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Supplement of

Storm Xaver over Europe in December 2013: Overview of energy impacts and North Sea events

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Figure S1. Wind speed (10 minute average, adjusted to 10 m height) and wind direction on 5 Dec. 2013 at 18:00 GMT for selected station records in the National Climate Data Center (NCDC) database.
Figure S2. Maximum significant wave height for the 5–6 Dec. 2013. The data has been compiled from CEFAS-Wavenet (wavenet.cefas.co.uk) for the UK sector, from time series diagrams from the website of the Bundesamt für Seeschifffahrt und Hydrologie (BSH) for German sites, from time series data from Denmark's Kystdirektoratet website (https://kyst.dk/soeterritoriet/maalinger-og-data/), from RWS (2014) for three Netherlands stations, and from time series diagrams from the MIROS monthly data reports for the Norwegian platforms of Draugen, Ekofisk, Gullfaks, Heidrun, Norne, Ormen Lange, Sleipner, and Troll.
Figure S3. Thematic map of energy impacts by Storm Xaver on 5–6 Dec. 2013. The platform identifiers are: BU Buchan Alpha, EK Ekofisk, VA? Valhall, The wind turbine accident letter identifiers are: B blade damage, L lightning strike, T tower collapse, X? 'exploded'. The numbers are the number of customers (households and businesses) without power at some point during the storm.
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Figure S11. Progression of the tidal crests and storm surge peak around the North Sea on 5–6 Dec. 2013.
Figure S12. Arrangement of extreme short period water level fluctuations counter-clockwise around the coast of the North Sea during Storm Xaver with reported maritime incidents and accidents. The extreme short period water level fluctuations are the highest (red bar) and second highest (blue bar) range of up-crossing oscillations in the tide gauge records during the two-day period 5–6 Dec. 2013.
### Table S1. Tide gauge information for 77 sites in the United Kingdom, France, Belgium, the Netherlands, Germany, Denmark, Sweden and Norway.

| N  | Station Name       | Abb | Country | Latitude (degree) | Longitude (degree) | Δt orig (min) | Δt use (min) | Source |
|----|--------------------|-----|---------|-------------------|-------------------|---------------|-------------|--------|
| 1  | Lerwick            | LW  | UK      | 60.15             | -1.14             | 15            | 15          | BODC   |
| 2  | Wick               | WK  | UK      | 58.44             | -3.09             | 15            | 15          | BODC   |
| 3  | Aberdeen           | AB  | UK      | 57.14             | -2.08             | 15            | 15          | BODC   |
| 4  | Leith              | LE  | UK      | 55.99             | -3.18             | 15            | 15          | BODC   |
| 5  | North Shields      | NS  | UK      | 55.01             | -1.44             | 15            | 15          | BODC   |
| 6  | Whitby             | WH  | UK      | 54.49             | -0.61             | 15            | 15          | BODC   |
| 7  | Cromer             | CR  | UK      | 52.93             | 1.30              | 15            | 15          | BODC   |
| 8  | Lowestoft          | LT  | UK      | 52.47             | 1.75              | 15            | 15          | BODC   |
| 9  | Dover              | DV  | UK      | 51.11             | 1.32              | 15            | 15          | BODC   |
| 10 | Calais             | CA  | FR      | 50.97             | 1.87              | 60            | 60          | GESLA  |
| 11 | Dunkerque          | DK  | FR      | 51.05             | 2.37              | 60            | 60          | GESLA  |
| 12 | Cadzand            | CZ  | NE      | 51.38             | 3.38              | 10            | 10          | RWS    |
| 13 | Westkapelle        | WL  | NE      | 51.52             | 3.43              | 10            | 10          | RWS    |
| 14 | Vlissingen         | VL  | NE      | 51.44             | 3.60              | 10            | 10          | RWS    |
| 15 | Terneuzen          | TE  | NE      | 51.33             | 3.83              | 10            | 10          | RWS    |
| 16 | Roompot buiten     | RM  | NE      | 51.62             | 3.68              | 10            | 10          | RWS    |
| 17 | Hansweert          | HW  | NE      | 51.45             | 4.00              | 10            | 10          | RWS    |
| 18 | Bath               | BA  | NE      | 51.40             | 4.22              | 10            | 10          | RWS    |
| 19 | Euro platform      | EU  | NE      | 51.99             | 3.28              | 10            | 10          | RWS    |
| 20 | Brouwershavensche Gat 08 | BH | NE  | 51.75 | 3.82 | 10 | 10 | RWS |
| 21 | Lichteiland Goeree | LG | NE  | 51.93 | 3.67 | 10 | 10 | RWS |
| 22 | Hoek van Holland   | HH  | NE      | 51.98             | 4.12              | 10            | 10          | RWS    |
| 23 | Scheveningen       | SC  | NE      | 52.10             | 4.26              | 10            | 10          | RWS    |
| 24 | Den Helder         | DH  | NE      | 52.96             | 4.74              | 10            | 10          | RWS    |
| 25 | Oudeschild         | OS  | NE      | 53.03             | 4.85              | 10            | 10          | RWS    |
| 26 | Texel Noordzee     | TX  | NE      | 53.12             | 4.73              | 10            | 10          | RWS    |
| 27 | Kornwerderzand buiten | KW | NE  | 53.07 | 5.33 | 10 | 10 | RWS |
| 28 | Vlieland haven     | VH  | NE      | 53.30             | 5.09              | 10            | 10          | RWS    |
| 29 | West–Terschelling  | TL  | NE      | 53.36             | 5.22              | 10            | 10          | RWS    |
| 30 | Terschelling Noordzee | TN | NE  | 53.44 | 5.33 | 10 | 10 | RWS |
| 31 | Nes                | NE  | NE      | 53.43             | 5.77              | 10            | 10          | RWS    |
| 32 | Wierumergronden    | WG  | NE      | 53.52             | 5.96              | 10            | 10          | RWS    |
| 33 | Lauwersoog         | LR  | NE      | 53.41             | 6.20              | 10            | 10          | RWS    |
| 34 | Schiermonnikoog    | SM  | NE      | 53.47             | 6.20              | 10            | 10          | RWS    |
| 35 | Huibergat          | HG  | NE      | 53.57             | 6.40              | 10            | 10          | RWS    |
| 36 | Eemshaven          | EE  | NE      | 53.45             | 6.83              | 10            | 10          | RWS    |
| 37 | Delfzijl           | DF  | NE      | 53.33             | 6.93              | 10            | 10          | RWS    |
| 38 | Nieuwe Statenzijl  | NZ  | NE      | 53.23             | 7.21              | 10            | 10          | RWS    |
| 39 | Borkum–Suedstrand  | BK  | DE      | 53.58             | 6.66              | 1             | 10          | BAFG   |
| 40 | Emshoern           | EH  | DE      | 53.49             | 6.84              | 1             | 10          | BAFG   |
| N | Station Name               | Abb | Country/Land abbreviations | Latitude (degree) | Longitude (degree) | Δt orig (min) | Δt use (min) | Source |
|---|---------------------------|-----|----------------------------|------------------|-------------------|--------------|--------------|--------|
| 41 | Borkum–Fischerthalje      | BF  | DE                         | 53.56            | 6.75              | 1            | 10           | BAFG   |
| 42 | Emden                     | EM  | DE                         | 53.33            | 7.18              | 1            | 10           | BAFG   |
| 43 | Norderney–Riffgat          | ND  | DE                         | 53.70            | 7.16              | 1            | 10           | BAFG   |
| 44 | Langeoog                  | LA  | DE                         | 53.72            | 7.52              | 1            | 10           | BAFG   |
| 45 | Spiekeroog                | SK  | DE                         | 53.75            | 7.68              | 1            | 10           | BAFG   |
| 46 | Wangerooge–West           | WW  | DE                         | 53.78            | 7.87              | 1            | 10           | BAFG   |
| 47 | Wangerooge–Nord           | WN  | DE                         | 53.81            | 7.93              | 1            | 10           | BAFG   |
| 48 | Mellumplace               | MP  | DE                         | 53.77            | 8.09              | 1            | 10           | BAFG   |
| 49 | LT Alte Weser             | AW  | DE                         | 53.86            | 8.13              | 1            | 10           | BAFG   |
| 50 | Helgoland–Suedhafen       | HS  | DE                         | 54.18            | 7.89              | 1            | 10           | BAFG   |
| 51 | Helgoland–Binnenhafen     | HE  | DE                         | 54.18            | 7.89              | 1            | 10           | BAFG   |
| 52 | Cuxhaven–Steubenhoeft     | CU  | DE                         | 53.87            | 8.72              | 1            | 10           | BAFG   |
| 53 | Mittelgrund               | MG  | DE                         | 53.94            | 8.64              | 1            | 10           | BAFG   |
| 54 | Hamburg–St. Pauli         | HB  | DE                         | 53.55            | 9.97              | 1            | 10           | BAFG   |
| 55 | Buesum                    | BU  | DE                         | 54.12            | 8.86              | 1            | 10           | BAFG   |
| 56 | Eidersperrwerk            | EI  | DE                         | 54.27            | 8.85              | 1            | 10           | BAFG   |
| 57 | Husum                     | HU  | DE                         | 54.47            | 9.03              | 1            | 10           | BAFG   |
| 58 | Wittduen                  | WI  | DE                         | 54.63            | 8.39              | 1            | 10           | BAFG   |
| 59 | Dagebuell                 | DA  | DE                         | 54.73            | 8.68              | 1            | 10           | BAFG   |
| 60 | Hoernum                   | HR  | DE                         | 54.76            | 8.30              | 1            | 10           | BAFG   |
| 61 | Lii                        | LS  | DE                         | 55.02            | 8.44              | 1            | 10           | BAFG   |
| 62 | Hojer                     | HO  | DK                         | 54.96            | 8.66              | 10           | 10           | KDI    |
| 63 | Havnbe                   | HY  | DK                         | 55.09            | 8.57              | 10           | 10           | KDI    |
| 64 | Ribe                      | RI  | DK                         | 55.34            | 8.68              | 10           | 10           | KDI    |
| 65 | Esbjerg                   | EJ  | DK                         | 55.47            | 8.42              | 10           | 10           | KDI    |
| 66 | Hvide Sande (Havet)       | HV  | DK                         | 56.00            | 8.11              | 10           | 10           | KDI    |
| 67 | Thorsminde (Havn)         | TS  | DK                         | 56.37            | 8.12              | 10           | 10           | KDI    |
| 68 | Thyboron (Havn)           | TH  | DK                         | 56.71            | 8.22              | 10           | 10           | KDI    |
| 69 | Tregde                    | TG  | NO                         | 58.01            | 7.56              | 10           | 10           | Kartv  |
| 70 | Stavanger                 | SV  | NO                         | 58.97            | 5.73              | 10           | 10           | Kartv  |
| 71 | Bergen                    | BG  | NO                         | 60.39            | 5.32              | 10           | 10           | Kartv  |
| 72 | Maloy                     | MY  | NO                         | 61.94            | 5.11              | 10           | 10           | Kartv  |
| 73 | Sheerness                 | SH  | UK                         | 51.45            | 0.74              | 15           | 15           | IOC    |
| 74 | Ostend                    | OE  | BE                         | 51.23            | 2.92              | 5            | 10           | IOC    |
| 75 | Hthshals                  | HI  | DK                         | 57.60            | 9.97              | 10           | 10           | IOC    |
| 76 | Goteborg-Torshamnen       | GT  | SW                         | 57.68            | 11.78             | 5            | 10           | IOC    |
| 77 | Smogen                    | SG  | SW                         | 58.35            | 11.22             | 5            | 10           | IOC    |

Notes:

[1] Index

[2] Station name

[3] Station abbreviation used in the figures

[4] Country/Land abbreviations: UK United Kingdom, FR France, BE Belgium, NE Netherlands, DE Germany, DK Denmark, SW Sweden, NO Norway

[5] Latitude

[6] Longitude

[7] Original data time interval in file from issuing source

[8] Data time interval used in the spectral analysis, averaging data from the issuing source where necessary
[9] Issuing source abbreviations: BODC (British Oceanographic Data Centre) https://bodc.ac.uk/data/hosted_data_systems/sea_level/uk_tide_gauge_network/, GESLA (Global Extreme Sea Level Analysis) https://www.gesla.org, RWS (Rijkswatersaat Waterinfo) https://waterinfo.rws.nl/#!/nav/expert/alle-groepen/ , BAFG (Bundesanstalt fuer Gewaesserkunde) email communication with Wilfried Wiechmann at Datenstelle-M1@bafg.de , KDI (Kystdirektoratet) https://kystatlas.kyst.dk/public2/data/vandstand/vandstand.html, Kartv (Kartverket) api.sehavniva.no/tideapi_en.html, IOC (Intergovernmental Oceanographic Commission, Sea level Monitoring Facility) www.ioc-sealevelmonitoring.org/index.php
Table S2. Summary of maritime incidents in the North Sea area during Storm Xaver 5–6 Dec 2013.

Notes:

| N  | Ship/Platform Name or Incident | Abb  | Latitude (deg) | Longitude (deg) | Date (GMT dd/mm/yyyy) | Time GMT hh:mm | Source                                                                 |
|----|--------------------------------|------|----------------|----------------|-----------------------|----------------|-------------------------------------------------------------------------|
| 1  | Burak Bayraktar                 | BRK  | 53.19          | 4.79           | 05/12/2013            | 23:40          | Fleet20131207, 24Liveblog                                              |
| 2  | cutter GO–20                   | G2O  | 51.85          | 3.94           | 05/12/2013            | 14:00          | 24Liveblog, Granneman                                                  |
| 3  | Balticborg                     | BLT  | 53.42          | 4.80           | 06/12/2013            | 08:00          | 24Liveblog, Granneman                                                  |
| 4  | Elka Athina                    | ELK  | 53.64          | 4.13           | 06/12/2013            | 15:17          | 24Liveblog, Granneman                                                  |
| 5  | lost containers                | cnt  | 51.31          | 3.75           | 05/12/2013            | 19:00          | GVA20131205                                                            |
| 6  | Ladybug                        | LDB  | 51.30          | 4.27           | 05/12/2013            | 17:00          | GVA20131205                                                            |
| 7  | incident4                      | inc  | 52.71          | 5.27           | 05/12/2013            | 14:00          | Granneman                                                              |
| 8  | Pauline Russ                   | PLN  | 53.85          | 8.83           | 06/12/2013            | 07:40          | Reemts                                                                  |
| 9  | FINO1                          | FN1  | 54.01          | 6.59           | 06/12/2013            | 00:00          | FINO1                                                                   |
| 10 | Fano–1                         | Fa1  | 55.35          | 8.23           | 05/12/2013            | 22:00          | DMI                                                                     |
| 11 | Fano–2                         | Fa2  | 55.35          | 8.23           | 06/12/2013            | 10:00          | DMI                                                                     |
| 12 | Nymindegab–1                   | Ny1  | 55.81          | 8.23           | 05/12/2013            | 16:00          | DMI                                                                     |
| 13 | Nymindegab–2                   | Ny2  | 55.81          | 8.23           | 05/12/2013            | 17:30          | DMI                                                                     |
| 14 | Nymindegab–3                   | Ny3  | 55.81          | 8.23           | 06/12/2013            | 00:30          | DMI                                                                     |
| 15 | Nymindegab–4                   | Ny4  | 55.81          | 8.23           | 06/12/2013            | 13:30          | DMI                                                                     |
| 16 | Hirtshals–1                    | Hi1  | 57.61          | 9.96           | 05/12/2013            | 20:00          | DMI                                                                     |
| 17 | Hirtshals–2                    | Hi2  | 57.61          | 9.96           | 05/12/2013            | 21:30          | DMI                                                                     |
| 18 | Westerland–1                   | We1  | 54.92          | 8.22           | 05/12/2013            | 19:50          | LSH                                                                     |
| 19 | Westerland–2                   | We3  | 54.92          | 8.22           | 06/12/2013            | 03:00          | LSH                                                                     |
| 20 | Westerland–3                   | We3  | 54.92          | 8.22           | 06/12/2013            | 15:14          | LSH                                                                     |

[1] Index
[2] Ship/platform name or incident identifier
[3] Abbreviation used in the figures
[4] Latitude
[5] Longitude
[6] Date of incident
[7] Time of incident
[8] Source:

- 24liveblog: Internet site: 24liveblog, Storm 5-6 December 2013 https://live.24liveblog.com/live/UYXaD, last access: 14 Apr 2020
- FINO1: Internet site: FINO1, 15-m wave damaged FINO1, 08Jan2014. http://www.fino1.de/meldungen/alle-meldungen/137-15-meter-welle-beschaedigt-fino1
- Fleet20131207: Internet site: Fleetmon, Container ship Burak Bayraktar in trouble off Texel, Netherlands, (correspondent: Mikhail Voytenko, 7Dec2013 06:31) https://www.fleetmon.com/maritime-news/2013/2810/container-ship-burak-bayraktar-trouble-texel-nethe/
- Granneman: Email communication with Edwin Granneman, Netherlands Coastguard, 27 Feb. 2020
- GVA20131205: GVA, Vijf containers even op drift op de Schelde, 05/12/2013 20:57. https://www.gva.be/cnt/aid1500792/vijf-containers-op-drift-op-de-schelde-2
- Reemts: Email communication with Antke Reemts of the German Maritime Search and Rescue Service, 20 Sep. 2018
- DMI: Analysis of data from Denmark's Kystdirektoratet website (https://kyst.dk/soeterritoriet/maalinge-og-data/)
- LSH: Digitized time series data of significant wave height from Luecht, Fabian and Ove Peters, Bericht über die Sturmflut vom 05.-06.12.2013 an der Westküste Schleswig-Holsteins, Landesbetrieb für Küstenschutz, Nationalpark und Meeresschutz Schleswig-Holstein, Husum 26Feb2014, 19pp. [pdf document properties: title=Lfd; Author=Thorsten Nommensen; datestamp: 11Dec2018]
Table S3. Sorted list of maximum ranges of up-crossing oscillations derived from the short period time series reconstructions for each North Sea tide gauge station of this analysis.

