Storm Britta

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1. Introduction

Storm Britta hit the North Sea 31st October to 1st November 2006. Significant wave height (Hs) of 10 m was measured at FINO 1, which is a once in 20-year event and classified as rogue wave. The 10-min mean surface wind speed at the storm peak is about 24 m/s; this wind strength normally corresponds to much lower wave heights during other storms. Apart from the large waves, storm Britta was also characteristic of open cell wind structure, with significant wind variation in both time (e.g. 10 m/s in 30 minutes) and space (5 m/s over 3 km). Such wind and wave conditions have been a severe threat for many offshore functions, including wind farm operation and maintenance. It is therefore of great importance to predict it correctly.

In order to predict such a storm accurately, one needs to find out the mechanisms behind. Among a series of studies of Britta, Emeis and Türk (2009) considered that the convective condition makes Britta different and is responsible for the large waves. Pleskachevsky et al. (2012) concluded that the wind gustiness related to the open cells could be the explanation of the generation of the rogue wave. The current study aims at revealing more of the mechanisms behind Britta in order to model accurately storms of this kind.

2. Approach

Measurements and numerical modeling are used jointly. Measurements include meteorological and wave observations from 10 stations over the North Sea (Fig. 1), SAR data and cloud pictures. Cloud pictures were used to study the development, path and mesoscale features of the storm. SAR data and images are used to study the spatial distribution of wind speed. Wind and wave (speed and direction) at 10 stations are examined simultaneously throughout the storms.

We used the Coupled Ocean-Atmosphere-Wave-Sediment-Transport (COAWST), which includes three model components, the mesoscale atmospheric Weather Research and Forecasting (WRF) model, the spectral wave model for nearshore (SWAN), and the Model Coupling Toolkit. WRF and SWAN used the same domain setup, with three nested domains, as shown in Fig. 1, with spatial resolutions of 18 km, 6 km and 2 km, respectively. In WRF, each domain has 46 vertical sigma levels. We used MYNN 3.0 PBL closure scheme, Thompson microphysics scheme and RRTM radiation schemes in all three domains. The cumulus scheme is turned off for domain II and III. The initial and boundary forcing of WRF is provided by the Climate Forecast System Reanalysis (CFSR). The 0.312^o-resolution sea surface temperature (SST) data from CFSR are. In SWAN, we use the 1/8 arc-minute bathymetry data from Digital Terrain Model of European Marine Observation and data network. SWAN initiates from a JONSWAP spectrum and its open boundaries are set to JONSWAP spectrum with Hs = 0.5 m and peak wave period of 1 s, with 36 directional bins used. The wind input and white-capping dissipation source function are based on scheme from Komen et al. (1984).

WRF transfers 10-m wind to SWAN. SWAN feeds back peak wave period, which is used to calculate the roughness length with the Fan et al. (2012) scheme as a function of wave age in SWAN. The exchange of information between WRF and SWAN is 2-way online, every 90 seconds. We modeled three days starting 2006-10-30 00:00 and ending 2006-11-02 00:00, in two runs with each lasting 36 hours.

To investigate the special conditions associated with Britta, 12 storms identified from measurements at FINO 1 are analyzed altogether.

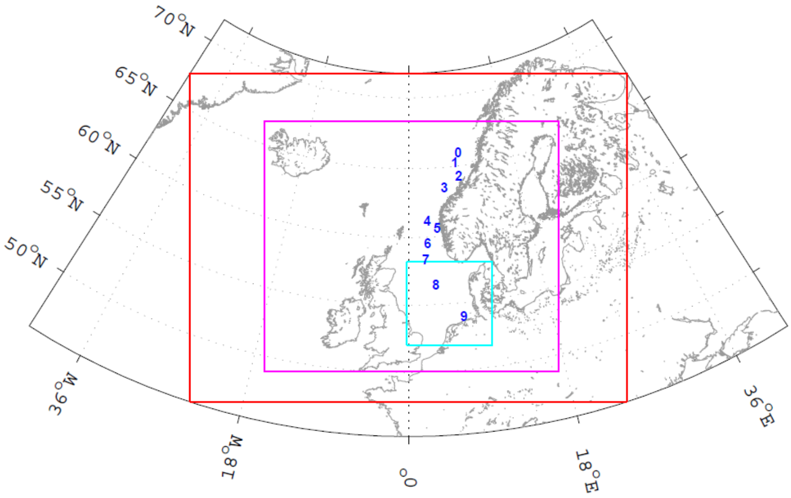

Figure 1. The three model domains of COAWST (WRF+SWAN) and the 10 stations: Norne (0), Heidrun (1), Draugen (2), Ormen-Lange (3), Gullfaks-C (4), Troll-A (5), Heimdal (6), Sleipner-A (7), Ekofisk (8) and FINO 1 (9).

