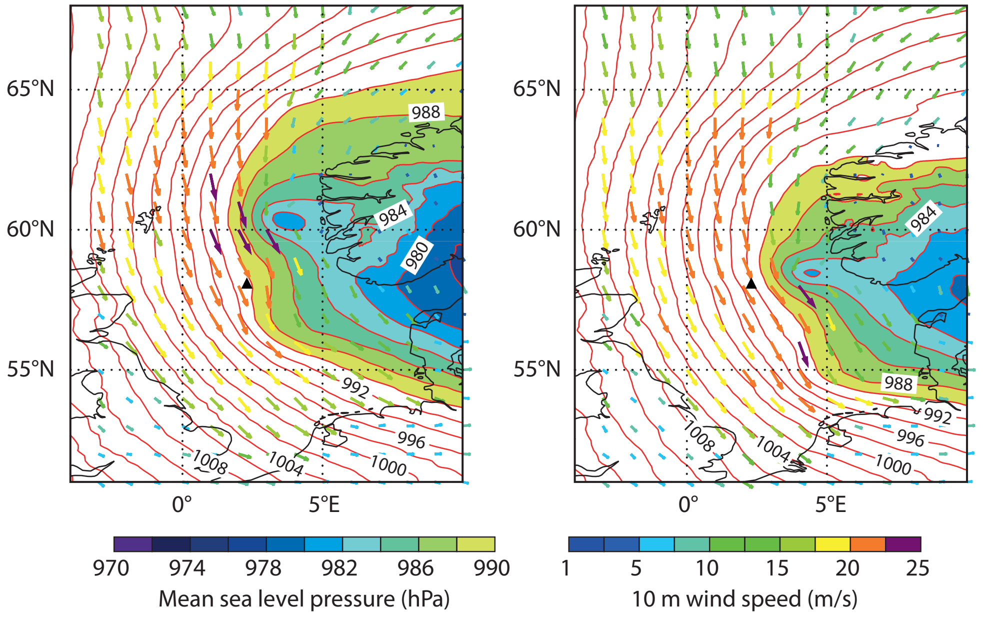
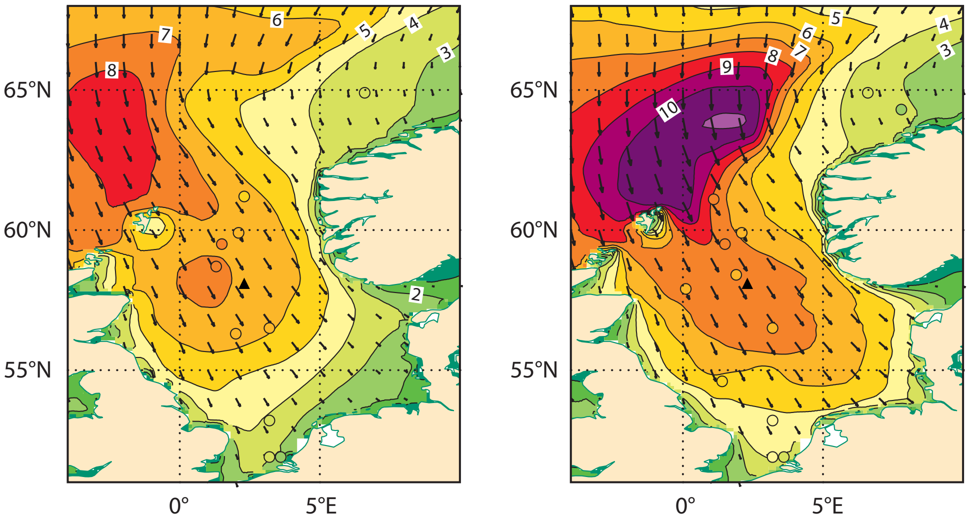


Figure 1 High-resolution forecasts of 10-metre wind (arrows) and mean sea level pressure (contours, shading) in the North and Norwegian Seas on 1 January 1995, showing (a) a 0-hour forecast, (b) a 6-hour forecast, (c) a 12-hour forecast, and (d) a 15-hour forecast, all starting from 00 UTC. The black triangle shows the position of the Draupner platform.

As shown in Figure 2, an extensive area of southward-propagating waves follows the polar low. A detailed analysis of the 2D wave energy spectra indicates the presence of partly crossing-sea conditions at the platform at the time of the freak wave event. The small number of in-situ wave height observations obtained at the time by ECMWF are also shown. At Draupner, the maximum modelled significant wave height is close to 11 m, about 1 m lower than the reported height. An interesting detail emerges when analysing the motion of the polar low.

