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Assessing extreme events for energy meteorology: media and scientific publications to track the events of a North Sea storm

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Abstract

Important issues for energy meteorology are to assess environmental conditions for normal operating conditions and extreme events for the ultimate limit state of engineering structures. Autumn and winter storms are a challenge for onshore and offshore energy infrastructure in northern Europe, and sometimes cause damage and disruptions. The incidence of extreme storms has increased over the past 20 years, leading to increased pressure on energy infrastructure. This paper summarizes the events of a storm from October 30 to November 2, 2006 using media reports, government publications, and scientific articles to create an overview of the meteorology and infrastructure impacts.

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Keywords: North Sea storm; Britta; storm surge; gust; wind turbine

1. Introduction

Energy meteorology needs accurate assessments of meteorological conditions both for normal operating conditions and also for extreme events that may place infrastructure at risk and necessitate costly repairs. Weather

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conditions vary from place to place, and also there are differences in the way that different branches of the energy industry address weather events. Typical weather extremes that affect societal infrastructure – including energy – include storms, inland floods, coastal storm surges, heat waves, and heavy snowfall. Infrequently, lightning, tornadoes, and wind gusts may be a problem in some locations. In Europe, autumn and winter extra-tropical storms are often the most serious weather events that can lead to disruptions of energy infrastructure on a large regional scale [1].

In many cases, energy infrastructure is constructed according to design guidelines that prescribe the normal and extreme environmental operating conditions at a particular site [2]. Design guidelines are based on meteorological station data or other information that has been collected over an extended time period. However, this may lead to problems if there are long term changes in weather patterns that might arise from interdecadal climate variability or climate warming effects [3]. While it is difficult to ascribe single extreme weather events to climate warming [4], recent years have seen increases in certain high impact weather events that are relevant for energy infrastructure. For example, there have been a number of maximum temperature records broken over the past two decades for average summertime temperatures in large parts of Europe. In 2006, this had an important impact on French and German nuclear power stations, whose operation requires large amounts of cooling water within certain temperature thresholds [3]. As well, since the late 1990s there has been an increase in the number of powerful winter storms that have passed across Europe, resulting in societal infrastructure damage and high insurance losses [5,6,7]. Certain branches of the energy industry, like the new initiatives in offshore wind energy, may be more susceptible to these environmental trends [8].

This paper presents an overview of a severe autumn storm that passed over northern Europe on Oct. 30–Nov. 2, 2006. The storm was given name 'Britta' by the German weather service [9], 'Allerheiligenvloed' in the Netherlands [10,11,12] and 'Borgny' in Norway [13]. 'Britta' is most often used in present literature.

2. Winds and Gusts

The Britta storm passed across northern Europe with high winds from Ireland to Poland and low temperatures from an outbreak of polar air that stretched from Scandinavia to the Mediterranean. The trajectory of the low pressure center passed north of Scotland, across western Norway and northern Denmark, and then through the Baltic. Details of the path and evolution of the low pressure center in the Atlantic are presented in several reports [9,11,14], and the division of the low pressure center in the Baltic is presented in other sources [15,16]. The storm followed a path across the northern edge of the North Sea that is recognized to be particularly damaging for maritime infrastructure because of large waves. The wave field develops in the strong north winds of the long uninterrupted fetch that occur behind the propagating low pressure center [5,17]. The offshore wind field was recorded by the Quikscat satellite scatterometer and reveals the spatial extent and maximum wind speeds over the North Sea at the