3. Main body of abstract

Britta is a strong low pressure system passed across the North Sea, passing Norway, southern Sweden, across the Baltic Sea and reaching the Baltic countries. A cold air outbreak occurred accompanying this system and open cells developed.

COAWST successfully reproduced the synoptic meteorological and wave conditions as indicated by the cloud picture, SAR image and measurements from stations.

Figure 2 shows snapshots from various data source for the time around 10 am on 1st November, 2006. Both the cloud picture (Fig. 2a) and the SAR image (Fig. 2b) show mesoscale open cell structures. In Fig. 2c measurements from a number stations show consistently the strong wind and wave vectors propagating from north to south. Figure 2d shows the snapshot of the 10-m wind speed from model domain III, which overlaps partly with the SAR data domain; the open cells are present and the wind magnitudes are comparable, though it is known the SAR data are of high uncertainty when winds exceed 20 m/s. Our spectral analysis of the spatial wind variability in the wave number suggests that COAWST captures the wind variability for scales greater than about 14 km (7 times the model spatial resolution), however, the spatial variability is lower than that given in the SAR data. Note that the SAR data has a spatial resolution of approximately 500 m. This behavior of COAWST is due to the numerical smoothing nature of WRF (Skamarock 2004).

Figure 3 shows the modeled and measured wind speed at 100 m at FINO 1 as well as the significant wave height, Hs. The model results captured well the storm peak, both the magnitude and the phase, both of the wind and of the wave. Similar good agreement is also obtained at the other site in domain III, Ekofisk.

A number of other storms are examined to find out why rogue waves only occurred during Britta. The conditions that have been examined are: (1) wind strength; (2) stability; (3) open cell present or absent; (4) existence of a long and undisturbed water fetch with strong, persistent mean wind, allowing the development and propagation of large waves. The other storms satisfy one, two or three of the first three conditions, but none of them satisfied the four conditions all together, like Britta. The analysis suggests that open cells are associated with convective condition along with a cold front, which secures the strong winds. For Britta, the first three conditions are inter-connected, but it is the position and the path of this storm that realized condition (4).