| N  | Station Name                  | Range (cm) | Midpoint of Oscillation (h after start 5 Dec 2013) | Duration of Oscillation (h) |
|----|-------------------------------|------------|---------------------------------------------------|-----------------------------|
| 1  | Thorsminde (Havn)             | 97.1       | 14.58                                             | 2.83                        |
| 2  | Hvide Sande (Havet)           | 53.5       | 19.67                                             | 2.00                        |
| 3  | Brouwershavensche Gat 08      | 51.1       | 16.42                                             | 3.17                        |
| 4  | Terneuzen                     | 51.0       | 38.58                                             | 3.50                        |
| 5  | Cadzand                       | 50.7       | 37.67                                             | 3.67                        |
| 6  | Westkapelle                   | 50.3       | 12.92                                             | 3.50                        |
| 7  | Bath                          | 45.9       | 39.67                                             | 3.67                        |
| 8  | Roompot buiten                | 45.7       | 13.08                                             | 3.17                        |
| 9  | Scheveningen                  | 45.3       | 15.92                                             | 1.50                        |
| 10 | Calais                        | 45.2       | 27.50                                             | 3.00                        |
| 11 | Hansweert                     | 44.9       | 39.00                                             | 3.67                        |
| 12 | Ostend                        | 43.1       | 35.83                                             | 3.33                        |
| 13 | Vlissingen                    | 42.2       | 13.17                                             | 3.67                        |
| 14 | Whitby                        | 36.9       | 10.38                                             | 2.25                        |
| 15 | Huibergat                     | 34.7       | 18.75                                             | 3.17                        |
| 16 | Delfzijl                      | 34.3       | 32.67                                             | 2.00                        |
| 17 | Thyboron (Havn)               | 34.0       | 14.83                                             | 2.00                        |
| 18 | Wierumergronden               | 33.3       | 19.42                                             | 1.50                        |
| 19 | Texel Noordzee                | 33.1       | 41.08                                             | 3.17                        |
| 20 | Hoek van Holland              | 31.9       | 19.83                                             | 2.67                        |
| 21 | Dunkerque                     | 31.6       | 21.00                                             | 4.00                        |
| 22 | Terschelling Noordzee         | 31.6       | 13.33                                             | 4.33                        |
| 23 | North Shields                 | 29.3       | 9.50                                              | 2.50                        |
| 24 | Dover                         | 29.2       | 35.38                                             | 3.25                        |
| 25 | Leith                         | 29.2       | 8.63                                              | 4.25                        |
| 26 | Hamburg–St. Pauli             | 28.6       | 26.02                                             | 3.50                        |
| 27 | Nieuwe Statenzijl             | 27.9       | 21.58                                             | 2.83                        |
| 28 | Lowestoft                      | 27.4       | 15.00                                             | 1.00                        |
| 29 | Borkum–Suedstrand             | 27.1       | 14.43                                             | 2.33                        |
| 30 | Den Helder                    | 26.7       | 3.67                                              | 3.33                        |
| 31 | Cromer                        | 26.0       | 10.38                                             | 4.75                        |
| 32 | Eemshaven                     | 25.8       | 33.58                                             | 1.50                        |
| 33 | Schiermonnikoog               | 24.7       | 19.67                                             | 4.00                        |
| 34 | Emshoorn                      | 24.5       | 19.93                                             | 3.67                        |
| 35 | Lauwersoog                    | 24.0       | 19.58                                             | 4.17                        |
| 36 | Wangerooge–Nord               | 23.7       | 15.35                                             | 1.50                        |
| 37 | Husum                         | 23.3       | 5.10                                              | 4.00                        |
| 38 | Emden                         | 22.7       | 8.35                                              | 3.83                        |
| 39 | Esbjerg                       | 21.9       | 14.33                                             | 1.00                        |
| 40 | Eidersperrwerk                | 21.8       | 22.52                                             | 3.50                        |
Table S3a (continued)

| N  | Station Name                  | Range (cm) | Midpoint of Oscillation (h after start 5 Dec 2013) | Duration of Oscillation (h) |
|----|-------------------------------|------------|----------------------------------------------------|-----------------------------|
| 41 | Kornwerderzand buiten         | 21.7       | 30.17                                              | 4.00                        |
| 42 | Cuxhaven–Steubenhoef           | 20.2       | 9.52                                               | 3.50                        |
| 43 | Lerwick                       | 19.9       | 45.50                                              | 0.50                        |
| 44 | Hojer                         | 19.8       | 29.42                                              | 1.50                        |
| 45 | Dagebuell                     | 19.1       | 22.43                                              | 3.67                        |
| 46 | Nes                           | 19.1       | 24.33                                              | 2.00                        |
| 47 | Ribe                          | 18.9       | 27.17                                              | 1.67                        |
| 48 | Borkum–Fischerbalje           | 18.9       | 7.02                                               | 3.50                        |
| 49 | Norderney–Riffgat             | 18.7       | 7.27                                               | 3.33                        |
| 50 | Langeoog                      | 18.6       | 15.02                                              | 3.17                        |
| 51 | Hirtshals                     | 18.5       | 23.75                                              | 0.83                        |
| 52 | West–Terschelling             | 18.5       | 41.92                                              | 3.83                        |
| 53 | Lichteiland Goeree            | 18.5       | 13.25                                              | 3.50                        |
| 54 | Hoernum                       | 18.4       | 13.52                                              | 3.83                        |
| 55 | Buesum                        | 18.4       | 22.68                                              | 3.50                        |
| 56 | Mellumplate                   | 18.0       | 45.68                                              | 3.17                        |
| 57 | Spiekeroog                    | 17.8       | 16.43                                              | 1.33                        |
| 58 | Sheerness                     | 17.2       | 8.00                                               | 3.50                        |
| 59 | Oudeschild                    | 17.0       | 4.00                                               | 3.33                        |
| 60 | LT Alte Weser                 | 16.6       | 8.35                                               | 3.50                        |
| 61 | GoteborgTorshamnen            | 15.0       | 19.75                                              | 3.17                        |
| 62 | Wangerooge–West               | 14.4       | 15.43                                              | 3.33                        |
| 63 | Havneby                       | 14.1       | 15.58                                              | 2.83                        |
| 64 | Wittduen                      | 13.5       | 13.60                                              | 4.00                        |
| 65 | Euro platform                 | 13.5       | 26.83                                              | 1.67                        |
| 66 | Vlieiland haven               | 13.1       | 14.75                                              | 1.83                        |
| 67 | Smogen                        | 13.0       | 25.08                                              | 1.17                        |
| 68 | Wick                          | 12.9       | 6.62                                               | 2.25                        |
| 69 | Mittelgrund                   | 12.5       | 9.27                                               | 3.67                        |
| 70 | Aberdeen                      | 11.9       | 23.63                                              | 0.75                        |
| 71 | Stavanger                     | 11.3       | 9.67                                               | 3.33                        |
| 72 | Helgoland–Suedhafen           | 10.3       | 30.27                                              | 1.33                        |
| 73 | List                          | 8.4        | 27.27                                              | 4.00                        |
| 74 | Helgoland–Binnenhafen         | 7.9        | 8.10                                               | 3.67                        |
| 75 | Tregde                        | 5.7        | 13.25                                              | 3.50                        |
| 76 | Mafoy                         | 5.6        | 8.92                                               | 2.50                        |
| 77 | Bergen                        | 4.9        | 6.08                                               | 3.50                        |
| N  | Location                  | Country | Latitude (degree) | Longitude (degree) | Return Period (year) | Source  |
|----|----------------------------|---------|-------------------|--------------------|----------------------|---------|
| 1  | Thornham                  | UK      | 52.96             | 0.58               | 4578                 | WEA15   |
| 2  | Blakeney                   | UK      | 52.95             | 1.01               | 1876                 | WEA15   |
| 3  | Spurn Head                 | UK      | 53.58             | 0.12               | 1800                 | WEA15   |
| 4  | Burnham Overy Staith      | UK      | 52.96             | 0.75               | 1736                 | WEA15   |
| 5  | Scott Head                 | UK      | 52.98             | 0.71               | 1513                 | WEA15   |
| 6  | Stiffkey                   | UK      | 52.95             | 0.93               | 1331                 | WEA15   |
| 7  | Hull                       | UK      | 53.73             | -0.27              | 1285                 | WEA15   |
| 8  | Rye                        | UK      | 50.95             | 0.74               | 1166                 | WEA15   |
| 9  | Roskilde Havn              | DK      | 55.70             | 12.10              | 976                  | DEA19   |
| 10 | Dover                      | UK      | 51.11             | 1.32               | 843                  | SW20    |
| 11 | Bridlington                | UK      | 54.08             | 0.18               | 824                  | WEA15   |
| 12 | Kings Lynn                 | UK      | 52.76             | 0.39               | 800                  | WEA15   |
| 13 | Immingham                  | UK      | 53.63             | -0.19              | 787                  | SW20    |
| 14 | Boston                     | UK      | 52.98             | -0.03              | 707                  | WEA15   |
| 15 | Wells–Next–The–Sea         | UK      | 52.95             | 0.85               | 692                  | WEA15   |
| 16 | Scarborough                | UK      | 54.28             | -0.39              | 626                  | WEA15   |
| 17 | Whitby                     | UK      | 54.49             | -0.61              | 588                  | WEA15   |
| 18 | Pevensey Bay               | UK      | 50.82             | 0.34               | 449                  | WEA15   |
| 19 | North Shields              | UK      | 55.01             | -1.44              | 429                  | WEA15   |
| 20 | Thorshimde Havet           | DK      | 56.40             | 8.10               | 407                  | DEA19   |
| 21 | Kobenhavns Havn           | DK      | 55.70             | 12.60              | 285                  | DEA19   |
| 22 | Thorshimde Havn            | DK      | 56.40             | 8.10               | 243                  | DEA19   |
| 23 | Hornbaek Havn              | DK      | 56.10             | 12.50              | 220                  | DEA19   |
| 24 | Lowestoft                  | UK      | 52.47             | 1.75               | 196                  | WEA15b  |
| 25 | Holbaek Havn               | DK      | 55.70             | 11.70              | 187                  | DEA19   |
| 26 | Hals                       | DK      | 57.00             | 10.30              | 169                  | DEA19   |
| 27 | Alderburgh (Slaughden)     | UK      | 52.16             | 1.60               | 164                  | WEA15   |
| 28 | Great Yarmouth             | UK      | 52.57             | 1.73               | 146                  | WEA15   |
| 29 | Deal Pier                  | UK      | 51.22             | 1.41               | 79                   | WEA15   |
| 30 | Arun Platform              | UK      | 50.77             | -0.49              | 75                   | WEA15   |
| 31 | Delfzijl                   | NE      | 53.33             | 6.93               | 66                   | RWS14b  |
| 32 | Bruns Sluse Havet          | DK      | 55.20             | 8.70               | 63                   | DEA19   |
| 33 | Sandown                    | UK      | 50.65             | -1.15              | 49                   | WEA15   |
| 34 | Liverpool                  | UK      | 53.45             | -3.02              | 43                   | SW20    |
| 35 | Havnebyen/Sjaellands Odde  | DK      | 56.00             | 11.40              | 42                   | DEA19   |
Table S4 (continued)

| N  | Location          | Country | Latitude (degree) | Longitude (degree) | Return Period (year) | Source |
|----|-------------------|---------|-------------------|--------------------|----------------------|--------|
| 36 | Newhaven          | UK      | 50.78             | 0.06               | 42                   | WEA15  |
| 37 | Herne Bay         | UK      | 51.38             | 1.12               | 39                   | WEA15  |
| 38 | Southwold         | UK      | 52.33             | 1.68               | 39                   | WEA15  |
| 39 | Calshot           | UK      | 50.82             | -1.30              | 34                   | WEA15  |
| 40 | Odense Fjord (Gabet) | DK | 55.50             | 10.60              | 33                   | DEA19  |
| 41 | Nr. Sundby        | DK      | 57.10             | 9.90               | 31                   | DEA19  |
| 42 | Mando Havet       | DK      | 55.30             | 8.60               | 29                   | DEA19  |
| 43 | Clacton–on–Sea    | UK      | 51.79             | 1.16               | 29                   | WEA15  |
| 44 | Harwich           | UK      | 51.95             | 1.29               | 29                   | WEA15  |
| 45 | Tilbury           | UK      | 51.45             | 0.37               | 24                   | WEA15  |
| 46 | Slipshavn         | DK      | 55.30             | 10.80              | 23                   | DEA19  |
| 47 | Grena Havn        | DK      | 56.40             | 10.90              | 22                   | DEA19  |
| 48 | Ballen Havn       | DK      | 55.80             | 10.60              | 22                   | DEA19  |
| 49 | Juelsminde Havn   | DK      | 55.70             | 10.00              | 22                   | DEA19  |
| 50 | Leith             | UK      | 55.99             | -3.18              | 22                   | WEA15  |
| 51 | Aberdeen          | UK      | 57.14             | -2.08              | 20                   | SW20   |
| 52 | Cromer            | UK      | 52.93             | 1.30               | 20                   | WEA15  |
| 53 | Hansholm          | DK      | 57.10             | 8.60               | 19                   | DEA19  |
| 54 | Aarhus Havn       | DK      | 56.10             | 10.20              | 19                   | DEA19  |
| 55 | Vlissingen        | NE      | 51.45             | 3.60               | 18                   | RWS14b |
| 56 | Shoreham          | UK      | 53.83             | -0.25              | 18                   | WEA15  |
| 57 | Southend–on–Sea   | UK      | 51.52             | 0.72               | 17                   | WEA15  |
| 58 | Kalandborg Havn   | DK      | 55.70             | 11.10              | 15                   | DEA19  |
| 59 | Lemvig Havn       | DK      | 56.60             | 8.30               | 15                   | DEA19  |
| 60 | Sheerness         | UK      | 51.45             | 0.74               | 15                   | WEA15  |
| 61 | Llandudno         | UK      | 53.33             | -3.83              | 15                   | SW20   |
| 62 | Attrup            | DK      | 57.00             | 9.50               | 13                   | DEA19  |
| 63 | Roompot buiten    | NE      | 51.62             | 3.67               | 12                   | RWS14b |
| 64 | Vidaasluens–Hojer I | DK | 55.00             | 8.70               | 12                   | DEA19  |
| 65 | Graabyd Barre     | DK      | 55.40             | 8.30               | 12                   | DEA19  |
| 66 | Portsmouth        | UK      | 50.80             | -1.11              | 12                   | SW20   |
| 67 | Bogense Havn      | DK      | 55.60             | 10.10              | 11                   | DEA19  |
| 68 | Koros Havn        | DK      | 55.30             | 11.10              | 10                   | DEA19  |
| 69 | Kerteminde Havn   | DK      | 55.50             | 10.70              | 10                   | DEA19  |
| 70 | Southampton       | UK      | 50.88             | -1.40              | 10                   | WEA15  |
Table S4 (continued)

| N  | Location            | Country | Latitude (degree) | Longitude (degree) | Return Period (years) | Source                  |
|----|---------------------|---------|-------------------|--------------------|-----------------------|-------------------------|
| 71 | Ullapool            | UK      | 57.90             | -5.16              | 9.0                   | SW20                    |
| 72 | Randers Havn        | DK      | 56.50             | 10.00              | 8.9                   | DEA19                   |
| 73 | Hirtshals Havn      | DK      | 57.60             | 10.00              | 8.8                   | DEA19                   |
| 74 | Skagen              | DK      | 57.70             | 10.60              | 8.6                   | DEA19                   |
| 75 | Hoek van Holland    | NE      | 51.98             | 4.12               | 8.3                   | RWS14b                  |
| 76 | Dordrecht           | NE      | 51.82             | 4.67               | 7.7                   | RWS14b                  |
| 77 | Hvide Sande Havn    | DK      | 56.00             | 8.10               | 6.6                   | DEA19                   |
| 78 | Fredericia Havn     | DK      | 55.60             | 9.80               | 5.3                   | DEA19                   |
| 79 | Ribe Kammersluse Flyder | DK  | 55.30             | 8.70               | 4.5                   | DEA19                   |
| 80 | Antwerpen           | BE      | 51.22             | 4.40               | 4.5                   | NEA14                   |
| 81 | Karrebæksminde      | DK      | 55.20             | 11.60              | 4.4                   | DEA19                   |
| 82 | Den Helder          | NE      | 52.97             | 4.75               | 4.2                   | RWS14b                  |
| 83 | Heysham             | UK      | 54.03             | -2.92              | 4.0                   | WEA15                   |
| 84 | Tobermory           | UK      | 56.62             | -6.06              | 4.0                   | WEA15                   |
| 85 | Esbjerg Havn        | DK      | 55.50             | 8.40               | 3.8                   | DEA19                   |
| 86 | Skive Havn          | DK      | 56.60             | 9.10               | 3.1                   | DEA19                   |
| 87 | Ballum Sluse        | DK      | 55.10             | 8.70               | 3.0                   | DEA19                   |
| 88 | Holyhead            | UK      | 53.31             | -4.62              | 3.0                   | WEA15                   |
| 89 | Yarmouth            | UK      | 52.57             | 1.73               | 3.0                   | WEA15                   |
| 90 | Havnøby Havn        | DK      | 55.10             | 8.60               | 2.9                   | DEA19                   |
| 91 | Harlingen           | NE      | 53.17             | 5.42               | 2.9                   | RWS14b                  |
| 92 | Lymington           | UK      | 50.74             | -1.51              | 2.0                   | WEA15                   |
| 93 | Hvide Sande Havet   | DK      | 56.00             | 8.10               | 1.8                   | DEA19                   |
| 94 | Drogden Fyr         | DK      | 55.50             | 12.70              | 1.3                   | DEA19                   |
| 95 | Logster             | DK      | 57.00             | 9.20               | 1.2                   | DEA19                   |
| 96 | Koege Havn          | DK      | 55.50             | 12.20              | 1.0                   | DEA19                   |
| 97 | Stornaway           | UK      | 58.21             | -6.39              | 1.0                   | WEA15                   |
| 98 | Kinlochbervie       | UK      | 58.46             | -5.05              | 1.0                   | WEA15                   |
| 99 | Wick                | UK      | 58.44             | -3.09              | 1.0                   | WEA15                   |
| 100| West Bay Harbour    | UK      | 50.71             | -2.76              | 1.0                   | WEA15                   |
| 101| Kloster Havn        | DK      | 56.30             | 8.30               | 0.25                  | DEA19                   |
| 102| Roedvig Havn        | DK      | 55.30             | 12.40              | 0.22                  | DEA19                   |
| 103| Hvalpsund           | DK      | 56.70             | 9.20               | 0.09                  | DEA19                   |
| 104| Kalvehave           | DK      | 55.00             | 12.20              | 0.06                  | DEA19                   |

Notes:

[1] Index
[2] Location
[3] Country code
[4] Latitude
[5] Longitude
[6] Return period (years)
[8] Source:

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SECTION III. Working tables for literature survey