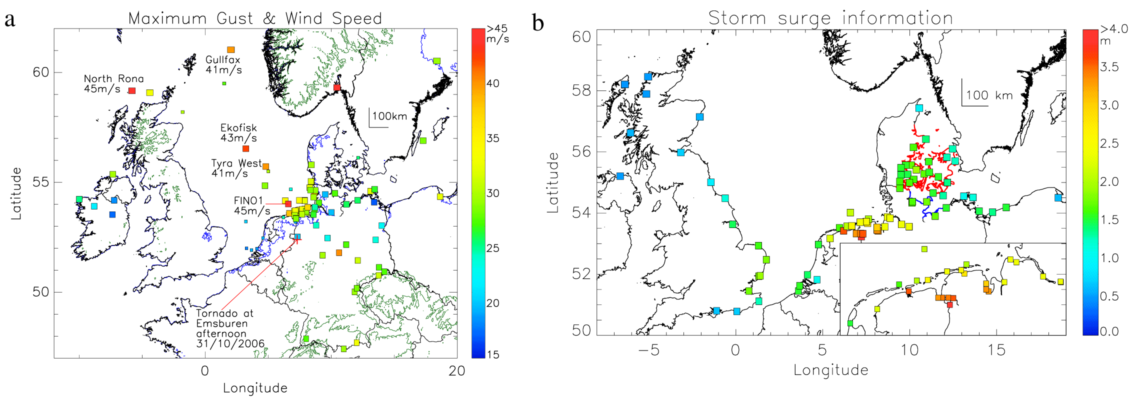

Fig. 1 (a) maximum wind gusts and (b) maximum storm surge reported during the Britta storm of Oct. 31–Nov. 1, 2006.

height of the storm between late Oct.31 and early Nov. 1, 2006 [18].

Onshore, high winds and gusts were prominent in the media reports and press releases associated with the storm (Fig. 1a). High winds were registered first from Ireland on Oct. 30–31, 2006 [19]. Gusts above the hurricane threshold (~32 m/s) were reported from Scottish islands and certain offshore platforms in the North Sea [16]. In Germany, high winds and gusts were reported from the Frisian islands and coastal areas during the predawn hours of Nov. 1 and extended southwards across the country to the Alps during the day [9,16]. In Denmark, meteorological reports note that the high wind field advanced suddenly across the country on the morning of Nov. 1 with one station registering a jump in wind speed from 3m/s to 26m/s over a time interval of only a few minutes [20].

3. Storm Surge

The storm surge associated with the Britta storm was prominent in media reports especially from the Netherlands, Germany, and Denmark. Fig. 1b shows a map of the maximum sea levels that were recorded in northwest Europe. The storm surge is expressed as height above the high tide level (or skew surge) for North Sea stations or height above normal sea level for Danish and Baltic stations, which have a small tidal range. The highest storm surge was reported for the North Sea coast of Germany and the Netherlands. However, the areas impacted by the storm surge extended over a much larger area and included also the United Kingdom, Denmark, and Poland. The map has been compiled from different sources. These include online government documents and website information for the United Kingdom [21,22,23], Netherlands [11,12], and Denmark [24,25,26]. Media reports, government reports and scientific documents were used for Germany [9,14,16,27,28,29] and Poland [30,31,32]. The storm surge entered the North Sea over the top of Scotland and propagated as a coastal wave that travelled counterclockwise around the North Sea, passing the east coast of England, the Netherlands, Germany, and Denmark in sequence. Maximum sea levels occurred where the travelling storm surge wave and high tide wave coincided [33,34]. For some locations in the United Kingdom, the storm surge impacted two successive high tide levels, and many stations on the west coast of the country facing the Atlantic Ocean registered extreme minimum levels during the storm. The flooding events in eastern Denmark (Danish Inner Waters) and the southwestern Baltic Sea occurred on Nov. 1.

The damage associated with the storm surge was not directly linked with the maximum water levels shown in Fig. 1b. Different locations around the North Sea coast have different normal high tide levels, and infrastructure damage is linked to the level of the storm surge above this level. Coastal engineering structures take this into account by assessing of how often certain high water levels are expected to occur within the design lifetime of the structure: the 'return period' of storm surge levels [33]. For bad storm surges, media reports also describe the seriousness of a flood by reporting the last time that such an event happened in the past or by giving a series of past precedents. This