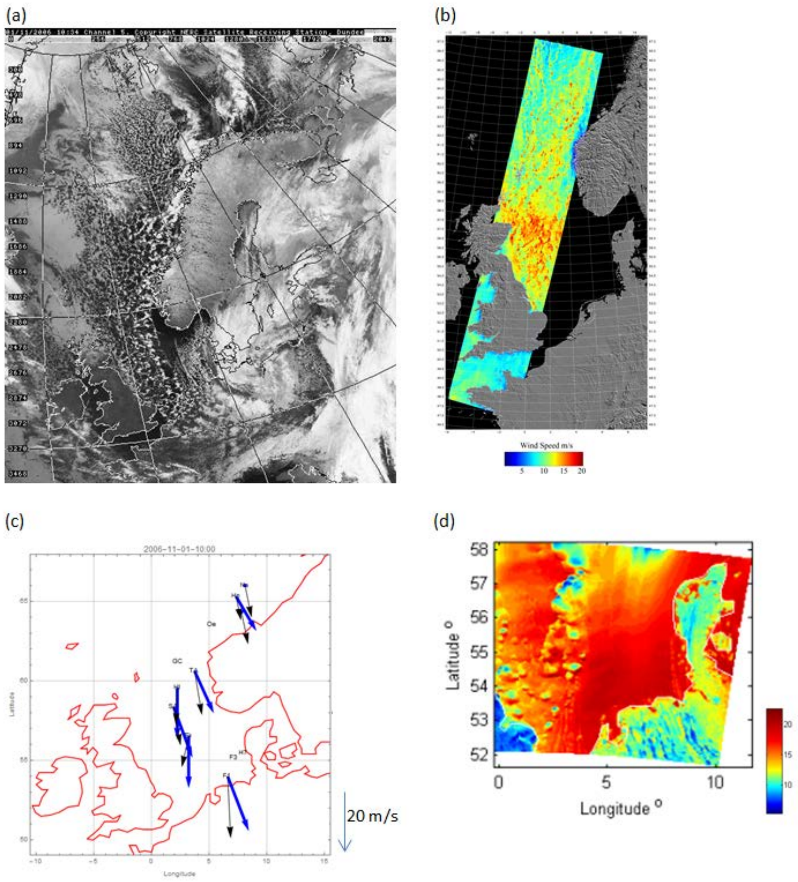

Figure 2. At about 10:00 am on 1st November, 2006. (a) Cloud picture at 10:34 am. (b) SAR image of the 10-m wind speed at 10:26:41 am. (c) Wind (black arrow) and wave (blue arrows) vectors at stations over the North Sea at 10:00 am. The arrow outside the frame shows the scale. (d) COAWST (WRF+SWAN) modeled 10-m wind speed for model domain III, at 10:00 am.

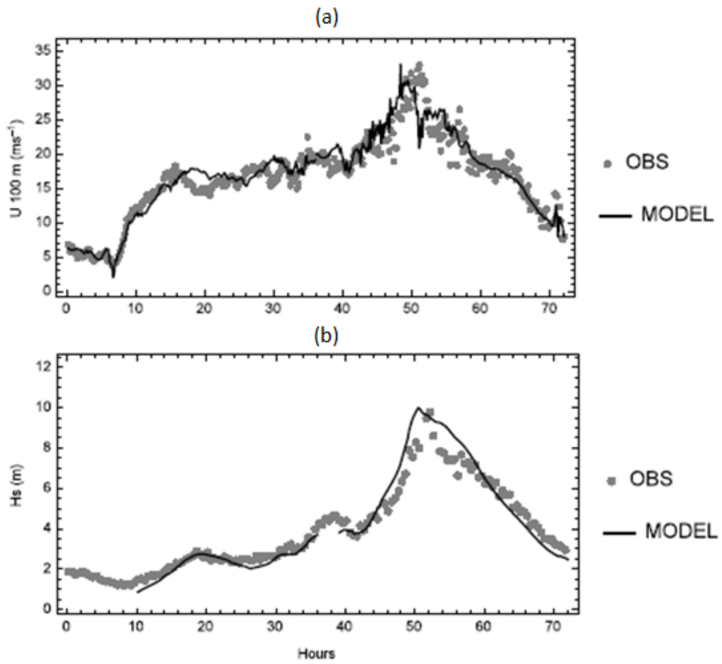

Figure 3. Modeled and measured wind speed at 100 m (a) and significant wave height Hs at FINO 1. X-axes shows the time in hours starting from 2006-10-30 00:00. Observed Hs peaks at hour 51, which is 4 am on 2006-11-01.

4. Conclusion

The modeling system COAWST is capable of modeling a major storm such as Britta where rogue waves developed. This study adds to the existing studies of storm Britta with findings of the key mechanism in the development of rogue waves: a long and undisturbed fetch with strong and persistent wind for more than half day that allows the development and propagation of strong waves.

Convective conditions, open cells and cold fronts that are all present during Britta are inter-related and they contribute to another necessary condition to the generation of rogue waves: strong winds.

5. Learning objectives

There is nothing mysterious about storm Britta. To successfully model such a model, the key mechanisms need to be taken into account in the modeling system. Therefore the setup of the modeling system is very important. Here, special attention has been paid to (1) the setup of the domain big enough to allow the storm to develop, (2) optimal large scale forcing data and sea surface temperature data to secure the development of the cold front, (3) resolution high enough to allow the development of open cells and the impact of these winds to waves, (4) optimal wave parameter specification, (5) initial time modeling time.

COAWST is a powerful tool to model the challenging offshore wind and wave conditions such as storms, and to serve the many needs in wind energy applications, such as operation and maintenance, extreme wind and extreme wave estimations.

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