Table S0. Master list of tables in working notes

| Table | Content |
|-------|---------|
| S0    | Master list of tables in working notes |
| S1    | List of sources reviewed for project |
| S2    | List of normal photos of event (arranged by year and then alphabetically) |
| S3    | Ranking of storm among events; assessing importance of storm (arranged by year and then alphabetically) |
| S4    | Severe forecast (arranged by year and then alphabetically) |
| S5    | Storm not as bad as expected; not as bad as it could have been (arranged by year and then alphabetically) |
| S6    | Storm worse than expected (arranged by year and then alphabetically) |
| S7    | Extended period bad weather (arranged by year and then alphabetically) |
| S8    | Names of the storm (arranged by year and then alphabetically) |
| S9    | Satellite pictures and weather maps (arranged by year and then alphabetically) |
| S10   | Satellite altimeter strip maps (arranged by year and then alphabetically) |
| S11   | List meteorological data (arranged by year and then alphabetically) |
| S12   | Significant wave height and sea state (arranged by year and then alphabetically) |
| S13   | Wave period and other wave data (arranged by year and then alphabetically) |
| S14   | Surge reports and quantitative water levels (arranged by year and then alphabetically) |
| S15   | Water current information (arranged by year and then alphabetically) |
| S16   | Return period of water level; ranking of water level |
| S17   | Return period of wind speed; ranking of wind speed |
| S18   | Storm trajectory map (arranged by year and then alphabetically) |
| S19   | Unusual pressure drop; time series central pressure; explosive characteristics (arranged by year and then alphabetically) |
| S20   | Squall line, convective thunderstorms, tornadoes (arranged by year and then alphabetically) |
| S21   | Lightning (arranged by year and then alphabetically) |
| S22   | Meso-vortex (arranged by year and then alphabetically) |
| S23   | Meteotsunami (arranged by year and then alphabetically) |
| S24   | Infragravity wave (arranged by year and then alphabetically) |
| S25   | Wave dynamics and dike breaches; wave runup studies (arranged by year and then alphabetically) |
| S26   | Precipitation, river level dike breaches (arranged by year and then alphabetically) |
| S27   | Unusual peak of significant wave height in northern North Sea (arranged by year and then alphabetically) |
| S28   | Double surge peak from wind and travelling wave (arranged by year and then alphabetically) |
| S29   | Modelled turbulence kinetic energy in wave model (arranged by year and then alphabetically) |
| S30   | Fatalities & injuries |
| S31   | Coastal flooding and evacuations (arranged by year and then alphabetically) |
| S32   | Coastal dike heights and protection levels (arranged by year and then alphabetically) |
| S33   | Surge barrier closures (arranged by year and then alphabetically) |
| S34   | Beach damage and coastal issues (arranged by year and then alphabetically) |
| S35   | Power interruptions (arranged by year and then alphabetically) |
| S36   | List bridge closures, cancelled ferry crossings, port closures, airport cancel, rail interruptions, traffic accidents (arranged by year and then alphabetically) |
| S37   | Structural damage to wind farms and wind energy impacts (arranged by year and then alphabetically) |
| S38   | Hydropower impacts (arranged by year and then alphabetically) |
| S39   | Structural damage to buildings, pier, and cultural monuments (arranged by year and then alphabetically) |
| S40   | Forest damage and tree falls (arranged by year and then alphabetically) |
| S41   | General ship/rig emergency reports/offshore incidents/platform evacuations (arranged by year and then alphabetically) |
| S42   | Instrument failures during storm (arranged by year and then alphabetically) |
| S43   | Model results and fields (arranged by year and then alphabetically) |
| S44   | Climatological background of storm; unusual preceding weather events (arranged by year and then alphabetically) |
| S45   | Xaver surge soon after spring tide; phase of surge and tide (arranged by year and then alphabetically) |
| S46   | Tide analysis (arranged by year and then alphabetically) |
| S47   | Data filtering and discretization issues (arranged by year and then alphabetically) |
| S48   | Difficulties in modelling Storm Xaver water levels and surge (arranged by year and then alphabetically) |
| S49   | Future sea level rise and flooding effects (arranged by year and then alphabetically) |
| S50   | Storm event as manifestation of climate change (arranged by year and then alphabetically) |
| S51   | Baltic Sea events (arranged by year and then alphabetically) |
| S52   | Aftermath: new defenses & new design criteria (arranged by year and then alphabetically) |
| S53   | Worst case storm surge situation (arranged by year and then alphabetically) |
| S54   | Damage costs; insurance losses (arranged by year and then alphabetically) |
| S55   | Online data sets (arranged by year and then alphabetically) |
| S56   | Context and background information where Storm Xaver not mentioned (arranged by year and then alphabetically) |
| S57   | Climatological background for Storm Britta in Nov 2006; Storm Xaver not mentioned (arranged alphabetically) |
| S58   | Errors in source reports for Xaver (arranged by year and then alphabetically) |
| S59   | Abbreviations used in manuscript (arranged by year and then alphabetically) |
| S60   | People contacted for information about Storm Xaver (arranged by year and then alphabetically) |

Table S1. List of sources reviewed for project (arranged by year and then alphabetically)
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Table S2. List of normal photos of event (arranged by year and then alphabetically)

| Source | Full Reference and Notes |
|--------|--------------------------|
| BBC (20131206) | BBC. In pictures: Winter storm hits UK, 5 December 2013, https://www.bbc.com/news/uk-scotland-25231224 FG1. [PHOTO] Thousands evacuated from homes as storms hit much of UK. Residents on this street in Rhyll, north Wales, rescued by RNLI (Reuters). FG2. [PHOTO] British Red Cross set up rescue centre in the Denbhigshe town but say 500 people could still be in need of help (Reuters). FG3. [PHOTO] Storm hit Welsh coastline about lunchtime (AP). FG4. [PHOTO] Earlier in West Lothian lorry driver dies when vehicle blown over on to two cars (PA). FG5. [PHOTO] High winds brought down this lorry near Hamilton (PA). FG6. [PHOTO] Many roads have been closed across Scotland due to fallen trees (AP). FG7. [PHOTO] This HGV overturned and came to rest in a precarious position on the M90 Friarton Bridge near Perth (PA). FG8. [PHOTO] Meanwhile residents in Great Yarmouth Norfolk have been filling sandbags in preparation for the stormy weather moving south (Getty Images). FG9. [PHOTO] It's a scene repeated in Gorleston-on-Sea on the east coast of England as residents prepare for the worst (Reuters). FG10. [PHOTO] Elsewhere in England, high tides followed the storm's tidal surges, hitting coastal towns including Blackpool (AP). FG11. [PHOTO] The famous Blackpool beach was battered by the tide (AP). FG12. [PHOTO] In Merseyside the storm claimed a pirate ship build earlier this year out of drift wood on New Brighton beach. (Bob Warwick). FG13. [PHOTO] This dramatic shot captures the scene on the Wirral as the storm hit the north west of England (Laura Steen). FG14. [PHOTO] Further north the Cumbrian coastal village of Allonby has been battered by heavy seas (PA). FG15. [PHOTO] Many homes in Northern Ireland have been left without power due to... |
| Source                  | Content                                                                                                                                                                                                 |
|------------------------|---------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| BBC (20131206)         | BBC20131206, Deadly storm and tidal surge batter northern Europe, BBC 6 Dec 2013 (report by Anna Holligan)  
|- PHOTO: Residents of Hamburg woke up to find the historic fish market flooded  
|- PHOTO: Helsingor, southern Sweden: the coast road was flooded  
|- PHOTO: tidal surge battered Emden in northern Germany near Dutch border  
|- PHOTO: storm at Hemsby, eastern England, pushed several homes off the cliff  
|- PHOTO: in Scotland, a lorry driver was killed when his vehicle blew over  
|- PHOTO: heavy snow caused traffic chaos at Olpe, near Germany's industrial Ruhr region  
|- PHOTO: there were also traffic jams in snow parts of southern Sweden |
| BT (20131208)          | BT, Offer for Bodil: Koebte huset 15.august - nu er det vaek, 08Dec2013, 16:44, (contributor: Morten Eggert)  
|- PHOTO: house tipped over cliff onto beach, family of 3 |
| Daily Mail (20131206)  | Daily Mail, Hail storm strikes Europe causing death and destruction and leading to cancellation of hundreds of flights, 6Dec2013. (correspondent: Nick Enoch), https://www.dailymail.co.uk/news/article-2519517/Huge-storm-strikes-Europe-causing-death-destruction-leading-cancellation-hundreds-flights.html |
| Fleetmon (20131207)    | Fleetmon, Container ship Burak Bayraktar in trouble off Texel, Netherlands, (contributor: Mikhail Voytenko), 7 Dec 2013 06:31  
|- FIG: map of ship positions  
|- FIG: ship Burak Bayraktar in distress |
| GP (20131206)          | GP, Fortsatt risk for halka, 6Dec2013 (contributor: D Henriksson, K Viksson, P Sydsvik, TA Akerblom)  
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|- FIG: Trafikproblem. Traffic jam on Riksavg 40 at Tolkaubre west of Ulricehamn (Adam Bise) |
| Kristeligt Dagblad      | Kristeligt Dagblad, Stormen blaeser Skotland omkuld: Doodsfald og nebrud, (contributor: Ritzaau), 05Dec2013 12:50  
|- http://www.kristeligt-dagblad.dk/udland/stormen-bl%C3%A6ser-skotland-omkuld-d%C3%B8dsfald-og-nebrud  
|- FIG: [PHOTO] Litter bins are washed along the promenade and waves batter the sea wall in Blackpool, NW England on 5Dec2013 as high winds hit north of England and Scotland. PHOTO: Paul Ellis |
| National Wind Watch     | National Wind Watch, 10Dec2013, Xaver zeroerst ein Windrad bei Vlatten, original source: Aachener Zeitung, 6Dec2013  
|- https://www.wind-watch.org/news/2013/12/10/xaver-zeroerst-ein-windrad-bei-vlatten/  
|- FIG: [PHOTO] near Vlatten storm Xaver destroyed a wind turbine. Foto: Victorius |
| National Wind Watch     | National Wind Watch, Storm 'Xaver': Windrad sturerst auf Acker, 10Dec2013b, credit: von Manfred Reinmarr, Koelnische Rundschau, 06/12/2013, https://www.wind-watch.org/news/2013/12/10/sturm-xaver-windrad-sturzt-auf-acker/  
|- PHOTO: turbine covering the field of Wilhelm-Josef Schaefer at Vlatten.  
|- PHOTO: hollow inside of turbine |
| National Wind Watch     | National Wind Watch, Storm 'Xaver': Windrad sturerst auf Acker, 10Dec2013b, credit: von Manfred Reinmarr, Koelnische Rundschau, 06/12/2013, https://www.wind-watch.org/news/2013/12/10/sturm-xaver-windrad-sturzt-auf-acker/  
|- FIG: [PHOTO] 100 meter colossus on the field by Mechernich (photo: Kuffner)  
|- FIG: [PHOTO] wind turbine broken at 25m height level and on field  
|- FIG: [PHOTO] Amazingly hollow: wind turbine 4 investigated by experts |
| Nordbayern (20131207)   | Nordbayern, Deining: 'Xaver' reiss rotorbblatt von Windrad ab. Windkraftanlage schleuderte Eisbrocken auf die Strasse, 07/12/2013, 12:07. https://www.nordbayern.de/region/neumarkt/deining-xaver-reiss-rotorbblatt-von-windrad-ab-1.3326492  
|- FIG: wind blade sails 150m from turbine Thursday-Friday night from Anlage 7 of Deinning Windpark. Blade was damaged during mounting and was to be exchanged. Area around site closed, [Gunter Distler]  
|- FIG: Field covered with snow with woods in background |
| Spiegel International   | Spiegel International, Winter storm 'Xaver' batters northern Europe, 6 Dec 2013, 12:56  
|- http://www.spiegel.de/international/europe/tidal-surge-winter-storm-xaver-batters-northern-europe-a-937576.html#  
|- FIG1. Parts of N Europe hit on Thursday and Friday with a tidal surge as low-pressure system Xaver blows through the region, bringing icy hurricane-force winds. Here, the North Sea rages near the German town of Emden on Friday morning (Reuters).  
|- FIG2. The storm brought rain, hail and snow with the tidal surge, and the German port city of Hamburg seen its worst flooding in decades, forcing authorities to close off parts of the city center on Thursday night. Here, woman passes by the storm surge in central Hamburg (DPA)  
|- FIG3. People stand on benches in Hamburg's historic fish market which has been flooded by the Elbe River due to the storm (AFP) |
Dunbar et al (2014)  

Dunbar I, N Phipps, M Szonyi, Risk Nexus. After the storm: how the UK's flood defences performed during the surge following Xaver, Flood resilience review 09.14, Zurich Insurance Company Ltd., Mythenquai 2, 8002, Zurich, Switzerland [document properties: date 28Aug2014; author= Zurich]  

FIG. p.15. Scarborough beach front sustained significant storm damage, including damage to sea wall  

FIG. p.16. Flooded building being dried out at a location in Lowestoft  

FIG. p.17. Visible water line from the surge event at a location with protection installed.  

FIG. p.20. Post-flood clean-up operation underway in Scarborough where sea front arcades and cafes were flooded along the South Bay. The tidal level here was estimated at approximately 6m above normal levels.

Eriksen (2014)  

Eriksen J, Rekordstande i Isefjorden og Roskilde Fjord. Vejet, 138, 2-40-48, 2014  

FIG. [PHOTO] aerial view of the Thames Barrier closed during the surge

FIG11. [PHOTO] Seaweed flood line on dike at Emmapolder; west of Eemshaven

FIG8. [PHOTO] closed flood gate at Delfzijl 0

RWS (2014b)  

RWS, 2013-2014 Winter Storms in Europe. An Insurance and Catastrophe Modeling Perspective. RMS White Paper. [PDF TIMESTAMP 11Mar2014]  

FIG8. [PHOTO] Storm flood at Landungsbrueckengebaude on 6Dec2013 0420

FIG19. [PHOTO] Aerial oblique photo from 06/12/2013 of the height of Bergenmeersen and Paardeweide (viewing direction from upstream to downstream)

Goennert et al (2014)  

Goennert G, O Mueller, M Schaper, K Sossidi, Die Sturmflut nach dem Tief Xaver von 5. bis 7. Dezember 2013. Berichte des Landesbetriebes Strassen, Bruecken und Gewaesser (LSBG), Freie und Hansestadt Hamburg, Nr. 16/2014, 26pp.

FIG6. [PHOTO] Moorfleet main dike on morning of 6Dec2013

FIG8. [PHOTO] Storm flood at Landungsbrueckengebaude on 6Dec2013 0420

FIG9. [PHOTO] Photo of level from the old rail bridge at Frederiksund taken on a seith with still weather and normal water levels. One can see a single bridge pilefrom the old rail bridge and in the background railbed causeway (Jesper Eriksen)

FINO1 (20140108)  

FINO1, 15-m wave damaged FINO1, 08Jan2014. http://www.fino1.de/meldungen/alle-meldungen/137-15-meter-welle-beschaeidigt-fino1

FIG. [PHOTO] ripped 15m deck grating on 15m side of the FINO1 platform

FIG. [PHOTO] photo smashed small wooden deck at 17m

Goennert and Heyken (2014)  

Knaack H and H Heyken, Xaver hatte sehr schwere Stumflut im Gepaeck, Jahresbericht 2013. Der Zukunft verplichtet, NLWKN, Niedersaechsischer Landesbetrieb fuer Wasserwirtschaft, Kuesten- und Nutenschutz, pp.8-9, document date stamp 24Apr2014.

FIG. [PHOTO] 60000 cubic meters sand will be brought to Juist to strengthen the dunes

RMS (2014)  

RMS, 2013-2014 Winter Storms in Europe. An Insurance and Catastrophe Modeling Perspective. RMS White Paper. [PDF TIMESTAMP 11Mar2014]  

FIG8. [PHOTO] Repair work underway at the breached Boston Dike

RWS (2014b)  

RWS, Stormvloedrapport van 5 t/m 7 december (SR91) Sint-Nicolaasvloed 2013, Watermanagementcentrum Nederland, Rijkswaterstaat, prepared by Ing. J. Kroos, 19 Mar 2014b, 48 pp

FIG. [PHOTO] closed flood gate at Delfzijl 06Dec2013

FIG11. [PHOTO] Seaweed flood line on dike at Eemmapolder; west of Eemshaven

Staneva et al (2014)  

Staneva I, K Wahle, E Stanev, Response of the German Bight Hydro and Sediment Dynamics to Wave, Tidal and Atmospheric Forcing, 3rd GODAE OceanView Coastal Oceans and Shelf Seas Task Team (COSS-TT) International Coordination Workshop, 21-24 January 2014, Rnccon Beach Resort, Puerto Rico, 36pp

FIG. [PHOTO] wave impact on pier in Germany

FIG. [PHOTO] flooded fish market

Thorne (2014)  

Thorne, Colin. Geographies of UK flooding in 2013/4, The Geographical Journal, 180, 297-309, 2014.

FIG. [PHOTO] aerial view of the Thames Barrier closed during the surge

Van Rooijen and Oost (2014)  

van Rooijen A, A Oost, Memo: Regionale advisering Ameland Noordwest, Deltares, 1209381-008-ZKS-0008, 43pp, 18Dec2014 [PDF document properties: ttl=Regional advisering: Ameland NW; author=Arnold van Rooijen; keywords: 1209381-008-ZKS-0008; date stamp: 18/12/2014]

FIG.4. [PHOTO] Impacts on the westkop of Ameland after the Sinterklaasstorm of 5-6Dec2013 (exact location unknown)

Axer et al (2015)  

Axer T, T Bistry, M Klawa, M Mueller, M Suessner, Deutsche Ruck Stromvloed dokumentation 2013 Deutschland, 2013, Deutsche Rueckversicherungs-Aktiengesellschaft, Hansaallee 177, 40549 Dusseldorf, www.deutschreueck.de [pdf document information: author=filiz; date stamp=07Aug2015]

FIG. p.59. [PHOTO] topped Christmas tree in front of the Schloss Bellevue, residence of Bundespräsident Joachim Gauck

Carrion (2015)  

Carrion Arextabala, BI, Morphological impact of the Sinterklaas storm at Het Zwin. Numerical modelling with Xbeach, M.Sc. Civil Engineering, Delft University of Technology, 2015.

FIG2.10.[PHOTO] General view of the Dutch dunes at Het Zwin and records of

in 2m of seawater from 1953 surge with ground floor washed away)
large portion of dunes scarred by Sinterklaasstorm

-FIG11. [PHOTO] Record of the overwash event

Fischer et al. (2015)

-Fischer, JG, C Senet, A Schneehorst, O Ouitzen, S Schirmel, K Herklotz, Sea state measurements in Germanys first offshore wind farm “alpha ventus”, in the south-eastern parts of the North Sea, 2015 IEEE/OES Eleventh Current, Waves and Turbulence Measurement (CWTM), 2015 [PDF document properties: datestamp: 14/01/2015]

-FIG2. [PHOTO] Extreme wave events at FINO1 in German Bight

(a) FINO1 research platform in German Bight
(b) Damage to lower hatchway of FINO1 (2013)

NLWKN (20151210)

NLWKN20151210, Sturmflutwarnung des Betriebsteil Norden-Norderney, NLWKN Niedersachsiscscher Landesbetrieb fuer Wasserwirtschaft, Kuesten- und Naturschutz, Niedersachsen, document date stamp 10Dec2015.

FIG. [PHOTO] Harlingerland coast - Nikolausflut 2013; sea on dyke
FIG. [PHOTO] Neuharlingersiel - Nikolausflut 2013; coastal walkway flooded
FIG. [PHOTO] unidentified scene on German coast; sea on dyke

Spencer et al (2015)

Spencer T, SM Brooks, BR Evans, JA Tempest, J Moeller, Southern North Sea storm surge event of Dec.5, 2013: Water levels, waves, and coastal impacts, Earth Science Reviews, 146, 120-145, 2015.