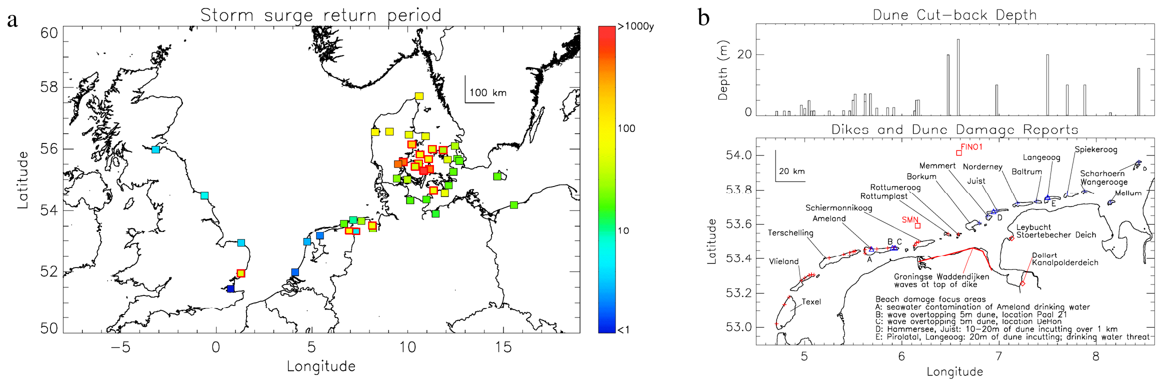

Fig. 2 (a) Previous occurrence of surge height (from press releases) or calculated return period (for Denmark) of water levels that were reached during the highest skew surge (or height over the high tide level) during the Britta storm (see text for details); (b) (top) coastal dune cut-back depths for the Frisian islands of the Netherlands and Germany and (bottom) regional map of the Frisian islands map showing dune damage focus areas (blue triangles), offshore wave recorders (red squares), and important mainland dikes (red diamonds and line).

information is used to construct approximate return periods for the surge associated with the Britta storm at the German and Polish coastal stations shown in Fig. 2a. For the United Kingdom [21,22,23] and the Netherlands [11,12], the governmental authorities presented tabulated lists of previous storm surges that were instrumentally recorded. These data permitted the calculation of average return periods, and these are also shown in Fig. 2a.

For some locations, media and government reports indicated that water levels at the height of the Britta storm surge were never previously recorded by instruments. In the North Sea area, this was the case for the tide gauge stations at Harwich in the United Kingdom and Delfzijl in the Netherlands. For these stations, Fig. 2a shows the return period simply as the tide gauge station record length, and the symbols are outlined in red. The implication is that the return period was probably longer, and the estimate is not well constrained by the available data. The Delfzijl case was of special concern for the Netherlands coastal authority because the measured water levels were significantly higher than the predictions of the forecasting model that was used to issue advance warnings [10].

For many Danish locations in the Inner Danish Waters in the eastern part of the country, the Britta storm flooding was also an event with no precedent in the instrument records, and these are also outlined with red boxes in Fig. 2a. Here, the storm surge was particularly severe because of strong north winds were blowing southward along the Kattegat and Baltic Sea [24,34]. The following year, the Danish coastal authority published a revised report of 20-, 50-, and 100-year surge levels based on standard procedures for extrapolating extreme values in time series of limited duration [26]. The information permitted a quantification of the return period of a sea surge at the level that was encountered during the Britta storm, and these results are shown in Fig.2a. A couple of stations indicate that the Britta flood approached or exceeded the level of a 1000 year event, and this supports an assessment of the significance of the storm surge by Denmark's national insurance authority, which was made the following year [35].