From the model output, it is straightforward to estimate that the speed at which the low was moving was about 15 m/s. This is too fast for dynamical wave generation to occur, i.e. for a wave system to move at the same speed as the low and to continuously receive energy from it. For a wave group speed of 15 m/s, the corresponding wave peak period is around 19 s, which is much larger than typically found in studies of the Draupner storm.

a Zero-hour forecast **b** Six-hour forecast



c Twelve-hour forecast **d** Fifteen-hour forecast

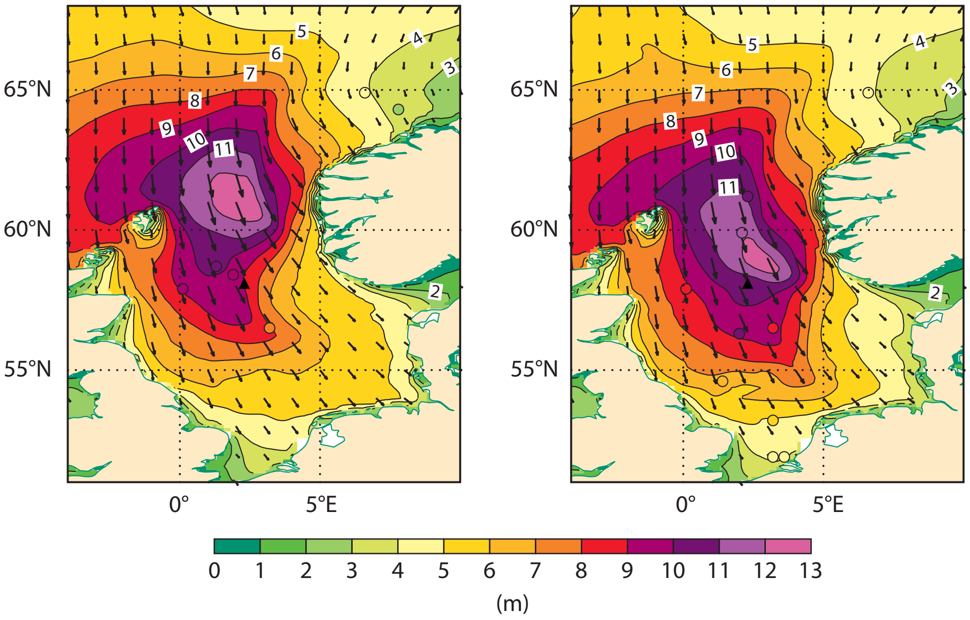


Figure 2 High-resolution forecasts of significant wave height distribution (shading) and mean wave direction (arrows) in the North and Norwegian Seas on 1 January 1995, showing (a) a 0-hour forecast (b) a 6-hour forecast, (c) a 12-hour forecast and (d) a 15-hour forecast, all starting from 00 UTC. The black triangle shows the position of the Draupner platform. Coloured circles denote corresponding wave height observations (same colour scale as for the forecasts) as archived at ECMWF.

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However, given the prevailing meteorological conditions, it can be assumed that there was wave energy in this frequency range or just below it. These wave components were moving with the storm, while at the same time receiving energy from nonlinear interactions with the bulk of the wind-sea frequency spectrum (and not directly from the wind as their phase speed was higher than the wind speed). As a result, the area of the highest waves followed the trajectory of the low. *Cavaleri et al*. (2016a) interpret this as a 'dynamically locked' low-frequency part of the spectrum, which is fed by non-linear interactions with the wind-sea part of the spectrum and moves with and at the same speed as the storm. It is only at 15 UTC, when the centre of the low passed near the Draupner area, that the 'locked' low-frequency wave components are present together with a substantial local wind-generated system.

Resolution and observations

It is clear that the high horizontal resolution is an essential element in the success of this latest simulation. As shown by *Cavaleri et al*. (2016a), running the same experiment at TL799 does not produce a well-defined polar low but rather an area with slightly more intense winds embedded in the large-scale circulation caused by the depression over Sweden. Similarly, by comparing this TL799 run with the corresponding forecast from the dedicated reanalysis, it was shown that model improvements since ERA-Interim were also a contributing factor, since with the old model the area with intense wind was much more confined.

As for the predictability of the event, longer-range forecasts were not very good at anticipating the evolution of the polar low. There might be several reasons why earlier analyses did not have the relevant information, resolution being one of them. The polar low was only noticeable in the analysis map when it was already on its way south. Its whole trajectory from the far north (about 66° N), where it was identified, to the Dutch coast took less than 24 hours. There was no clue of its existence, and hence no possible prediction based on it, before 1 January 00 UTC. This points to a lack of observations, which is today possibly being alleviated as a result of a strong interest in the Arctic. For example, EUMETNET have deployed additional marine buoys in the area, which measure surface pressure with high accuracy.

Demystifying the Draupner wave

Based on the simulations described above, Cavaleri et al. (2016b) have analysed the Draupner wave, drawing on recent work on the distribution of extreme waves and crest heights. From this vantage point, the Draupner event, like probably most of the large waves reported in the literature, loses much of the mystery surrounding it: such waves are a regular part of large storms and coming across them is just a matter of probability depending on the spatial and temporal scales considered.

In the case of the Draupner, the wave conditions, both in terms of height and spectral shape, made encountering a particularly high wave and crest particularly likely. The probability of such an event may have been enhanced by the presence of two crossing low-frequency wave systems that could only be properly modelled because of recent improvements in the IFS and the use of increased resolution. Cavaleri et al. (2016b) have introduced the concept of 'dynamical swell' to identify the part of the wave spectrum which moves with the storm without receiving energy from the wind because of its higher phase speed, but which is made more energetic via nonlinear interactions from the active part of the wind-sea spectrum. This condition may be more common than had been thought, particularly in the case of fast-moving storms.

Further reading

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