-FIG2. [PHOTO] Impacts of storm surge of 5-6Dec2013:
(a) Fresh cliff falls overlying near basal notchling, Covenlythe Cliffs Suffolk
(b) sand dune cliffing and retreat, Donna Nook North Lincolnshire
(c) large reactivated washover fan, central Scoll Head North Norfolk cost
(d) breaching of the Cley-Weybourne barrier with flooding of freshwater marshes
(e) collapse of the Wallberswick-Dunwich gravel barrier, Dingle Marshes Suffolk
(f) multiple breaches in the NW section earthen flood defense bank, Blakeney Freshes, North Norfolk

-FIG8. [PHOTO] Local variations in surge water levels, North Norfolk coast
(a) Massive debris bank reaching 5.95m ODN, Privet Hill, Scoll Head Island
(b) typical back barrier driftline at 5.52m ODN Great Aster Marsh, Scoll Head Island
(c) drift at up to 6.30m ODN on exposed seaward-facing dunes Holme
(d) water level at limit of storm surge inundation 4.43m ODN Holme Golf Course
(e) cliffing on seaward margin of Holkam Gap embankment 6.37m ODN
(f) Driftline in pine plantation, Holkam Gap 4.46m ODN

-FIG9. [AERIAL PHOTO] Net shoreline movement (NSM, m) dynamics
(a) Covenlythe, Suffolk Coast (Aug 2013-08Dec2013),
(b) Holkham Gap, North Norfolk (Aug 2013-16Jan2014),
(c) Scoll Head Island (Aug 2013-14Feb and 03Mar2014)

-Vanmassenhove (2015)

Vanmassenhove, Niels, Storm surge measures ports Flemish coast, Blankenberge, Tuesday February 3rd, Maritimes Sientverlening en Kust, Coastal Division, Flanders Hydraulic Research.[document properties: title=Geintegreerd Kustveiligheidsplan; author=Maarten; datestamp=27/02/2015]

-FigS9: [PHOTO] view of one of the critical points in the harbour of Ostend during the December 2013 storm
-FigS10: [PHOTO] emergency workers placing sandbags Ostend during Dec2013 flood
-FigS11: [PHOTO] harbour of Ostend during Dec 2013 storm

Matelski (2016)

Matelski, Birgit, Erfahrungen aus der Sturmflut Xaver von 5. und 6.12.2013 und dem Weihnachtschwohrwasser 2014 in Schleswig-Holstein, IWASA 2016 Tagungsbeitrag, (46. IWASA, 7-8 Januar 2016; Internationales Wasserbau-Symposium Aachen. [pdf document properties: autor=sonja; datestamp: 26Apr2016]

-FIG7. [PHOTO] Aerial photo showing retreat of southern tip of Sylt Island (Hoernum Odde)
FIG8. [PHOTO] Photo of dikes damage Nordstrand Alter Koog
FIG9. [PHOTO] Loose grass being gathered from inland dike

Nederhoff et al (2016)

Nederhoff K, E Elias, T Vermaas, Erosion op Ameland Noordwest. Modelstudie: simulaties met Delft3D en XBeach, Deltas, 117pp, July, 2016

-FIG2.4. [PHOTO] Impact on the westklop of Ameland after the Sinterklaassstorm 5-6Dec2013

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Sorensen CS, Water NOT wanted - Coastal floods and flooding protection in Denmark, In RA Herrmann & J Jensen (eds), Sicherung von Daemmen, Deichen und Staunagen: Handbuch fuer Theorie und Praxis (Vol V, pp3-21). Siegen: Universiataet Siegen, 2016

-FiG12. [PHOTO] High water levels in the town of Lemvig, the Limfjord, during Storm Xaver 05Dec2013. Note the flood protection wall winding along the harbour front. (water level at 40cm of crest)
-FiG13. [PHOTO] Floods in identical locations in 1921 and during Xaver 6Dec2013 at Frederiksklund (left) and Helsinore (Seeland).
Sources: mx.dk (top left), helsingornetavis.dk (top right), and Ministeriet for Offentlige Arbejder (1922)
Brooks et al (2017) Brooks, SM, T Spencer, EK Christie, Storm impacts and shoreline recovery: Mechanisms and controls in the southern North Sea, Geomorphology, 283, 48-60, 2017.

-RIG2. [PHOTO] Superfrontage 2 on teh North Norfolk Coast.
(a) Brancaster Bay looking east towards Scolt Head Island in the far distance, showing barrier cliffing following the 5Dec2013 storm (photo SM Brooks 12/01/2016)
(b) the barrier at Holkham Bay looking east towards Wells-next-the-Sea shortly after the 5-6Dec2013 storm (photo T Spencer 16/01/2014)
(d) general set up of Scolt Head Island showing the breakwater and back barriers following the 5Dec storm with Brancaster Bay in the far distance (photo M. Page 09/12/2013)

Evans (2017) Evans, Sun Yan, E/2 Appendix 1, History of flooding sources, Boston Barrier Transport & Works Act order application, Public Inquiry documents, [pdf document properties: author=BDB; datestamp=16/07/2018] https://consult.environment-agency.gov.uk/engagement/bostonbarriermwo/results/appendix-1---history-of-flooding-sources.pdf

-RIG. [PHOTO] two night photographs showing flooding in streets of Boston 5Dec2013

Ribeiro et al (2017) Ribeiro R, R Rudge, D Kucinska, Analysis of physical factors of the windstorm Xaver in Poland: post-hazard review, Weather, 72, 2017, pp.378-382

-RIG6. [PHOTO] The island of Hooge on 5th December 2013 at two different times (a) 0850UTC and (b) 1500UTC (Dagebuell, 2013)

Staneva et al (2017) Staneva J, H Guenther, O Krueger, C Schrumml, V Alari, O Breivik, J-R Bidlot, K Mogensen, Impact of wind waves on the air-sea momentum fluxes for different wind and sea state conditions and oceanic responses, 1st International Workshop on waves, storm surges and coastal hazards, Liverpool, UK 10-15Sep2017 [pdf document properties: title=Anlass; author=Patrick Kalb-Anlass; datestamp=20/09/2017]

-RIG. [PHOTO] Photo wave impact at unknown coastal location in German Bight

-RIG. [PHOTO] Photo of Hamburg fish market

DEMA (2018) Danish Emergency Management Agency DEMA, National Risk Profile for Denmark, April 2018

-Fig. [PHOTO] A house in Roskilde is flooded from storm Xaver during German Bodil.

Fery et al (2018) Fery, Natascha, Birger Tinz, Lydia Gates, Reproduction of storms over the North Sea and the Baltic with the Danish Emergency Management Agency DEMA, National Risk Profile for Denmark

North Norfolk District Council Coastal Team (2018) North Norfolk District Council Coastal Team, Refurbishment of sea walls and groynes 2013-2015; Cromer Coast Protection, (picture of plaque on wall taken 27Dec2018) www.northnorfolk.org/coastal

-RIG6. [PHOTO] Photo damaged sea wall Cromer after Dec2013 storm Xaver

Giannopoulos et al (2018) Giannopoulos G, L Peake, B Reid, J Andrews, A Grant, I Lorenzoni, M Goulden, J Waters, T Dolphin, J Bremer, TJ Tolhurst, Environmental and social impacts of the 2013 storm surge on the North Norfolk coast, powerpoint presentation date stamp 15May2019, unknown conference

-RIG1. (a) [MAP] schematic of the study area of the Storm Surge in the North Norfolk coast, (b) before and (c) after the storm surge

-RIG2. [PHOTO] Field photos showing physical alterations by the storm surge to the coastal freshwater ecosystem
(a) protective dykes were eroded away and the sediments were dispersed,
(b) large areas were flooded with seawater that ponded for up to 1 months
(c) distinct patches of ponded seawater caused anoxic depressions.

North Norfolk District Council Coastal Team (2019) North Norfolk District Council Coastal Team, Sheringham Sea Defences; Repair and Recovery from the December 2013 storm surge, www.northnorfolk.org/coastal, photo of plaque on wall taken 30Dec2019

-RIG1. [PHOTO] damaged promenade Sheringham
-RIG2. [PHOTO] damaged promenade and earth bank Sheringham
-RIG3. [PHOTO] damaged sea wall and earth bank Sheringham
-RIG4. [PHOTO] tractor and cement truck repairing the damaged promenade Sheringham.

Wikipedia (20191002) Wikipedia, Stormen Bodil, https://da.wikipedia.org/wiki/Stormen_Bodil#cite_note-39 (accessed 02Oct2019)

-RIG1. [PHOTO] Flooding in Hamburg
-RIG3. [PHOTO] Tree fall in Denmark, Hadsund, north of Randers
-RIG4. [PHOTO] Fish market in Hamburg. 2h after the peak water level, high water level continued at 7m above sea level

Andrews (2020) Andrews, JE, Spit extension and barrier rollover at Blakeney Point and Salthouse: historic map and field observations, Bull. geol. Soc. Norfolk, 69, 35-63, 2020

*Figs. [PHOTO] damaged back barrier marshes at Salthouse (Dec2013) looking N. The emergent islands in the floodwater are Little Eye (left) and the remains of Great Eye (right). The area W of Littel Eye with teh row of posts is the site of the Little Eye breach channel. Image from Mr. David North
-Fig9. Landward edge of 5Dec2013 shingle washover fans spilling onto reclaimed saltmarsh at Beach Road. The islands of brown sediment top left are the remnants of Great Eye also visible in Fig8. Photograph taken 2Jan2014.
-Fig11. Comparison of washover fans W of Little Eye in aerial photos (a) then in June 2008 after the Nov2007 surge and (b) taken in Sep2014 after the Dec2013 surge. The shingle free re-entrant between the fans in (b) is centred on TG 07675 44428. Cley Eye pillbox is clear in the bottom right of both images.
-Fig12. Little Eye breach channel (a) looking seaward (N) and (b) looking landward (S). Note the pale grey Holocene muds exposed by channel bed erosion. The elevation of these muds, just above mean sea level can be used to infer an age of around 2000years BP based on the data in Funnell & Boomer (1998, p55). Images from Mr. David North 12Dec2013.
FIG13. Transient ebb tidal delta formed at the sea end of the 'Little Eye breach channel'. Image from Mr. David North 12Dec2013

FIG14. Arnold's (Pope's) Marsh breach channel viewed (a) from the backbarrier looking E. The artificially steepened bank east of the channel was overtopped in 2013 retained some topography, (b) view SE along the barrier crest. Image from Mr. David North 2Jan2014.

Wiki (2020-01-24) WIKI, Cyclone Xaver, https://en.wikipedia.org/wiki/Cyclone_Xaver accessed 24Jan2020

FIG [PHOTO] Bremerhaven flooded by the waters of the Weser River
FIG [PHOTO] repairing electricity cables in the wake of Xaver, Balsatsund, Unost, Shetland
FIG [PHOTO] Cyclone Xaver unleashing high waves near Warnemunde Germany
FIG [PHOTO] Defences overtopped at Victoria Dock, Hull
FIG [PHOTO] Homes undermined by the surge Hemsby Norfolk
FIG [PHOTO] Flooding in Hamburg's Hafencity
FIG [PHOTO] Breach sea dike at Burnham Norton, Norfolk, Seaward to left; flooding to right
FIG [PHOTO] December 2013 storm surge on Sheringham seafront

Wiki (2020-04-29) Wikipedia (20200429), https://sv.wikipedia.org/wiki/Stormen_Sven#/cite_note-15, accessed 29Apr2020

FIG. Flooding in Hamburg due to Storm Sven, which was called Xaver there

Wiki (2020-05-02) Wikipedia, Orkan Xaver, https://de.wikipedia.org/wiki/Orkan_Xaver (accessed 2 May 2020)

FIG4. [PHOTO] On the German Baltic coast the main feature for a period was the extreme minimum water level. Here Eckernfoerde
FIG5. [PHOTO] Hamburg Hafencity
FIG6. [PHOTO] Coast damage at Hemsby, Norfolk
FIG7. [PHOTO] Flooding of Grossen Elbstrasse in Hamburg-Altona
FIG8. [PHOTO] Impact on Handewitter Forst Apr 2014

Table S3. Ranking of storm among events; assessing importance of storm (arranged by year and then alphabetically)

| Source | Full Reference and Notes |
|--------|--------------------------|
| Aftenposten | Aftenposten, Varlsar full storm I Sor-Norge, 5Dec2013 15:03 (correspondent Per Annar Holm) https://www.aftenposten.no/norge/tbKEJ/varlsar-full-storm-i-sor-norge -last serious Norway storm Hilde, affecting Trondelag & Helgeland |
| Air Worldwide | Air Worldwide, Press Release, Boston, 12Dec2013. https://www.air-worldwide.com/In-the-News/AIR-Estimates-Losses-from-European-Windstorm-Xaver-at-Between-EUR-700-Million-and-EUR-1-4-Billion/ (accessed 02Jan1990) -comparisons with storm Christian Oct2013 and storm Anatol Dec1999 -wind speeds for Xaver less than Christian and Xaver -storm Xaver similar to the 1Feb1953 storm in terms of surge |
| BBC | BBC 20131206, Deadly storm and tidal surge batter northern Europe, BBC 6 Dec 2013 (report by Anna Holligan) -worst storm surge in England in 60 years -Hamburg experienced largest storm surge since 1960s |
| Bloomberg (2013) | Bloomberg, Hamburg, has worst flood in 37 year amid European storms, Nicholas Brautlecht, 6Dec2013, 02:58PM GMT https://www.bloomberg.com/news/articles/2013-12-06/hamburg-has-worst-flood-in-37-years-as-storms-rage-across-europe -second highest water level on record (37y) -lower than storm surge 1976, higher than storm surge 1962 |
| BSH | BSH, Die Nordseesturmfluten von 5. und 6.12.2013, 3pp, prepared by Stockmann.K. (title: Sturmflut 2013 bmi101; author stamp: bm1101; document time stamp: 12/10/2013 12:5136PM) -winds not so strong as Hurricane Christian 28Oct2013 -water level progression similar to storm surge Feb 1962 -Hamburg St Pauli skew surge Feb 1962=4.03m; Dec 2013=3.98cm |
| BODC (20132105) | BODC, Storm surge and coastal flooding. News and Events, 5Dec2013. -this is the only storm surge press release among the collection of press releases spanning 2004-2018 |
| Deutschlander et al (2013) | Deutschlander T, K Frnchen, S Haeseler, C Lefebvre, Orkantief XAVER ubere Nordeuropea von 5. bis 7. Dezember 2013, Deutscher Wetterdienst DW, Stand 30. Dezember 2013, 19pp. -highest water level ever measured at Oresund Sweden -UK Environment Agency says worst storm surge in 60 years -Xaver storm surge at Hamburg at 3.98m uuber MTHw was 5th highest in 100 years after 1976 (4.67m), 1962 (4.03m), 1994 (3.98m), 1995 (3.99m) -Storm Xaver water levels on North Sea coast were highest since Storm Brita Nov. 2006 |
| Gccapitalideas (20131209) | gccapitalideas, Windstorm Xaver, 9Dec2013, https://www.gccapitalideas.com/2013/12/09/windstorm-xaver/ -most severe storm surge in the UK since 1953 |
| Gray (2013) | Gray, Tom. Into the Wind. The AWEA Blog. Ireland, U.K., Germany set new wind generation records. https://www.aweblog.org/ireland-u-k-germany-set-new-wind-generation-records/-, 11Dec2013 -record wind energy production Germany 06Dec2013 |
| Kunz et al (2013206) | Kunz M, B Muehr, K Schroetter, T Bessel, S Moehrle, T Muenzberg, S Brink, H-M Schmidt, Winterstorm Xaver - Report. 06Dec2013 - Report No.1, Situation Report - 19:00CET, CEDIM Forensic Disaster Analysis Group (FDA), Center for Disaster Management and Risk Reduction Technology. -three largest comparable events in Germany: Kyrill (18-19Jan2007); Lothar (26Dec1999); Daria/Vivian/Wiebke -new extreme water levels Dagebillu, Husum, Buesum, Eidersperwerk, Cuxhaven -top 10 absolute high water levels Hamburg: 03Jan1976=06Dec2013=18Jan1994=10Jan1995=03Dec1999=24Nov1981=25Jan1993=28Feb1990=05Feb1999=17Feb1962 |
| The Lowestoft Journal (20131214) | The Lowestoft Journal, Suffolk MP hits out at environment secretary in statement about the floods, 14Dec2013, correspondent: Annabelle Dickson. -conservative government minister wrote storm put defenses to greatest test in 60 years; for some locations water level was a 1
In 500 year event.

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Mills, Ian, Remko Scharoo, Luciana Fenoglio, Xaver affected much of northern Europe on 5 and December and caused worst storm surge for decades in the North Sea. https://www.euromet.net/int/website/home/News/DAT_2087062.html (last accessed: 19Nov2019, 28Jun2020)
-record surges in Wadden Sea and barrier islands of the Netherlands and Germany
-comparison of altimeter strip information for Saral/Altika since launch in early 2013: SWH and wind speeds highest of previous 9 months

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NLWKN, Sturmflutgefahr an der Kueste und auf den Inseln, Zwei meter ueber den normalen Hochwasser in der Nacht zum Freitag moeglich / pressinformation von 29 November 2013, (written by Herma Heyken, Presseprecherin), 03/12/2013 https://www.nlwkn.niedersachsen.de/startseite/aktuelles/presse_und_offentlichkeitsarbeit/pressemitteilungen/sturmflutgefahr-an-der-kueste-und-auf-den-inseln-120187.html
-last great storm surge on Niedersachsen coast was Hurricane Lennart Jan 2013 with 12 month quiet period before that
-storm surge for Britta 1Nov2006 was a 100 year event for the Niedersachsen North Sea coast with Borkum water level of 2.70m the same as the 1962 surge.

NLWKN (20131206)
NLWKN, Schwere Sturmflut gut Ueberstanden, Wasserstaende zwischen Zweieinhalte und Knapp vier metern registriert // pressinformation von 6. Dezember 2013, (Ansprechpartnerin: Herma Heyken), 06/12/2013.
-counts as worst storm surge of last 100y; 2006 record reached partly
-table comparing skew surge between Storm Xaver, Storm Britta, and 1962 storm surge; Storm Xaver was highest at most stations.