4. Coastal Erosion and Damage

There were reports of coastal damage during the Britta storm in areas close to offshore gas production platforms (Netherlands) and planned offshore wind parks (Netherlands and Germany). The coastal damage was mostly associated with the erosion of the sand dunes and cliffs that form large stretches of coastline around southern North Sea coastline of England, Netherlands, Germany, and Denmark, and also the Baltic Sea coastline of Poland. The coastal dunes form barriers to sea flooding in some areas, and also act as a natural freshwater storage on the Frisian islands of the Netherlands and Germany [36]. Reports of significant coastal damage were located for the Netherlands [11,37], Germany [38], and Denmark [39]. For the Netherlands and Germany, the beach survey reports were presented in detail, and Fig 2b (upper panel) shows this data plotted together. The figure highlights that many

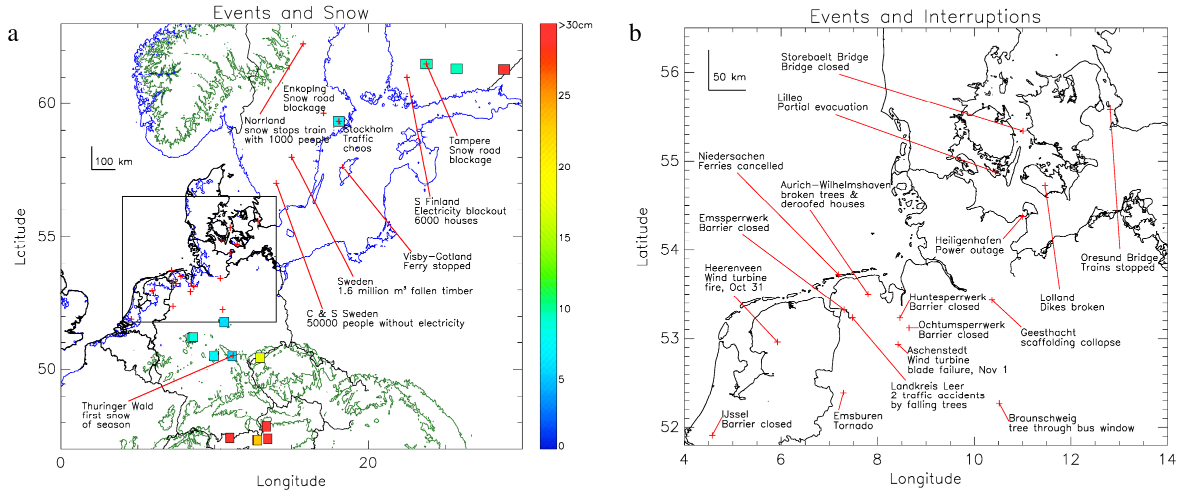

Fig. 3 (a) map of societal infrastructure impacts during the Britta storm with snow accumulations given by colour coded symbols; (b) events within the map inset box showing infrastructure impacts in the focus region of the Netherlands, northern Germany and southern Denmark.

Frisian islands were impacted during the storm with the worst damage occurring on the German islands in the east. The mechanism of dune damage during a storm is complicated, and the storm surge water level may be the most important factor, followed by the significant wave height [30]. In the North Sea, the Britta storm was associated with high significant wave heights near the coast, and the wave field was recorded by Datawell Waverider buoys at Schiermonnikoog Nord and FINO1 (see Fig. 2b, lower panel). Press releases from the coastal authorities in both the Netherlands and the German state of Niedersachsen verified that the coastal protection dykes on the mainland were not significantly damaged by the surge [11,38]. Later scientific reports indicate that there was a large transport of bottom sediments in the Wadden Sea during the storm [29].

5. Interruptions of Societal and Energy Infrastructure

The reported impacts on societal and energy infrastructure are presented in Fig. 3a, and Fig. 3b shows a detailed map of a focus area in northern Germany, Netherlands, and southern Denmark. Large areas of Scandinavia were affected by snow storms that interrupted transport infrastructure and caused power interruptions for tens of thousands of people mainly in Sweden and Finland [40]. The storm surge and high winds resulted in stopped ferry services for the Frisian islands, Inner Danish Waters, and Swedish island of Gotland. There were interruptions on the main bridge connecting Denmark and Sweden. The storm surge caused a power outage for the German city of Heiligenhafen on the Baltic coast, and there was flooding of harbor areas in the southern North Sea and southwestern Baltic Sea [16].