NOS (20131206)
NOS, Hoogste waterstand sinds 1953, 06/12/2013, 09:52, https://www.nos.nl/artikel/583218-hoogste-waterstand-sinds-1953.html
-highest water level in Vlissingen (3.99m NAP) since 1953 surge (4.55m NAP)

Ozeanografisch Meteorologisch Station (2013)
Oceanografisch Meteorologisch Station, Stormverslag 05-06 december 2013, 26pp, 2013 [pdf document properties: author=Myriam Sys; datestamp=15Dec2013]
-water levels in Oostende (633cm TAW) were the highest since 1Feb1953 (666cm TAW)

SMHI (20131210)
SMHI, Stormen Sven gav nya vattenstandsrekord i Oresund, https://www.smhi.se/nyhetsarkiv/stormen-sven-gav-nya-vattenstandsrekord-i-oresund-1.34732, updated 20Mar2017; original datestamp 10Dec2013
-maximum trough-crest height Vadoeroama 10.7m; less than record of 13.9m during Adventstorm 2011
-water level record maximum at Viken (1.67m; 1976 start) and Barseback (1.59m; 1993 start)
-water level record minimum at Skanoor (~1.58m); old record ~1.55m during Dec 1999 storm

Spiegel International (20131206)
Spiegel International, Winter storm 'Xaver' batters northern Europe,6 Dec 2013, 12:56 https://www.spiegel.de/international/europe/tidal-surge-winter-storm-xaver-batters-northern-europe-a-937576.html#
-UK coastal water levels could be the highest in 60 years
-Hamburg water levels at 6m; the level was reached just twice in the early 1990s

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Sueddeutsche Zeitung, Xaver: holte sich Land; Sturmschaden auf Sylt, https://www.sueddeutsche.de/panorama/sturmschaeden-auf-sylt-xaver-holte-sich-land-1.1844100
-record sea state level of 66m; highest since record start in 1987

Syler Rundschau (20131209)
Syler Rundschau, Folgen des Orkans. Xaver 'knabberte' Sylt massiv an, 09Dec2013 06:00 (from Friederike Reussner) https://www.shz.de/lokales/syler-rundschau/xaver-knabberte-sylt-massiv-an-id5098481.html
-Arfsf Hinrichsen, Landesamt fuer Kuestenschutz on Sylt beach damage: 'Das war schon heftig, solhe Schaeden habe ich selten gesehen'

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Unwetterzentrale, Orkantief XAVER - ein weiterer schwerer Wintersturm der letzten Jahrzehnte, Thomas Savert and Stefan Laps, Dec. 2013 http://www.unwetterzentrale.de/uwz/9298.html
-rank 2 storm surge; Storm Xaver storm surge lower than 03Jan1976
-equal lines observed for Storm Xaver (2013), Kyrill (2007) & Emma (2008)

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AON Benfield, Impact forecasting, December 2013 Global Catastrophe Recap, 2014. [document properties: abrandt; date stamp: 10Jan2014]
-1 of 4 featured global catastrophe events for Dec 2013
-others are Storm Dirk 23-25Dec2013; winter storms US and Canada; floods SE Brazil worst in decades

ABBPower (2014)
ABBPower, Ensuring Flood Resilience. An overview of the 5/6 December 2013, Associated British Ports, Marine Environmental Research, July, 2014
-rank 1 water levels: Leith, North Shields, Immingham, Cromer, Dover
-rank 2 water levels: Aberdeen, Lowestoff
-Immingham flooding during 2013 surge but not 1953

BBC (20141205)
BBC, East coast surge: what happened next? (report by Richard Haugh), 5Dec2014
-comparison with Storm Xaver 2013 to 1953 surge

CH2MHill Halcrow (2014)
CH2MHill Halcrow, Cell 1 Regional Coastal Monitoring Programme, Wave Data Analysis Report 2: 2013-2014, Final Report, March 2014 [document properties: author=Andy.Parson@ch2m.com; datestamp; 0404/2014]
-Newbiggin wave buoy: storm analysis 2010-2014; Storm Xaver had highest energy at peak and wave period but not largest peak height
-North Shields tide gauge: Storm Xaver had rank 1 water level that exceeded 31Jan1953 (rank2)
-Tyne Tees buoy: Storm Xaver did not have exceptional wave conditions
-Whitby waverider buoy: Storm Xaver had highest peak wave energy in record 2010-2014
-Whitby tide gauge: Storm Xaver water level at rank 1; previous storm flood water level record 01Feb1982 (rank 2)
-Scarborough tide gauge: Storm Xaver was rank1 water level event; next highest water level Jan2005

Dunbar et al. (2014)
Dunbar I, N Phips, M Szonja, Risk Nexus. After the storm: how the UK's flood defences performed during the surge following Xaver, Flood resilience review 09.14, Zurich Insurance Company Ltd., Mythenquai 2, 8002, Zurich, Switzerland [document properties: date 28Aug2014; author=Zurich]
-comparable water levels between 1953 & 2013
-previous stormiest December Dec 1969 (gusts over threshold).
-Dover water level 4.7m OD; highest since 1905
-new water level record Kingston upon Hull 5.8m on 26Dec2013
-1953 surge event highest for at least 250y
-Southend water level 4.1m or 0.06 m higher than previous record in 2007
Eden (2014)  

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- Roskilde 2.06m rank 1 storm surge in record back to 1992; previous record 1.36m 6Feb1999  
- Roskilde water level at 100-200y return level  
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- Bodil similar to 1973 storm  

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- storm Xaver as assessed as having extreme water level and wave conditions at the 1 in 100 year level; similar to 2006 and 2007  
- water level at Delfzijl at level of 1 in 50 year to 1 in 100 year recurrence level.  
- Storm Xaver assessed as one of the most severe storms in terms of wind speed and water level for which there are proper wave measurements in the Wadden Sea  

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- Storm Xaver was rank 2 storm surge after 03Jan1973  

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- Hewson, T., L. Magnusson, O. Breivik, F. Prates, I. Tsoncevsky, HJW de Vries, Windstorms in northwest Europe in late 2013, ECMWF Newsletter, No 139, pp 22-28, Spring 2014.  
- FIG1. Areas exceeding the 5-year return period of 24-hour maximum wind gust for windstorms (a) Christian and (b) Xaver as diagnosed using the ERA-Interim reanalysis as a proxy for observations.  
- Record surges were set up by the wind storm along the east coast of Britain, the coasts of the Netherlands and in the Germany Bight.  

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- Knaack, H. and H. Heyken, Xaver had sehr schwere Sturmflut im Gepaeck, Jahresbericht 2013. Der Zukunft verplichtet, An Insurance and Catastrophe Modeling Perspective. RMS White Paper.  
- Storm Xaver was rank 2 storm surge after 03Jan1973  

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- Kristandt, J., B. Brecht, H. Frank, H. Knaack, Optimization of empirical storm surge forecast-modeling of high resolution wind fields, Die Kueste, 81, 301-348, 2014  
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Leiding et al. (2014)  

- Leiding, T., B. Timz, G. Rosenhagen, C. Lefevre, S. Haesseler, S. Hagemann, B. Luecht, D. Sting, P. Schwenk, S. Mueller, O. Ottozen, K. Herkelz, K. Kinder, T. Neumann, Meteorological and Oceanographic Conditions at the FINO platforms during the severe storms Christian and Xaver, DEWI Magazin, No.44, p16-25, 2014.  
- FINO1: Storm Xaver had wind speed record since measurement start in 2002; previous wind speed record Storm Karla 30Dec2006 23:50UTC with 47.5m/s gust at 103m and 37m/s 10min sustained wind speed  
- FINO2: Storm Christian set wind speed record since measurement start in 2007; Storm Xaver storm surge was remarkable for long duration with wind speeds >30m/s for 3h; wind turbine cutoff thresholds of 25m/s were exceeded for 27h  
- FINO3: Storm Christian set record for wind speed and gust since measurement start in 2009; for Storm Xaver wind speed exceeded 25m/s for >24h; ‘FINO3 has weathered both storms without significant damage’  

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- Luecht, Fabian and Ove Peters, Bericht ueber die Sturmflut vom 05.-06.12.2013 an der Westkueste Schleswig-Holsteins, Landesbetrieb fuer Kuestenschutz, Nationalpark und Meeresschutz Schleswig-Holstein, Husum 26Feb2014, 19pp. [pdf document properties: title=Lfd; Author=Thorsten Nommensen; datestamp 24Apr2014]  
- Xaver water levels at Ems higher than 1952 and 1967  
- Xaver true surge was rank 2 event after 1962  
- Xaver water levels on Weser and Elbemuendung lower than 1962 1976 events (i.e., rank 3)  

Mai (2014)  

- Mai, S., Sea state at the research platform FINO1 during the winter storm ‘Xaver’, BFG, Bundesamt fuer Gewasserkunde, document properties: author=Mai, date=16May2014  
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- Nossent J, L Boeckx, T Taverniers, M Deschamps, T Verwaest, F Mostaert, Sinterklaassstorm 6 december 2013. Beschrijving van de hydrometrische gebeurtenissen, Versie 4.0. WL Rapporten, 00 28, Spring 2014.  
- Antwerp storm surge level ranked as a 4-5 year event  
- Antwerp water levels exceeded during 1954 (7.77 mTAW), 03Jan1976 (7.31 mTAW), 27Feb1990 (7.52 mTAW), 11Nov1992 (7.39 mTAW), 14Nov1993 (7.53 mTAW), 18Jan1994 (7.37 mTAW)  

Pelt (2014)  

- Pelt AS, BODIL’s stormflood i de indre dansk farvande, Vejret, 138, 24-29, 2014  
- mostly rank 1 water levels in measurement records of Roskilde Havn, Torsminde, Hornbaek, Klampenborg, Tolboden Kobenhavn, Sjællandsl Oddie, Greann, Odense Fjord  
- rank 3 wind speed at Odense  
- Bodil storm surge was highest in Oresun and SE Kattegat since 1862.  

RMS (2014)  

- RMS, 2013-2014 Winter Storms in Europe. An Insurance and Catastrophe Modeling Perspective. RMS White Paper.  
- water levels on east coast at 1953 levels  
- 6.99m water level in Hamburg was same as 1962 event  

RWS (2014a)  

- RWS, Watermanagementcentrum Nederland, Stormvloedflitsen 2013-07 van 5 t/m 7 december 2013, Rijkswaterstaat (document time stamp: 07Jan2014), 2014a
- Delzijl: previous water level record exceeded by 1cm during Storm Xaver; expected 15 times per 1000 years
- Vlissingen: highest water level since 1953; expected once in 20y
- Hook van Holland: Storm Xaver water levels exceed by Storm Tilo 09Nov2007 and 1953 event.
- skew surge statistics: Delzijl twice per 100y; Vlissingen once per seven years.

RWS (2014b)

RWS, Stormvioldrapport van 5 t/m 7 december (SR91) Sint-Nicolaasvloed 2013, Watermanagementcentrum Nederland, Rijkswaterstaat, prepared by Ing. J. Knos, 19Mar 2014b, 48 pp
- previous storm surge report 21 Mar 2008: 5.5y previously
- Belgium: highest water level since 1953
- UK: water level higher than 1953
- Vlissingen: rank 2 event 1900-2013
- Hook van Holland: rank 3 event 1900-2013
- Den Helder: rank 10 event 1900-2013
- Harlingen: rank 1 event 1932-2013
- Delzijl: rank 2 event 1900-2013

Slingo et al (2014)

Slingo J, S Belcher, A Scaife, M McCarthy, A Sauter, K McBeath, A Jenkins, C Huntingford, T Marsh, J Hannaford, S Parry, The Recent Storms and Floods in the UK, 29pp, Met Office, Fitzroy Road, Exeter, Devon, EX1 3PB, UK, February, 2014 [pdf document properties: author=huw.lewis; date stamp=11Feb2014]
- East coast storm surge 5-6Dec2013 was worst event since 1953. Comparable damage averted because of improved sea defences and advance forecasts
- surge event 5-6Dec2013 subordinate to later storms from end of Dec to Feb that caused inland flooding and coastal damage in southwest
- Dec 2013 had highest number of stations recording gusts over a high threshold

SMHI (20140703)

SMHI, Simone, Hilde, Sven och Ivar okt-dec 2013, 3 Jul 2014, https://www.smhi.se/kunskapsbanken/meteorologi/simone-hilde-sven-och-ivar-okt-dec-2013-1.76183
- Sven 1 of 4 serious storms Oct-Dec 2013
- Sven had least damage of 4 serious storms in terms of power outages & forest damage
- return period of winds 5-10y; locally 10-20years

Spencer et al (2014)

Spencer, T. S.M. Brooks, I. Moller, B.R. Evans, Where local matters: Impacts of a major North Sea storm surge, EOS, 95, 269-270, 29July2014
- worst storm surge in 60 years
- water levels comparable to & exceeded 01Feb1953 levels.

Staneva et al (2014)

Staneva J, K Wahle, E Stanev, Response of the German Bight Hydro and Sediment Dynamics to Wave, Tidal and Atmospheric Forcing, 3rd GODAE OceanView Coastal Oceans and Shelf Seas Task Team (COSS-TT) International Coordination Workshop, 21-24 January 2014, Rncon Beach Resort, Puerto Rico, 36pp
- coastal flooding during Storm Britta in 2006 worse than during Storm Xaver 2013
- Storm Britta 2006 assumed one of the worst for 100y on the Niedersachsen coast

Thorue (2014)

Thorue, Colin, Geographies of UK flooding in 2013/4, The Geographical Journal, 180, 297-309, 2014.
- Xaver storm surge highest ever recorded Humber & Thames estuaries

Van Dorland (2014)

van Dorland, R, Zwarte storm op 5 december, Zenit, p43, Januari 2014
- Storm Xaver is number 60 in KNMI list of severe storms since 1910

Axer et al (2015)

Axer T, T Bistry, M Klaw, M Mueller, M Suesser, Deutsche Ruck Sturm dokumentation 2013 Deutschland, 2013, Deutsche Rueckversicherung Aktiengesellschaft, Hansaalle 177, 40549 Dusseldorf, www.deutscherueck.de [pdf document information: author=filiz; date stamp=07Aug2015]
- Storm Xaver cause < half of damage of Storm Christian because wind field weaker
- more forest damage in dMeulenborg-Vorpommem during Xaver than Storm Christian.
- Storm Christian had a lot of topped tree damage (late October when leaves were still on trees)
- absolute water level during Xaver rank 2 after Capilla 1976
- skew surge dduring Xaver rank 3 after 1976 and 1962 events

Dan et al. (2015)

Dan, Sebastian, Anne-Lise Montreuil, Rosalia Delgado, Tomas van Oyen, Large storm impact on a beach under sand nourishments, The Proceedings of the Coastal Sediments 2015, edited by Ping Wang, Julie D Rosati, and Jun Cheng, Coastal Sediments 2015, San Diego, USA, 11-15May2015
- Storm Xaver had water levels that were the highest since the 1953 surge

Fenoglio-Marc et al. (2015)

Fenoglio-Marc L, R Scharroo, A Annuzziato, L Mendoza, M Becker, J Lillibridge, Cyclone Xaver seen by geodetic observations, Geophys Research Letters, 42, 9925-9932, 2015
- the largest storm signal captured by satellite altimetry to date...in the North Sea?

Gierlevsen et al. (2015)

Gierlevsen T, H Lauridsen, P Langhans, J Bédig, Med-ocean and wind resource related studies for nearshore windfarms in Denmark, seminar at the Danish Energy Agency, 27 February 2015.
- Storm Bodil (2013) one of three important severe storms for offshore wind energy

Haigh and Bradshaw (2015)

Haigh I and E Bradshaw, A century of UK coastal flooding, Planet Earth, Winter 2015, (pdf document properties: 13Jan2016)
- 7 of 96 record surge events in the 100 year data base occurred in the winter of 2013/4
- storms 5-6Dec2013 and 3Jan2014 were in the top 10 of sea level height.
- COBRA crisis committee briefed on several occasions on storms during 2013-2014 winter period

Jensen et al. (2015)

Jensen, J., A. Arn, T. Wahl, Yet another 100y storm surge event: the role of individual storm surges on design water levels, Journal of Marine Science and Technology, 23, 882-887, 2015
- highest water levels on record for some places
- media reported a century storm

Kendall and McCarthy (2015)

Kendall M and M McCarthy, The UK's wet and stormy winter of 2013/2014, Weather, 70, 40-47, 2015
- comparison of Dec 2013 surge with Jan-Feb 1953
- UK Dec rainfall rank 4 in time series from 1910

NLWKN (20151210)

NLWKN20151210, Sturmflutfwarnung betrieb der Betriebstelle Norden-Norderney, NLWKN Niedersachsischer Landesbetrieb fuer Wasserwirtschaft, Kuesten- und Naturschatz, Niedersachsen, document date stamp 10Dec2015.
- ranking of data since time series start (1951?) or less likely 1901?
- Emden surge height: 2006>2013>1962>1976.
- Norderney surge height: 1962>2013>1976>2006.
Cuxhaven surge height: 1976>1962>2013>2006

Patzer (2015) Patzer, Marianne, Storm surge forecasting at DMI and perspectives on teh use of Earth Observations, ESA eSurge Symposium, Deloates, the Netherlands, (powerpoint presentation) January 21, 2015-1000 year event in Danish fjords and Sealand north coast

Spencer et al (2015) Spencer T, SM Brooks, BR Evans, JA Tempest, I Moeller, hields, Whitby, Immingham, Lowestoft, Dover, Sheerness, Liverpool, Portsmouth, m Atlantic and North Sea storms, (Special Issue, No 75), 700-ent of Dec.5, 2013:

Wadey et al (2015a) Wadey MP, ID Haigh, RJ Nichols, JM Brown, K Horsburgh, B Carroll, SL Gallop, T Mason, E Bradshaw, A comparison of the 31 January-1 February 1953 and 5-6 December 2013 coastal flood events across the UK, UK Frontiers in Marine Science, 2, 84, 2015a:
-For some locations Xaver water level higher than 1953 flood; for other locations reverse true
-1953 storm much slower propagation across the North Sea leading to higher surge in south
-1953 had large forest damage in Scotland that was not observed for Xaver
-Storm Xaver reported as 'biggest North Sea surge for 60 years'
-COBRA meeting briefing on 05Dec2013 like for Storm Tilo 2007 (Cabinet Office Briefing Room A); 'the highest level of preparation in the UK for a potential regional or national disaster'

Wadey et al (2015b) Wadey MP, JM Brown, ID Haigh, T Dolphin, P Wisse, Assessment and comparison of extreme sea levels and waves during the 2013/2014 storm season in two UK coastal regions, Nat. Hazards Earth Syst. Sci. Discuss., 3, 2665-2708, 2015b.
- Lowest: highest water level in the measurement record since 1964 start; 1953 surge was higher
- Lowest: highest water level in record since start 1992; previous record 10Feb1997
- Lowest: 4 water level
- Lowest: rank 3 water level

Sibley et al (2015) Sibley A, D Cox, H Titley, Coastal flooding in England and Wales from Atlantic and North Sea storms during the 2013/2014 winter, Weather, 70, 62-70, 2015.
- Rank 1 water levels reached in North Shields, Whitby, Immingham, Lowestoft, Dover, Sheerness, Liverpool, Portsmouth, Newhaven, Ifracombe, Hinkley Point, Newport, Mumbles, Milford Haven, Fishguard, Barmouth
- Most significant storm surge event for over 60 years.
- Comparable significant wave height in 1953 and 2013
- Return period of 1953 surge at Lowestoft estimated at 50y
- Previous significant storm surges in history: 13-14Jan1916; 3Feb1825, 14Dec1717.
-COBRA briefings of storm surge on 5-6Dec2013

Vannassenhoven (2015) Vannassenhoven, Niels, Storm surge measures ports Flemish coast, Blankenberge, Tuesday February 3rd, Maritimes Stentverlening en Kunst, Coastal Division, Flanders Hydraulic Research,[document properties: title=Geointegreerd Kustveiligheidsplan; author=Maarten; datestamp=27/02/2015]
- Predicted water level of Dec2013 storm corresponded with a 50y storm flood
- Highest water level since 1953

Brooks et al (2016) Brooks SM, T Spencer, A McIvor, I Mollier, Reconstructing and understanding the impacts of storms and surges, southern North Sea, Earth Surface Processes and Landforms, 41, 855-864, 2016.
- Water levels during Storm Xaver higher along North Norfolk coast than any storm in data base starting 11Mar1883
- Return period water levels 188-787 years; about an order of magnitude higher than any 20th century storm

Dangendorf et al (2016) Dangendorf S, A Arns JG Pinto, P Ludwig, J Jensen, The exceptional influence of storm 'Xaver' on design water levels in the German Bight, Environmental Research Letters, 11, 2016, 054001
- Storm Xaver displaced Storm Capella 1976 as the observational maximum at many locations
- Storm Xaver had highest ever recorded extreme water levels in parts of the German Bight
- Only a few tide gauges registered new records

ECMWF (20160316) ECMWF (20160316), 201312 - Windstorm - Xaver/Boazi/Sven, North-western Europe
- https://confluence.ecmwf.int/pages/viewpage.action?pageId=28315390
- Storm surge was highest along east England coast for 60 years
- in the aftermath of the cyclone a blizzard hit Sweden

Matelki (2016) Matelki, Birgit, Erfahrungen aus der Sturmflut Xaver von 5. und 6.12.2013 und dem Weihnachtschwochwasser 2014 in Stillewasser, IWASA 2016 Tagungsbeitrag, (46. IWASA, 7-8 Januar 2016; Internationales Wasserbau-Symposium Aachen. [pdf document properties: autor=sonja; datenstamp=26Apr2016]
- For tide gauge on List auf Sylt highest water leve was rank 5 event in measurement time series since 1900
- Hamburg St. Paul: water level Xaver higher than 1962 surge
- Helgoland Binnenhafen: water level Xaver 38cm more than Storm Capella 03Jan1976
- Only a few tide gauges registered new records

Nederhoff et al (2016) Nederhoff K, E Elias, T Vermaas, Erosie op Ameland Noordwest. Modelstudie: simulaties met Delft3D en XBeach, Delftares, 117, pp. July, 2016.
- Sinterklaasstorm was a 50y event in terms of water level and wave height; damage to Amelander dunes

Sorensen (2016) Sorensen CS, Water NOT wanted - Coastal floods and flooding protection in Denmark, In RA Herrmann & J Jensen (eds), Sicherung von Dammem, Deichnen und Staunanlagen: Handbuch fuer Theorie und Praxis (Vol V pp3-21), Siegen: Universitaet Siegen, 2016.
- Highest ever water levels at Hornbaek & Copenhagen (series 1890-2015)
- Many houses uninhabitable for some time
- Storms caused more fatalities & dike breaches: 13-14Nov1872, 1921-1922, 1Nov2006 (inner seas)
- Other surges North Sea side: 1909, 1911, 30Sept1923, Jan 1976, 24Nov1981, 03Dec1999

Sorensen et al (2016a) Sorensen CS, NK Dronen, P Knudsen, J Jensen, P Sorensen, An extreme event as a games changer in coastal zone management, Journal of Coastal Research, (Special Issue, No 75), 700-704, 2016. Proceedings of the 14th International Coastal Symposium (Sydney, Australia) ed by A Vila-Concepto, E Bruce, DM Kennedy, RJ McCarroll, 2016a
- Highest water level in Hornbaek tide gauge record 1890-2015
- Rank 1 of highest Hornbaek storm surges: 01Jan1922, 18Dec1921, 7Nov1985, 27Nov2011, 5-6Dec2013
Sorensen et al. (2016b) Sorensen C, NH Broge, MR Molgaard, CS Schow, PThomsen, K Vognsen, P Knudsen, Assessing future flood hazards for adaptation planning in a northern European Coastal Community, Frontiers in Marine Science, 3:69, doi:10.3389/fmars.2016.00069, 2016b -Storm Xaver one one three Thyrboron flooding events explicitly mentioned: 1981, Dec 2013, Jan 2013

Staneva et al. (2016a) Staneva J, K Wahle, H Guenther, E Stanev, Coupling of wave and circulation models in coastal-ocean predicting systems: a case study for the German Bight, Ocean Sci., 12, 797-806, 2016a -storm Britta 2006 water level at 100 year return level -two extreme storm case studies at (Britta 2006 and Xaver 2013) to test coupled wave current model

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Evans (2017) Evans, Sun Yan, EA/2/2 Appendix 1, History of flooding sources, Boston Barrier Transport & Works Act order application, Public Inquiry documents, [pdf document properties: author=BDB, datestamp=16Mar2017] https://consult.environment-agency.gov.uk/engagement/bostonbarrierwaio/results/appendix-1---history-of-flooding-sources.pdf -5.2 m surge (more than 70cm above 1953) -water was 6.08 mODN; higher than 1953 & 1978

Frohle and Dreier (2017) Peter Frohle & Norman Dreier, EarlyDike - Sensor - und risiko basiertes Fruhwarnsystem fuer Seedeiche, Teilprojekt: Wellenmonitoring und Wellenbelastungssimulator (AF2), Hamburg, April 2017 -mentioned storms for wave runup analysis: Hurricane Tilo 8-9Nov2007, Hurricane Xaver 5-7 Dec 2013, Storm Elon and Felix 9-11 Jan 2013, Hurricane Barbara 26Dec2016

Jee (2017) Jee, Andrew, EA/13/2 Appendix 1. A summary of flooding events in Boston. [pdf document properties: author=Andrew Jee, Date stamp=17Mar2017] https://consult.environment-agency.gov.uk/engagement/bostonbarrierwaio/ -highest water levels at North Shields and Well among reported late 20th century storms. -at Wick: rank 2 water level after 1978

Jensen et al. (2017) Jensen J, S Niehuser, A Arns, S Dangendorf, Sensor- und risikobasiertes Frühwarn-system fuer Seedeiche (EarlyDike), API - Sturmflutmonitoring und Sturmflutssimulator - Fachbericht 2016, Siegen, April 2017 -Storm Xaver is the focus storm for the development of a wave model; only Storm Britta 2006 and Storm Xaver 2013 mentioned in the modelling exercise

Ribeiro et al. (2017) Ribeiro R, R Rudge, D Runciman, Analysis of physical factors of the windstorm Xaver in Poland: post-hazard review, Weather, 72, 2017, pp.378-382 -Poland IMGW classifies level 3 storm: damage to buildings, power lines, forest; transport problems; threat to life -Storm Xaver ranks with other severe European wind storms: Quimburga 1972, Wiebelke 1990, Oratia (2000), Kyrill (2007) -highest ever recorded storm surge water levels at some stations in England -Stavoren max wind speed 38m/s: highest ever recorded in Netherlands for any station since record start 1910

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Wahle et al. (2017) Wahle K, J Staneva, W Koch, I Fenoglio-Marc, HTM Ho-Hagemann, EV Stanev, An atmosphere-wave regional coupled model: improving prediction of wave heights in the southern North Sea, Ocean Sci., 13, 289-301, 2017.(doi:10.5194/os-13-289-2017) -one of most sever storms of the last decade

Ditlevsen et al. (2018) Ditlevsen C, MM Ramos, C Sorensen, UR Ciocan, T Ponikowizt, Hoyvandstatisikker 2017, Miljo- og Foeddervaremnerietet, Kystdirektoratet, Lemvig, Februar, 2018 -Storm Xaver had the highest storm surge in 9 of 67 stations; it was in the top 20 events for most stations.

Environment Agency (2018) Environment Agency, Thames Barrier Project Summer 2018, January, 2018 -largest recorded tide at Southend since 1978, before Thames Barrier became operational; largest surge along East Coast UK since 1953.

DEMA (2018) Danish Emergency Management Agency DEMA, National Risk Profile for Denmark, April 2018 -Storm Xaver was one of five Danish hurricane cases of last 100 years; others were 25-26Dec102, 23-24Oct1921, Oct 1967, 24-26Nov1981, 3-4Dec1999; then strong storms 8Jan2005, 28Oct2013, 5-Dec2013

Fery et al. (2018) Fery, Natascha, Birger Tinz, Lydia Gates, Reproduction of storms over the North Sea and the Baltic with the regional analysis COSMO-REA6 ISPR 2018, 17-19July2018, Bonn [pdf document properties: datestamp=16/07/2018] -Storm Xaver one of five focus storms in DWD Extremeness project: Britta 2006, Kyrill 2007, Tilo 2007, Christian 2013, Xaver 2013

Kystdirektoratet (2018) Kystdirektoratet, Shoreface nourishment effects. An analysis of the 2011 nourishment performed at Skodberge. Kystdirektoratet, Hojbovej 1, 7620 Lemvig, Dec 2018 [pdf document properties: title=Shoreface nourishment effects_Skodbjerge_20.12.2018, datestamp=20/12/2018] -storm with highest energy wave field in database 2006-2014; corresponds to period of highest erosional loss

North Norfolk District Council Coastal Team (2018) North Norfolk District Council Coastal Team, Refurbishment of sea walls and groynes 2013-2015; Cromer Coast Protection, picture of plaque on wall taken 27Dec2018: www.northnorfolk.org/coastal -water levels along North Norfolk Coast higher in places than 1953 storm surge -water levels at Thames Barrier highest ever since start of operations 1982

Ulm et al. (2018) Ulm, Marcus, Arne Arns, Juergen Jensen, Assessing consequences of extreme events for the German Bight, 36th International Conference on Coastal Engineering 2018 - Coastal Protection and Risk - ID 1527 -Storm Britta 2006 regarded by local authorities as a close call for dike breach risk

Giannopoulos Giannopoulos G, L Peake, B Reid, J Andrews, A Grant, I Lorenzoni, M Goulden, J Waters, T Dolphin, J Brenner, T. 
et al (2019)  Tolhurst, Environmental and social impacts of the 2013 storm surge on the North Norfolk coast, powerpoint presentation
date stamp 15May2019, unknown conference
- the biggest UK storm surge for 60 years' - UK Environment Agency
- tides along parts of N Norfolk coast reached higher levels than 1953

North Norfolk District Council Coastal Team (2019)  North Norfolk District Council Coastal Team, Sheringham Sea Defences; Repair and Recovery from the December 2013 storm surge, www.northnorfolk.coastal, photo of plaque on wall taken 06Dec2019
- for Storm Xaver water levels along parts of the Norfolk coast were higher than 1953 surge
- water levels at Thames Barrier highest ever since start of operations 1982

Rucinska (2019)  Rucinska D, Describing Storm Xaver in disaster terms, International Journal of Disaster Reduction, 34, 147-153, 2019
- Hamburg had the second highest ever storm surge
- highest ever extreme ocean level was registered in northern Germany
- Netherlands had the highest ever measured winds (38ms/s) since record start at Stavoren on the North Sea coast
- Netherlands wind speed was similar to 1953
- Denmark had the highest ever extreme ocean level
- UK had the highest storm surge since1953

Schenk and Mueller-Navarra (2019)  Schenk, L. and S. Mueller-Navarra. 3.4.4. Windstausstatistiken und Haufigkeit von Sturmfluten 2012-2015
https://www.bsh.de/DE/PUBLIKATIONEN/Nordseezustand_Aktuell/_Anlagen/Downloads/3_4_4_Windstatisitken.pdf?__blob=publicationFile&v=2 [pdf document properties: author=Ludwig Schenk; datestamp=14Feb2019]
- very severe storm surge with three consecutive storm tides
- Storm Xaver event resembled century surge of Feb1962

Wikipedia (20191002)  Wikipedia, Stormen Bodil, https://da.wikipedia.org/wiki/Stormen_Bodil#cite_note-39 (accessed 02Oct2019)
- Netherlands: highest water level since 1953
- German authorities report waves up to 6m; second highest since 1825(?)

Andrews (2020)  Andrews, JE, Spitz extension and barrier rollover at Blakeney Point and Salthouse: historic map and field observations, Bull. geol. Soc. Norfolk, 69, 35-63, 2020
- comparable North Norfolk coastal damage for storm surge Nov2007, storm surge Dec2013, storm surge Dec1938, storm surge Jan1995, storm surge 1953

JBA Risk Management (2020)  JBA Risk Management, Storm Xaver 2013. Event Commentary, 2020. [PDF document properties: author=Cameron Whitham]
- COBRA meeting on 05Dec2013 because storm had potential to be regional/national disaster.
- new water level record at Kingston-Upon-Hull

Surgewatch (20200304)  Surgewatch, Storm event 6th December 2013, https://www.surgewatch.org/events/1/ (last accessed 04Mar2020)
- biggest event to impact UK east coast in more than half a century
- in many instances water level water exceeded 1953 levels
- water levels exceeded the 5 year return period for 12 sites
- water level was highest on record for 12 sites
- Dover: return period 84y
- Lowestoft return period: 200y
- highest water level on record for Newhaven & Portsmouth

WIKI (20200124)  WIKI, Cyclone Xaver, https://en.wikipedia.org/wiki/Cyclone_Xaver accessed 24Jan2020
- AIR Worldwide estimated wind losses from storm 07-1.4 billion EUR; impact to be less than St. Jude storm
- UK forecast the worst storm surge in 60 years
- Germany liked the surge to the Hamburg surge of 1962

Wikipedia (20200502)  Wikipedia, Orkan Xaver, https://de.wikipedia.org/wiki/Orkan_Xaver (accessed 2 May 2020)
- weather pattern for Storm Xaver 2013 similar to 1962 Hamburg surge
- comparison with Capella 3-4Jan1976

Table S4. Severe forecast (arranged by year and then alphabetically)

| Source | Full Reference and Notes |
|--------|--------------------------|
| Aftenposten (20131205) | Aftenposten, Varsler full storm I Sor-Norge, 5Dec2013 15:03 (correspondent Per Annar Holm)
https://www.aftenposten.no/norge/bKExj/varsler-full-storm-i-soer-norge
-met.no has been monitoring Bodil for a week |
| BBC (20131204) | BBC, Workers off Talisman Snoepec oil platform Buchan Alpha over bad weather forecast,04Dec2013
-severe weather forecast; 85 people taken off Buchan Alpha platform and production shut |
| Bloomberg (2013) | Bloomberg, Hamburg has worst flood in 37 year amid European storms, Nicholas Brautlecht, 6Dec2013, 02:58PM GMT
https://www.bloomberg.com/news/articles/2013-12-06/hamburg-has-worst-flood-in-37-years-as-storms-rage-across-europe
-Thames Barrier closed with surge forecast to be worst for 60 years. |
| BODC (20131205) | BODC, Storm surge and coastal flooding. News and Events, 5Dec2013.
https://www.bodc.ac.uk/about/news_and_events/storm_surge_and_coastal_flooding.html
- 'EA and UKMO warning of gale force waves, large wave and storm surge Thu to Sat morning
-this is the only storm surge warning among the press releases 2004-2018 |
| Energy (20131204) | Energy Voice, Oil staff withdrawn from North Sea ahead of storm conditions, 04/12/2013 10:30AM,
https://www.energyvoice.com/other-news/healthandsafety/50140/oil-staff-withdrawn-north-sea-ahead-storm-conditions
-North Sea forecast 04/12/2013 for 10m waves and storm force winds
-evacuation of Ekofisk, Valhall, Buchan Alpha |
| DW (20131205) | DW, Storm Xaver pummels Europe, flood surge feared, 05/12/2013
-media report from late Thursday that surge water levels could rise >3.5m above normal in the Bremen-Hamburg area |
| Gandreassen (20131204) | Gandreassen, Oil workers moved from Ekofisk, 4Dec2013. https://gandreassen.com/oil-workers-moved-from-ekofisk/
-report of 157 workers evacuated from Ekofisk field 1 day in advance of storm Friday |
| GVA (20131205) | GVA, Vifj containers even op drift op de Schelde, 05/12/2013 20:57. https://www.gva.be/cnt/aid1500792/vijf-
- warnings of storm gate closures in Antwerp for the following day (06/12/2013)

Kunz et al (20131206)

Kunz M, B Muehr, K Schroeter, T Bessel, S Moehrle, T Muenzberg, S Brink, H-M Schmidt, Winterstorm Xaver - Report. 06Dec2013 - Report No.1, Situation Report - 19:00CET, CEDIM Forensic Disaster Analysis Group (FDA), Center for Disaster Management and Risk Reduction Technology,

- northern federal states prepared long before surge arrives

NLWKN (20131203)

NLWKN, Sturmflutgefahr an der Kueste und auf den Inseln, Zwei meter ueber dem normalen Hochwasser in der Nacht zum Freitag moeglich!pressinformation von 29 November 2013, (written by Herma Heyken, Pressesprecherin), 03/12/2013
https://www.nlwkn.niedersachsen.de/startseite/aktuelles/presse_und_offentlichkeitsarbeit/pressemitteilungen/sturmflutgefahren-an-der-kueste-und-auf-den-inseln-1203187.html
- storm surge danger for Thursday and Friday with water levels 2m above normal
- water level information for Storm Britta , ranked as 100y event on Niedersachsen coast; Borkum water level comparable with 1962 surge.
- storm surge predicted to be centered on Emsmundung and Jade

Oceanografisch Meteorologisch Station (2013)

Oceanografisch Meteorologisch Station, Stormv尔斯 05-06 december 2013, 26pp, 2013 [pdf document properties: author=Myriam Sys; datastamp=15Dec2013]
- wind forecasts available from 30Nov2013; storm conditions d=forecast starting from 01Dec2013
- detailed wind and sea state forecasts from 04Dec2013
- water level forecasts from different model from 01Dec2013

Uswetterzentrale (20131212)

Uswetterzentrale, Orkanstief XAVER – ein weiterer schwerer Wintersturm der letzten Jahrzehnte, Thomas Savert and Stefan Laps, Dec, 2013 http://www.unwetterzentrale.de/uwe/928.html
- US GFS model made predictions from 29Nov of storm on Dec.6.
- 3-4 days before the storm most model predicted gusts to hurricane strength

Upstream (20131205)

Upstream, North Sea production curtailed over storm, 05Dec2013 (contributor: Bill Lehane and News Wires)
- North Sea platform production reduced and platforms de-manned 05Dec2013 on basis of forecast of 10m waves

Hewson et al (2014)

Hewson T, L Magnusson, O Breivik, F Prates, T Tsondevsky, HJW de Vries, Windstorms in northwest Europe in late 2013, ECMWF Newsletter, No 139, pp 22-28, Spring 2014.
- ECMWF indication of strong winds 5-6 days in advance
- at longer lead times of 7-8days some of the ensemble runs predicted vigorous cyclones in the correct location but few were sufficiently extreme.

Nosent et al (2014)

Nosent J, L Boeckx, E Taverniers, M Deschamps, T Verwaest, F Mostaert, Sinterklaasstorm 6 december 2013.
- storm surge moel predictions in the Schelde estuary for different lead times

RWS (2014a)

RWS, Watermanagementcentrum Nederland, Stormvloedflits 2013-07 van 5 t/m 7 december 2013, Rijkswaterstaat (document time stamp: 07Jan2014), 2014a
- longterm forecast of storm surge on Netherlands coast from 30Nov2013

RWS (2014b)

RWS, Stormvloedrapport van 5 t/m 7 december (SR91) Sint-Nicolaasvloed 2013, Watermanagementcentrum Nederland, Rijkswaterstaat, prepared by Ing. J. Kroos, 19 Mar 2014b, pp 48
- advance forecast from 27Nov2013
- detailed 12h forecasts before surge maximum at each reference station

Axer et al (2015)

Axer T, T Bistry, M Klawa, M Mueller, M Saesser, Deutsche Ruck Sturm dokumentation 2013 Deutschland, 2013: Deutsche Rueckversicherung Aktiengesellschaft, Hansaalle 177, 40549 Duesseldorf, www.deutscherueck.de
- [pdf document information: author=filiz; date stamp=07Aug2015]
- damage low because of early warning of storm
- correct longrange forecast of development & impact
- 5-day advance forecast of significant storm surge potential
- 1-day before height, weather service & media broadcast hurricane gusts on coasts & northern Germany

Dan et al (2015)

Dan, Sebastian, Anne-Lise Montreuil, Rosalia Delgado, Thomas van Oyen, Large storm impact on a beach under sand nourishments, The Proceedings of the Coastal Sediments 2015, edited by Ping Wang, Julie D Rosati, and Jun Cheng, Coastal Sediments 2015, San Diego, USA, 11-15May2015
- pre-storm beach surveys were made on 3Dec2014

NLWKN (20151210)

NLWK20151210, Sturmflutwarnsdienst der Betriebstelle Norden-Norderney, NLWKN Niedersachsicher Landesbetrieb fuer Wasserwirtschaft, Kuesten- und Naturschutz, Niedersachsen, document date stamp 10Dec2015.
- upgrade of DWD model in 1998 to allow 5 day wind forecasts
- current forecast infrastructure: 5-day wind forecasts & 2-day surge forecasts from DWD models
- comparison of DWD models with BSH & KNMI forecasts
- hourly forecasts during surge event from local tide gauge & wind speed information
- surge surge season September to March

Wadey et al (2015)

Wadey MP, ID Haigh, RJ Nichols, JM Brown, K Horsburgh, B Carroll, SL Gallop, T Mason, E Bradshaw, A comparison of the 31 January-1 February 1953 and 5-6 December 2013 coastal flood events around the UK, UK Frontiers in Marine Science, 2, 84, 2015.
- noon 31Jan1953 forecast: ‘All districts will have gale force winds, severe in many places, and squally showers, mainly of hail or snow. Considerable snowfall may occur over high ground. Thunderstorms will occur here and there. It will be cold’ (no mention coastal flooding)
- Storm Xaver surge forecast 3 days in advance