Wind gusts caused roof damage and toppled trees in coastal areas of northern Germany. The German reports also emphasized a series of violent convection cells that passed southward from the North Sea to the Alps, resulting in heavy rain showers. Air temperatures dropped rapidly during the day on Nov. 1, and there were snow accumulations in highland regions in Germany by the morning of Nov. 2 [9,16]. In the wind energy industry, two onshore wind turbines were damaged during the storm at Heerenveen in the Netherlands on Oct. 31 and at Aschenstedt in Germany on Nov. 1 [41]. A tornado was reported at Emsburen near the Dutch-German border (Fig. 1a) on Oct. 31 with a characteristic swath of fallen trees at a woodland site [42].

The Britta storm was also important for offshore events, and these are summarized in Fig. 4a. There were a number of ships damaged or stranded in harbor and coastal events, mostly due to broken mooring lines or loss of control in high winds. There were also a number of offshore incidents where large waves broke the windows of the navigation bridge or swept away deck cargo [43]. There was a remarkable incident of a triple capsize of a Dutch motor lifeboat in offshore breaking waves near the islands of Schiermonnikoog and Borkum while attempting to

a

b

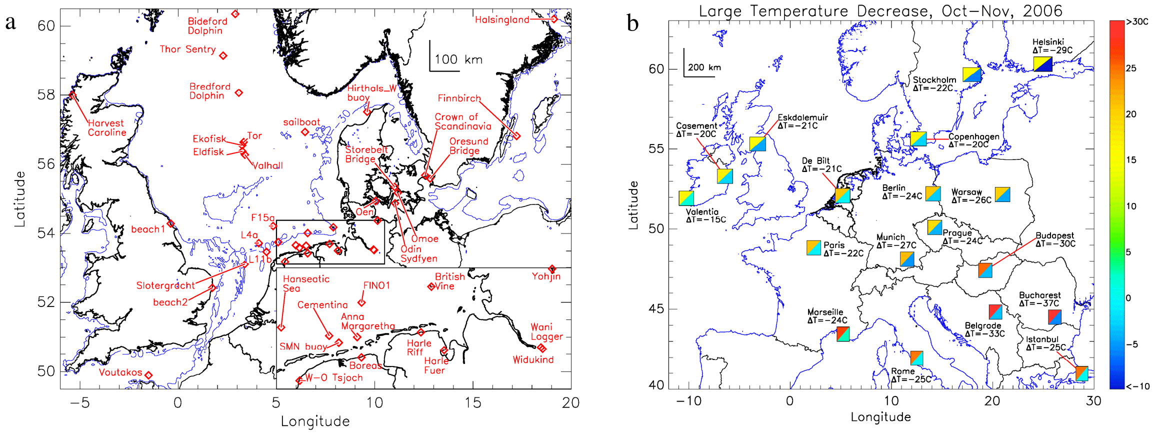

Fig. 4 (a) map of reported offshore events during the Britta storm; (b) map of maximum temperatures for October 2006 (upper left triangle of each coloured symbol) and minimum temperatures for November 2006 (lower right triangle of each coloured symbol) with the drop in temperature between the October maximum and November minimum printed beside each symbol.

rescue a larger cargo vessel that had been damaged by waves several hours earlier [44]. The motor lifeboat was designed for such an event, and reached harbor under its own power. The ship M/V Finnbirch sank near the island of Gotland in the Baltic Sea after waves caused a cargo shift [45].

Offshore energy infrastructure in the North Sea also registered some damage. Many media reports focused on the incident of the floating drilling platform Bredford Dolphin, which broke free from its tow during high winds while being transferred from Scotland to Poland for a refit [43,46]. In Norway, reports also focused on the case of the fixed production platform Valhall that sustained damage to its deck and some lifeboats from high waves [46,47,48]. Other damage incidents are briefly mentioned in public documents for Norwegian platforms Ekofisk and Eldfisk [48] and for gas production platforms nearer to the Dutch North Sea coast [44]. Except for the FINO1 research tower near the island of Borkum [49], there was no reported damage to North Sea offshore wind energy infrastructure during the storm. At the time, only the wind farms at Horns Rev (Denmark) and Scroby Sands (United Kingdom) were in operation in the North Sea.