Sibley et al. (2015) Sibley A, D Cox, H Titley, Coastal flooding in England and Wales from Atlantic and North Sea storms during the 2013/2014 winter, Weather, 70, 62-70, 2015
- ensemble forecast from 0600UTC 1Dec2013 indicates possible surge problem
- ensemble forecast from 0000UTC 5Dec2013 predicts surge height with small uncertainty range

ECMWF (20160316) ECMWF, Cyclone Xaver/Bodil/Sven, North-western Europe
https://confluence.ecmwf.int/pages/viewpage.action?pageId=28315390
- severe gusts forecast days in advance
- FIG4. [MAP] The series of figures above shows HRES forecasts of the maximum wind gust during 5Dec and the MSLP valid 12UTC. The color scale is the same as for the observations in the previous section. The first forecast is from 05Dec 00UTC and following is 04 dec and so on (1 day apart. Already the forecast from 9 days before had a cyclone in the area, but further west than the latest forecast
- FIG7. [MAP] Probability of maximum wind gust >33m/s on 5Dec. The first forecast is from 5 Dec 00UTC and the following are one day apart. Up 3.5-4 days before the event, the probability of hurricane wind gust were close to 100% in western Scotland and over the North Sea

Ribeiro et al (2017) Ribeiro R, R Rudge, D Rucinska, Analysis of physical factors of the windstorm Xaver in Poland: post-hazard review, Weather, 72, 2017, pp.378-382
- forecast program European Storm issued 18 storm forecasts 3-11Dec2013
- ESTOFEX forecast very dangerous weather from 5Dec2013 for Netherlands, Germany, Poland
- 35 warnings of strong winds 4-7Dec2013
- FIG5. [MAP] Forecasts of expected significant weather threats issued on (a) 05Dec 22UTC, (b) 5Dec 1139UTC, (c) 6Dec 2215UTC, 8Dec 0343UTC (significant weather threats UK, Netherlands, Germany Sweden Poland; Norway, Czech republic, Austria marginal

Wahle et al (2017) Wahle K, J Stanewa, W Koch, L Fenoglio; not as bad as expected
- 'one of the most severe storms of the last decade'

Wikipedia (20191002) Wikipedia, Stormen Bodil, https://da.wikipedia.org/wiki/Stormen_Bodil#cite_note-39 (accessed 02Oct2019)
- DMI observed low P 1 week previously over Greenland; warnings 5 days in advance
- Denmark Strait NW Island reports 4Dec2013 of powerful low P; developed expls over night
- UK Category 2 warning for Scotland & N part of England; risk gust 145 km/h
- EA warned of worst storm flood in 30y for English east coast
- DMI category 2 warning all Denmark, high water danger Vadehavet & inner Danish farvand
- SMHI warned of high snowfall & powerful gust
- NW Germany Niedersachsen, DWD warned gusts to 140km/h with repeat of 1962 storm surge

WIKI (20200124) WIKI, Cyclone Xaver, https://en.wikipedia.org/wiki/Cyclone_Xaver accessed 24Jan2020
- storm center only formed on 4 Dec 2013 off W coast of Iceland
- UK Met Office issued amber warning over Scotland & N England with forecast gusts to reach 145 km/h
- EA issued warning 4Dec2013 for E coast England for worst surge in 60 years in period 5-7 Dec 2013
- Netherlands: Friesland, Groningen, North Holland place on Red Alert with winds force 9-11 forecast
- Denmark: force 12 gusts expected
- Sweden: SMHI gave level 2 warning for heavy snowfall & snow drifts

Wikipedia (20200429) Wikipedia, Stormen Sven, https://sv.wikipedia.org/wiki/Stormen_Sven#cite_note-15, accessed 29Apr2020
- SMHI issued class-2 warning 4Dec2013 for south Sweden
- warning upgraded to class-3 for Skane to Osterlen; extended to include Halland

Wikipedia (20200502) Wikipedia, Orkan Xaver, https://de.wikipedia.org/wiki/Orkan_Xaver (accessed 2 May 2020)
- warnings of arctic storm starting from 1Dec2013
- UK issued surge warning for 30y event; then upgraded to 50y event

Table S5. Storm not as bad as expected; not as bad as it could have been (arranged by year and then alphabetically)

| Source | Full Reference and Notes |
|--------|--------------------------|
| Gccapitalideas (20131209) | gcccapitalideas, Windstorm Xaver, 9Dec2013, https://www.gccapitalideas.com/2013/12/09/windstorm-xaver/ |
- despite some reports of roof damage and the widespread disruption to transportation, damage from the powerful winds nevertheless appears to have been minimal and surge damage was limited by strengthened sea defences ...
- improved flood defences protected 800,000 properties, meaning the impact was not as severe as 1953

| Nordbayern (20131207) | Nordbayern, Deining: 'Xaver' reisst Rotorblatt von Windrad ab. Windkraftanlage schleuderte Eisbrocken auf die Strasse, 07/12/2013, 12:07. https://www.nordbayern.de/region/neumarkt/deining-xaver-reisst-rotorblatt-von-windrad-ab-1.3326492 |
- not much damage in northern Bavaria in spite of high winds

| Oceanografisch Meteorologisch Station (2013) | Oceanografisch Meteorologisch Station, Stormverlaat 05-06 december 2013, 26pp, 2013 [pdf document properties: author=Myriam Sys; datestamp=15Dec2013] |
- discussion of worst case scenario
- air pressure only went down to 1012hPa; could have dropped to 960hPa
- surge would have been worst if wind were more northerly

| Spiegel International (20131206) | Spiegel International, Winter storm Xaver batters northern Europe.6 Dec 2013, 12:56 https://www.spiegel.de/international/europe/tidal-surge-winter-storm-xaver-batters-northern-europe-a-937576.html# |
- storm danger manageable; authorities have not yet given the all clear
Unwetterzentrale (2013/12) Unwetterzentrale, Orkanrief XAVER - ein weiterer schwerer Wintersturm der letzten Jahrzehnte, Thomas Savert and Stefan Laps, Dec. 2013 http://www.unwetterzentrale.de/uwz/928.html - early warning prevented much damage

ABPmer (2014) ABPmer, Ensuring Flood Resilience. An overview of the 5/6 December 2013, Associated British Ports, Marine Environmental Research, July, 2014 - 2013 surge much less than 1953: fatalities, flooded properties, flooded agricultural land - aerial photo of London showing potential flooded area if Thames Barrier were absent

CH2M Halcrow (2014) CH2M Halcrow, Cell 1 Regional Coastal Monitoring Programme, Wave Data Analysis Report 2: 2013-2014, Final Report, March 2014 [document properties: author=Andy.Parson@ch2m.com; datestamp: 04/04/2014] - The storm surge that damaged many defences and received significant media attention on 5th and 6th Dec 2013 does not appear to have had exceptional wave conditions at the Tyne Tyes buoy, with a peak significant wave height of 4.7m and storm duration of 38 hours. However, the wave period was over 14 seconds, is unusual, and the longest storm wave period recorded

Dunbar et al (2014) Dunbar I, N Phupps, M Szonyi, Risk Nexus. After the storm: how the UK's flood defences performed during the surge following Xaver, Flood resilience review 09.14, Zurich Insurance Company Ltd., Mythenquai 2, 8002, Zurich, Switzerland [document properties: date 28/Aug/2014; author= Zurich] - EA aerial photo of London area flooded in absence of London Barrier - cost of 1953 flood 500mill GBP; 1983 construction cost 535mill GBP - EA: flood defences in Hull river & Humber estuary prevented flooding of 100000 homes & 250mill GBP loss - Warrington Water Scheme: flood protection scheme operated for first time during Xaver 2013; 1400 home protected

Luecht and Peters (2014) Luecht, Fabian and Ove Peters, Bericht ueber die Sturmflut vom 05-06.12.2013 an der Westkueste Schleswig-Holsteins, Landesbetrieb fuer Kuestenschutz, Nationalpark und Meeresschutz Schleswig-Holstein, Husum 26/Feb/2014, 19pp. [pdf document properties: title=Lfd; Author=Thorsten Nommensen; datestamp: 11-Dec2018] - in spite of extreme weather there was relatively little damage to coastal defences in Schleswig-Holstein - exception was rock armour on Halligen, which had massive damage

RMS (2014) RMS, 2013-2014 Winter Storms in Europe. An Insurance and Catastrophe Modeling Perspective. RMS White Paper. [PDF TIMESTAMP 11Mar2014] - wind damage in Europe minimal compared with US events - storm surge losses in winter 2013-2014 not exceptional - flood defences have evolved; damage not as bad at 1953 storm - storm surge losses for Germany were not as bad as 1962 or 1976 (Capella) events

Thorne (2014) Thorne, Colin, Geographies of UK flooding in 2013/4, The Geographical Journal, 180, 297-309, 2014. - disruption and damage from storm surge limited - UK flooding damage for all 2013/2014 events 290 million GBP; 2007 summer floods cost 3.2 billion GBP

Axer et al (2015) Axer, T, T Bistry, M Klaw, M Mueller, M Suesser, Deutsche Ruck Sturm dokumentation 2013 Deutschland. 2013, Deutsche Rueckversicherung Aktiengesellschaft, Hansaallee 177, 40549 Duesseldorf, www.deutscheueck.de [pdf document information: author=filiz; date stamp=07/Aug/2015] - limited damage because early warning of storm & storm surge protection developed over previous decade - no great damage because of early warning & investment in coast protection after 1953,1962,1976 - Baltic: storm surge lower than feared; sand bags made ready in Wismar - Im Vorfeld und waehrend des Ereignisses wurde aber die potenzielle Katastrophe an der Nordsee berichtet, die sich glucklicherweise nicht realisier(' potential catastrophe on North Sea not realized)

Dan et al (2015) Dan, Sebastian, Anne-Lise Montreuil, Rosalia Delgado, Tomas van Oyen, Large storm impact on a beach under sand nourishments, The Proceedings of the Coastal Sediments 2015, edited by Ping Wang, Julie D Rosati, and Jun Cheng, Coastal Sediments 2015, San Diego, USA, 11-15May2015 - 'The storm had a limited impact on teh study zone most probably due to the mild wave conditions and good volumetric state of the beach'

Jensen et al (2015) Jensen, J., A. Arns, T. Wahl, Yet another 100yr storm surge event: the role of individual storm surges on design water levels, Journal of Marine Science and Technology, 23, 882-887, 2015. - calculated return water levels much less than 100yr level reported in media

Dangendorf et al (2016) Dangendorf S, A Arns JG Pinto, P Ludwig, J Jensen, The exceptional influence of storm 'Xaver' on design water levels in the German Bight, Environmental Research Letters, 11, 2016, 054001 - tide & storm surge were out of phase; water levels could have been several decimeters higher

Matelski (2016) Matelski, Birgit, Erfahrungen aus der Sturmflut Xaver von 5. und 6.12.2013 und dem Weihnachtssturm 2013 in Shleswig-Holstein, IWASA 2016 Tagungsbeitrag, (46. IWASA, 7-8 Januar 2016; Internationales Wasserbau-Symposium Aachen. [pdf document properties: author=sonja; datestamp: 26/Apr/2016] - only a few stations registered new water level records

North Norfolk District Council Coastal Team (2018) North Norfolk District Council Coastal Team, Refurbishment of sea walls and groynes 2013-2015; Cromer Coast Protection, (picture of plaque on wall taken 27Dec2018) www.northernorfolk.co/coastal - no drowning fatalities in 2013 storm even though water levels similar to 1953 when >2000 drowned - reason: effective sea defenses and huge advances in surge forecasting, modern communication, emergency planning

Ulm et al (2018) Ulm, Marius, Arne Arns, Juergen Jensen, Assessing consequences of extreme events for the German Bight, 36th International Conference on Coastal Engineering 2018 - Coastal Protection and Risk - ID 1527 - earlier research suggests. Water levels may likely exceed historical events by at least 1.40m'

North Norfolk District Council Coastal Team (2019) North Norfolk District Council Coastal Team, Sheringham Sea Defences; Repair and Recovery from the December 2013 storm surge, www.northernorfolk.co.coastal, photo of plaque on wall taken 30Dec2019 - no drowning fatalities for 2013 storm in comparison to 2013 storm because of effective sea defenses, advances in weather/flood forecasting, modern communications, emergency planning

Wikipedia (20191002) Wikipedia, Stormen Bodil, https://da.wikipedia.org/wiki/Stormen_Bodil#cite_note-39 (accessed 02Oct2019) - storm much milder than expected on France's north coast near Denmark
Surgewatch (20200304) Surgewatch, Storm event 6th December 2013, https://www.surgewatch.org/events/1 (last accessed 04Mar2020)
-800000 properties protected by flood defences along 2800km coastline

WIKI (20200124) WIKI, Cyclone Xaver, https://en.wikipedia.org/wiki/Cyclone_Xaver accessed 24Jan2020
-Xaver storm surge weaker than expected on the north coast of France
-Peter Aldous MP Waveney: 'There is a strong sense in these communities that Parliament has not yet considered properly this narrowly averted national crisis.'

Wikipedia (20200502) Wikipedia, Orkan Xaver, https://de.wikipedia.org/wiki/Orkan_Xaver (accessed 2 May 2020)
'-In Deutschland waren die Schäden weniger verheerend als zuvor befürchtet.'

Table S6. Storm worse than expected (arranged by year and then alphabetically)

| Source | Full Reference and Notes |
|--------|--------------------------|
| Sueddeutsche Zeitung (20131215) | http://www.sueddeutsche.de/panorama/sturmschaeden-auf-sylt-xaver-holte-sich-land-1.1844100 -emergency sandbags placed at Keitum on east side of Sylt to prevent a water inbreach |
| Syllter Rundschau (20131209) | https://www.shz.de/lokales/sylter-rundschau/xaver-knabberte-sylt-massiv-an-09Dec2013-0600-(from-Friederike-Reussner).html -storm damages Sylt boundary dunes and dikes |
| Unwetterzentrale (201312) | https://www.unwetterzentrale.de/uwz/928.html | -10000 sand bags for temporary dike at Sahlenburg |
| BBC (20141205) | BBC, East coast surge: what happened next? (report by Richard Haugh), 5Dec2014 -house owners in Hemsby thought they would have 30y before the sand cliff washed away -photos show ambulance services evacuating people with zodiacs in the middle of the flood |
| Dunbar et al (2014) | Dunbar I, N Phipps, M Sonzy, Risk Nexus. After the storm: how the UK’s flood defences performed during the surge following Xaver, Flood resilience review 09.14, 6:00 (from Friederike Reussner) |
| Knaack and Heyken (2014) | Knaack H and H Heyken, Xaver hatte sehr schwere Sturmflut im Gepaeck, Jahresbericht 2013. Der Zukunft verpflichtet, NLWKN, Niedersaechsischer Landesbetrieb fuer Wasserwirtschaft, Kuesten- und Naturschutz, pp.8-9, document date stamp 24Apr2014. -winter of 2012-2013 had only one light storm surge at end of January; 2013-2014 had Orkan Christian and Xaver |
| RWS (2014b) | RWS, Stormvloedrapport van 5 t/m 7 december (SR91) Sint-Nicolaasvloed 2013, Watermanagementcentrum Nederland, Rijkswaterstaat, prepared by Ing. J. Kroos, 19 Mar 2014b, 48 pp -Deltzijl water level 52cm higher than forecast -Rooimoor buiten second higher error at 37cm higher than forecast |
| Haigh and Bradshaw (2015) | Haigh I and E Bradshaw, A century of UK coastal flooding, Planet Earth, Winter 2015, (pdf document properties: date 28Jan2014; author= Zurich) -COBRA crisis committee briefings for several storms |
| RWS (2014b) | -Deltzijl water level 52cm higher than forecast -Rooimoor buiten second higher error at 37cm higher than forecast |
| Jensen et al (2015) | Jensen, J., A. Arns, T. Wahl. Yet another 100yr storm surge event: the role of individual storm surges on design water levels, Journal of Marine Science and Technology, 23, 882-887, 2015. -design water levels had to be revised upward 10-20cm for Emden, Wilhelmshaven, Nordener |
| Vannassenhove (2015) | Vannassenhove, Niels, Storm surge measures ports Flemish coast; Blankenberge, Tuesday February 3rd, Maritieme Sientverlening en Kuist, Coastal Division, Flanders Hydraulic Research.[document properties: title=Geintegreerd Kustveiligheidsplan; author=Maarten; datestamp=27/02/2015] -emergency workers placed sandbags in Ostend Harbour |
| Wadley et al (2015a) | Wadley MP, JD Haigh, RJ Nichols, JM Brown, K Horsburgh, B Carroll, SL Gallop, T Mason, E Bradshaw, A comparison of the 31 January-1 February 1953 and 5-6 December 2013 coastal flood events around the UK, UK Frontiers in Marine Science, 2, 84, 2015a. -large differences in local water levels; reasons not clear -effect of wave field increasing the severity of the storm |
| Sibley et al (2015a) | Sibley A, D Cox, H Titley, Coastal flooding in England and Wales from Atlantic and North Sea storms during the 2013/2014 winter, Weather, 70, 62-70, 2015 -'Whitby: '...power outages to the town making recovery difficult' -River Haven at Boston south Lincolnshire: '…experienced breaches of sea defences with around 200 people evacuated' -'thousands of people were evacuated from homes in East Anglia as sea level rose' -Rhyl and Conwy: 'four hundred people were evacuated as high tides and wave overtopped flood defences' |
| Wadley et al (2015b) | Wadley MP, JM Brown, ID Haigh, T Dolphin, P Wisse, Assessment and comparison of extreme sea levels and waves during the 2013/2014 storm season in two UK coastal regions, Nat. Hazards Earth Syst. Sci. Discuss., 3, 2665-2708, 2015b. -breaching of water level defences in Suffolk |
| Evans (2017) | Evans, Sun Yan, EA2/2 Appendix 1, History of flooding sources, Boston Barrier Transport & Works Act order application, Public Inquiry documents, [pdf document properties: author=BBB; datestamp=16Mar2017] https://consult.environment-agency.gov.uk/engagement/bostonbarriertoa/results/appendix-1—history-of-flooding-sources.pdf -business and restaurants in norma operation until the flood hit |
| WIKI (20200124) | WIKI, Cyclone Xaver, https://en.wikipedia.org/wiki/Cyclone_Xaver accessed 24Jan2020 -Sweden, Denmark higher water level than expected |
| Wikipedia (20200429) | Wikipedia, Stormen Sven, https://sv.wikipedia.org/wiki/Stormen_Sven#cite_note-15, accessed 29Apr2020 -Upgrade of SMHI weather warning from class-2 to class-3 during storm on Thursday 5 Dec 2013 |
Table S7. Extended period bad weather (arranged by year and then alphabetically)