6. The Britta Storm in the Context of Weather Events in the Autumn of 2006

The Britta storm took place during an extended interval of bad weather in northwest Europe that lasted through most of October and November in 2006. Britta had the highest surge height during the series of storms, and analysts at the Bundesamt für Kartographie und Geodäsie assessed that the storm was more powerful than a defining event in February, 1962. The storms during the autumn of 2006 occurred in clusters. The storm sequence that preceded Britta started on Oct. 21, 2006, and another storm sequence started on Nov. 3, 2006 [50,51].

During this period, a series of shipping, coastal, and energy infrastructure incidents were reported that were related to the rough sea state or encounters with large waves. On Oct. 25, 2006 the ship Lass Moon lost part of its deck cargo (a wind turbine tower) overboard in rough weather in the North Sea while en route from Denmark to western Scotland [41,43]. On Oct. 26, 2006 the trawler Meridian sank in the northern North Sea during extreme sea state conditions while on picket duty to guard seabed petroleum infrastructure [43,52]. In the English Channel to the south, unusual long period swell waves inundated the shoreline area of Seaton in Devon (United Kingdom) on Oct. 24, 2006 [53]. On Nov. 8, 2006 the fishing trawler Hoheweg sank near the Alte Weser lighthouse in the German Bight after a rogue wave strike in unexpected circumstances [54,55]. The incident occurred close to planned offshore wind farms sites in the southern North Sea, and it was discussed at a wind turbine task group meeting of the International Energy Agency in Berlin, Germany in February, 2007 [56].

In the aftermath of the Britta storm on Nov. 4, 2006, Europe experienced one of its largest power failures, which affected many countries mainly in central and southwestern Europe. The immediate cause of the problem was a pre-planned alteration of the electrical power grid in northern Germany that was scheduled at a time that would pose the least risk. However, the electrical grid was unexpectedly overloaded, and there were automatic load shedding procedures implemented in 11 countries [57]. The problem lasted only about 40 minutes, but 15 million people had been affected [58]. Met Éireanne's Monthly Weather Bulletin for Nov., 2006 identified that the European power outage had an important weather component, and the rapid drop in temperatures associated with the Britta storm placed stress on European electrical grid [59]. A review of weather summaries from meteorological agencies reveals that the summer and autumn of 2006 had record high temperatures in many areas of central and western Europe [19,59,60,61,62]. The large magnitude of the temperature decrease in European cities from the October maximum to the November minimum is highlighted in Fig.4b [60,61]. It indicates temperature decreases of 20–30°C in many areas across Europe. Many central European cities had their highest October temperatures in the last week of the month, and all of locations shown in Fig 4b had their lowest November temperatures in the first 7 days. The results indicate that large areas of Europe went from warm summer conditions to freezing winter conditions over only a few days as a result of the cold air outbreak from the Britta storm.

7. Conclusion

This contribution presents a summary of meteorological events for the Britta storm in Europe on Oct. 30–Nov. 2, 2006. The storm was characterized by a high wind field and a storm surge in the North Sea and Baltic Sea areas. Societal infrastructure was damaged and interrupted during the storm, including some elements of energy infrastructure that are associated with petroleum production, wind energy, and electricity distribution. Compared with other extra-tropical storms in Europe, the relative impact of the Britta storm is difficult to assess. There were few fatalities, and insurance losses were low compared with other storms [1]. On the other hand, the storm highlighted certain extreme meteorological events that can affect energy infrastructure: extreme gusts, tornadoes, and high waves. Certain sectors of energy industry may be susceptible to extreme weather events associated with climate change [3]. For offshore wind energy, some European wind farms have experienced damage from met-ocean conditions of unexpected severity [8], and the issue was suggested in earlier case studies of high impact meteorological events in the North Sea [63,64]. The compilation of events presented here gives an outline of some of the practical issues of extreme events in energy meteorology.

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