| Source | Full Reference and Notes |
|--------|--------------------------|
| BBC (20131206) | BBC20131206: Deadly storm and tidal surge batter northern Europe; BBC 6 Dec 2013 (report by Anna Holligan) |
| -flights cancelled at Schipol on 5Dec2013 but back to normal on 6Dec2013 |
| BSH (2013) | BSH, Die Nordseesturmfluten von 5. und 6.12.2013, 3pp, prepared by Stockmann.K. (title: Sturmflut 2013 bm1101; author stamp: bm1101; document time stamp: 12/10/2013 12:5136PM) |
| -storm surge for 4 high tides from 5-7Dec2013 |
| Deutschlander et al. (2013) | Deutschlander T, K Frierich, S Haeseler, C Lefebvre, Orkantief XAVER uber Nordeuropa von 5. bis 7. Dezember 2013, Deutscher Wetterdienst DWD, Stand 30. Dezember 2013, 19pp. |
| -FIG7 [TIME SERIES] Time series of 10min gust for List/Sylt, Norderney, Rostock-Warnemuende shows high wind duration 5-7Dec2013 |
| -FIG17. Time series of 10-min average wind speed for Brocken shows storm lasting >3 days starting on 4 Dec 2013 |
| -‘Es wurde kurzzeitig winderlich mit Schnee bis in tiefe Lagen.’ |
| KNMI (2013) | KNMI, News report. De Zware storm van 5 december, 06 Dec 2013, https://www.knmi.nl/over-het-knmi/news/de-zware-storm-van-5-december |
| -storm surge from long duration of northwest winds and long-fetch wind field |
| SMHI (20131210) | SMHI, Stormen Sven gav nya vattenstandsrekord i Oresund. https://www.smhi.se/myhetsarkiv/stormen-sven-gav-nya-vattenstandsrekord-i-oresund-l-34732, updated 20Mar2017; original dataset 10Dec2013. |
| -short duration flood on west coast Sweden |
| Syller Rundschau (20131209) | Syller Rundschau, Folgen des Orkans. Xaver knabberte’ Sylt massiv an, 09Dec2013 06:00 (from Friederike Reussner) https://www.shz.de/lokales/syller-rundschau/xaver-knabberte-sylt-massiv-an-id5098481.html |
| -storm damages Sylt dunes and coast over 2-day period |
| SMHI, News report. De Zware storm van 5 december, 06 Dec 2013, https://www.knmi.nl/over-het-knmi/news/de-zware-storm-van-5-december |
| -storm surge from long duration of northwest winds and long-fetch wind field |
| Unwetterzentrale (201312) | Unwetterzentrale, Orkantief XAVER - ein weiterer schwerer Wintersturm der letzten Jahrzehnte, Thomas Savert and Stefan Laps, Dec. 2013 http://www.unwetterzentrale.de/uvw/928.html |
| -Xaver had exceptionally long duration |
| -Station Hiddensee-Dornbusch on Baltic Island had 41h of storm winds |
| -lure hurricane gusts for 32h from 5Dec2013 1610MEZ to 7Dec2013 0010MEZ |
| -storm gusts reported by Ellenbogen on north end of Sylt from 6Dec2013 07:10MEZ to 7Dec2013 03:10MEZ |
| ABPmer (2014) | ABPmer, Ensuring Flood Resilience. An overview of the 5/6 December 2013, Associated British Ports, Marine Environmental Research, July, 2014 |
| -prolonged severe weather events Dec2013-Mar2014 |
| ->50 closures of Thames Barrier during period Dec2013-Mar2014 |
| CH2MHill Halcrow (2014) | CH2MHill Halcrow, Cell 1 Regional Coastal Monitoring Programme, Wave Data Analysis Report 2: 2013-2014, Final Report, March 2014 [document properties: author=Andy.Parson@ch2m.com; document stamp: 04/04/2014] |
| -Newbiggin Ness wave buoy storm duration: 20h |
| -Tyne Tees Wavenet buoy storm duration: 38.5h |
| -Whithby wave rider storm duration: 26h |
| Eden (201402) | Eden, Phillip. Weather Log December 2013, Weather, Feb 2014, pp 1-iv |
| -48 hour cold snap |
| Goennert et al (2014) | Goennert G, O Mueller, M Schaper, K Sossidi, Die Sturmflut nach dem Tief Xaver von 5. bis 7. Dezember 2013, Berichte des Landesbetriebes Strassen, Bruecken und Gewaesser (LSBG), Freie und Hansestadt Hamburg, Nr. 16/2014, 26pp. |
| -storm speed over the North Sea over 20m/s for 19h in the direction 270-300 deg as measured at Scharhörn |
| Knaack and Heyken (2014) | Knaack H and H Heyken, Xaver hatte sehr schwere Sturmflut im Gepaeck, Jahresbericht 2013. Der Zukunft verplichtet, N.W.K.N., Niederseehrischer Landesbetrieb fuer Waserwirtschaft, Kuesten- und Naturschutz, pp.8-9, document date stamp 24Apr2014. |
| -Xaver low pressure center moved slowly across North Sea and brought 4 storm surges |
| Kristandt et al. (2014) | Kristandt, J., B. Brecht, H. Frank, H. Knaack. Optimization of empirical storm surge forecast-modeling of high resolution wind fields, Die Kueste, 81, 301-348, 2014 |
| -storm flooding continued over 4 tide cycle |
| Leiding et al (2014) | Leiding T, B Tinz, G Rosenhagen, C Lefevre, S Haeseler, S Hagemann, I Bastigkeit, D Stein, P Schwenk, S Mueller, O Otzien, K Herklotz, F Kinder, T Neumann, Meteorological and Oceanographic Conditions at the FINO platforms during the severe storms Christian and Xaver, DEWI Magazin, No.44, iv, p16-25, 2014. |
| -storm Xaver raged in German Bight for 2.5 days; several storm tides. |
| -Storm Xaver raged in German Bight for 2.5 days; several storm tides. |
| -fetch wind field |
| Luechtt and Peters (2014) | Luecht, Fabian and Ove Peters, Bericht uber die Sturmflut vom 05.-0.6.12.2013 an der Westkueste Schleswig-Holsteins, Landesbetrieb fuer Kuestenschutz, Nationalpark und Meeresschutz Schleswig-Holstein, Husum 22Feb2014, 19pp. [pdf document properties: title=Lfd; Author=Thorsten Nommensen; document stamp: 10Dec2018] |
| -storm flood levels on 3 consecutive tides |
| -storm flood duration was rank 8 in List tide gauge record going back to 1900 |
| -for worst storm tide water levels at NHN+2m for 532 min |
| Pelt (2014) | Pelt AS; BODIL’s stormflod i de indre dansk farvande, ‘Vejret, 138, 24-29, 2014 |
| -water levels above normal DVR90 from Dec 3, 2013 |
| -unusually long storm duration surge at Hornbaek 1h |
| -long duration 15h high water Kobenhavn |
| RMS (2014) | RMS, 2013-2014 Winter Storms in Europe. An Insurance and Catastrophe Modeling Perspective. RMS White Paper, [PDF TIMESTAMP 11Mar2014] |
| -storm surge lasted 40h across 3 tidal cycles |
| Spencer et al (2014) | Spencer, T. S.M. Brooks, T. Moller, B.R. Evans, Where local matters: Impacts of a major North Sea storm surge, EOS, 195, 269-270, 29July2014 |
| -2 month period of storms Dec2013-Jan2014 of which Xaver was the first |
Thorne (2014)  Thorne, Colin, Geographies of UK flooding in 2013/4, The Geographical Journal, 180, 297-309, 2014. -listing of all 2013/2014 winter storms that caused flooding and coast damage

Axer et al (2015)  Axer T, T Bistry, M Klawa, M Mueller, M Suesser, Deutsche Ruck Sturm dokumentation 2013 Deutschland, 2013, Deutsche Rueckversicherung Aktiengesellschaft, Hansaallee 177, 40549 Duesseldorf, www.deutscherueck.de [pdf document information: author=filtzu; date stamp=07Aug2015] -slow path Xaver from S Sweden into Baltic caused long duration >1day NW wind over Nsea & Baltic -consequence was unusually high sea state >8m in German Bight & Polish Baltic coast (DWD2013c)

Haigh and Bradshaw (2015)  Haigh I and E Bradshaw, A century of UK coastal flooding, Planet Earth, Winter 2015, (pdf document properties: 13Jan2016) -cluster of winter storms during winter 2013-2014

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Matelski (2016)  Matelski, Birgit, Erfahrungen aus der Sturmflut Xaver von 5. und 6.12.2013 und dem Weihnachtschwarchower 2014 in Shleswig-Holstein, IWASA 2016 Tagungsbeitrag, (46. IWASA, 7-8 Januar 2016; Internationales Wasserbau-Symposium Aachen. [pdf document properties: autor=sonja; date stamp=26Apr2016] -three storm surge peaks -long duration flood conditions: water on sand fo 9h; subjects dused to wave attack -on List auf Sylt water level >700cm PN for 532min

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Staneva et al (2016)  Staneva J, K Wahle, W Koch, A Behrens, L Fenoglio-Marc, EV Stanev, Coastal flooding: impact of waves on storm surge during extremes - a case study for the German Bight, Nat. Hazards Earth Syst. Sci., 16, 2373-2389, 2016. -During 4 to 7 December, the storm depression Xaver moved from thesouth of Iceland over the Faroe Islands to Norway and southern Sweden and further over the Baltic to Lithuania, Latvia, and Estonia

Frohle and Dreier (2017)  Frohle B, R Dreier, Early-Dike - Sensor - und risiko basertes Fruehwarnsystem fuer Seederche, Teilprojekt: Wellenmonitoring und Wellenbelastungssimulator (AP2), Hamburg, April 2017 -FIG13. Time series graph of 60m wind speed at FINO1; wind speed above 5m/s threshold 3-9Dec2013 -FIG14. Time series graph of 14m wind speed at Helgoland; wind speed above 5m/s threshold 3-9Dec2013

Wahle et al (2017)  Wahle K, J Staneva, W Koch, L Fenoglio-Marc, HTM Ho-Hagemann, EV Stanev, An atmosphere-wave regional coupled model: improving prediction of wave heights in the southern North Sea, Ocean Sci., 13, 289-301, 2017. (doi:10.5194/os-13-289-2017). -storm exceptional because of long duration of nearly two days

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Kystdirektoratet (2018)  Kystdirektoratet, Shoreface nourishment effects. An analysis of the 2011 nourishment performed at Skodbyerge. [pdf document properties: title=Shoreface nourishment effects_Skodbjerge_20.12.2018, datestamp=20/12/2018] -unusually long duration of high wave fields: 36h with Hm0>5m

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Wikipedia (20191002)  Wikipedia, Stormen Bodil, https://da.wikipedia.org/wiki/Stormen_Bodil#cite_note-39 (accessed 02Oct2019) -flooding in low-lying parts of Denmark for a week after the storm

WIKI (20200124)  WIKI, Cyclone Xaver, https://en.wikipedia.org/wiki/Cyclone_Xaver accessed 24Jan2020 -3 storms to UK around Christmas: Cyclone Dork, Anne, Christina with heavy rains and flooding -parts of England had wettest January from record start more than 100 years previously -Feb 2014 200 properties evacuated in Somerset & Devon -Europe February: flooding in France, large snowfalls Austria and Slovenia; large waves Portugal and Spain

Table S8. Names of the storm (arranged by year and then alphabetically)

| Name                        | Full Reference and Notes                                                                 |
|-----------------------------|-----------------------------------------------------------------------------------------|
| Bodil (Norway, Denmark)     | Atfenposten, Varsler full storm I Sor-Norge, 5Dec2015 15:03 (correspondent Per Annar Holm) https://www.atfenposten.no/norge/hKJEJl/varser-full-storm-i-soer-norge Deutschlander T, K Frierich, S Haeseler, C Lefebvre, Orkantief XAVER uber Nordeuropa von 5. bis 7. Dezember 2013, Deutscher Wetterdienst DWD, Stand 30. Dezember 2013, 19pp. Cipollini P, LJ West, HM Snathl, P Harwood, C Donlon, New altimeter products over shelf and coastal zone from the eSurge processor, poster presentation, 2014 [document time stamp: 2014/10/22] Hewson T, I Magnusson, O Breivik, F Prates, I Tosnevsky, HIW de Vries, Windstorms in northwest Europe in
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Cameron

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Table S9. Satellite pictures and weather maps (arranged by year and then alphabetically)

| Source | Full Reference and Notes |
|--------|-------------------------|
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-ABB2a.[MAP] Bodenanalyse Nordatlantik/Europa von 5.Dezember 2013, 00UTC  
-ABB2b.[MAP] Bodenanalyse Nordatlantik/Europa von 6.Dezember 2013, 18UTC  
-ABB2c.[MAP] Bodenanalyse Nordatlantik/Europa von 7.December 2013, 06UTC  
-ABB3.[MAP] Satellitenbild mit Luftdruck (in hPa) und Wind (Richtung und Geschwindigkeit) am 6.Dezember 2013 00UTC, ueber dem nordlichen Europa (Quelle: DWD)  
Photo of cloud field with superimposed surface air pressure & wind arrows  
-ABB4.[MAP] Satellitenbild von Europa con 6.Dezember 2013, 06UTC (Quelle: DWD)  
Photo of cloud field MET10 IR100-STC |
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-FIG1. Met-10 and Jason, 05Dec2013 1800UTC; channel IR 10.8um; source EUMETTrain  
-FIG2. Met-10, 05Dec2013, 1800UTC; Airmass with the MSLP (pressure lines) |
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-FIG1. [MAP] UKMO weather maps E Atlantic & Europe 04Dec2013 0600UTC to 07Dec2013 1200UTC  
-FIG2. [MAP] IR cloud image and eastern Atlantic for 4Dec2013 21MEZ, as base image for storm trajectory  
-FIG3. [MAP] IR satellite picture 05Dec2013 0800MEZ shows Xaver with it center over North Sea  
-FIG15. [MAP] Visible satellite image with lightning band in front of the Netherlands coast |
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-series of daily weather maps of surface pressure for Europe |
| Eriksen (2014) | Eriksen J, Rekordvandtandse i Sjöfjorden og Roskilde Fjord, Vejrjet, 138, 2 40-48, 2014  
-FIG1. Measured winds and surface air pressure torsdag kl 18utc.  
-Bodil is marked with a red L  
-FIG3. Measured winds and surface air pressure Friday kl 00utc.  
-Bodil is marked with a red L. Central P 962.5hPa  
-FIG4. Measured winds and surface air pressure Friday kl 06utc.  
-Bodil is marked with a red L. Central P 962.6hPa  
-FIG5. Measured winds and surface air pressure Friday kl 18utc.  
-Bodil is marked with a red L. Central P 970.7hPa  
-FIG6. Measured winds and surface air pressure Saturday kl 00utc.  
-Bodil is marked with a red L  
-FIG7. Measured winds and surface air pressure Saturday kl 06utc.  
-Bodil is marked with a red L |
| Goennert et al. (2014) | Goennert G, O Mueller, M Schaper, K Sossidu, Die Sturmflut nach dem Tief Xaver von 5. bis 7. Dezember 2013. |
Table S10. Satellite altimeter strip maps (arranged by year and then alphabetically)

| Source | Full Reference and Notes |
|--------|--------------------------|
| Mills et al (2013)| [MAP] ABB5. Map with data listed for maximum 3 second wind gusts over 6 hour time intervals. Data of all satellites during the study period (1Oct2013 to 31Dec2013) coupled model: improving prediction of wave heights in the southern North Sea, Ocean Sci., 13, 289-301, 2017.(doi:10.5194/os-13-289-2017). -FIG3. Tracks of all satellites during the study period (1Oct2013 to 31Dec2013) -FIG6. [STRIPMAP] Latitude profile of wave height (m) and wind speed (m/s) from the SARAL/Altika data and as modelled by WAM-NS under calm weather conditions on 13Nov2013. The track of the satellite (white line) is shown together with the model significant wave height at the time of the passage. *FIG7. [STRIPMAP] As Fig6 but for Storm Xaver on 6Dec2013 |
| Cipollini et al (2015) | [MAP] ABB6. Map with the Northern Germany, southern North Sea, western Baltic Sea and neighboring countries. 5 Dec 2013 12-18UTC & 6 Dec 2013 06-06UTC | Deutschlander T, K Frierich, S Haeseler, C Lefebvre, Orkantiefe XAVER uuber Nordeuropa von 5. bis 7. Dezember 2013, Deutscher Wetterdienst DWD, Stand 30. Dezember 2013, 1pp. |
data listed for 10-min average wind

| North Sea, western Baltic Sea and neighboring countries | 1900 UTC | Orkantief XAVER ueber Nordeuropa von 5. bis 7. Dezember 2013, Deutscher Wetterdienst DWD, Stand 30. Dezember 2013, 19pp. |

[TABLE] Highest daily peak gusts and 10-min mean wind speed

| Stations in Germany ranked in descending order of the peak gust on 5 Dec 2013 | 5 Dec 2013, 6 Dec 2013, 7 Dec 2013 | Deutschlander T, K Frierich, S Haeseler, C Lefebvre, Orkantief XAVER ueber Nordeuropa von 5. bis 7. Dezember 2013, Deutscher Wetterdienst DWD, Stand 30. Dezember 2013, 19pp. |

[FIG] ABB7. Time series of peak gust over 10-min intervals and 10-min average wind speed

| List/Sylt, Norderney, Rostock/Warnemünde | 5-8 Dec 2013 | Deutschlander T, K Frierich, S Haeseler, C Lefebvre, Orkantief XAVER ueber Nordeuropa von 5. bis 7. Dezember 2013, Deutscher Wetterdienst DWD, Stand 30. Dezember 2013, 19pp. |

[FIG] ABB8. Time series of 1-min average wind speed, peak gust and air pressure

| Hamburg St. Pauli | 5 Dec 2013 | Deutschlander T, K Frierich, S Haeseler, C Lefebvre, Orkantief XAVER ueber Nordeuropa von 5. bis 7. Dezember 2013, Deutscher Wetterdienst DWD, Stand 30. Dezember 2013, 19pp. |

[FIG] ABB9. Time series of wind direction

| List/Sylt, Norderney, Rostock/Warnemünde | 5-8 Dec 2013 | Deutschlander T, K Frierich, S Haeseler, C Lefebvre, Orkantief XAVER ueber Nordeuropa von 5. bis 7. Dezember 2013, Deutscher Wetterdienst DWD, Stand 30. Dezember 2013, 19pp. |

[MAP] ABB15. Daily precipitation in mm; initial values, unverified

| Germany | 5 Dec 2013 | Deutschlander T, K Frierich, S Haeseler, C Lefebvre, Orkantief XAVER ueber Nordeuropa von 5. bis 7. Dezember 2013, Deutscher Wetterdienst DWD, Stand 30. Dezember 2013, 19pp. |

[MAP] ABB16. Total snow height over one day

| Northern Germany | 6 Dec 2013 and 7 Dec 2013 | Deutschlander T, K Frierich, S Haeseler, C Lefebvre, Orkantief XAVER ueber Nordeuropa von 5. bis 7. Dezember 2013, Deutscher Wetterdienst DWD, Stand 30. Dezember 2013, 19pp. |

[FIG] ABB18. Time series of 10-min average wind speed

| Brocken | 3 day interval 4-6 Dec 2013 | Deutschlander T, K Frierich, S Haeseler, C Lefebvre, Orkantief XAVER ueber Nordeuropa von 5. bis 7. Dezember 2013, Deutscher Wetterdienst DWD, Stand 30. Dezember 2013, 19pp. |

(TEXT) statements of maximum 10 min wind speed and gust

| Stavoren (Netherlands); Nissum Fjord (Denmark); Eieroyra (Norway); Nidingen, Vaaderoamooa (Sweden); Snieszka/Schneekoppe, Ustka (Poland) | Point measurements | Deutschlander T, K Frierich, S Haeseler, C Lefebvre, Orkantief XAVER ueber Nordeuropa von 5. bis 7. Dezember 2013, Deutscher Wetterdienst DWD, Stand 30. Dezember 2013, 19pp. |

(TEXT) Maximum wind gust

| Stavoren, Vlieland | 5-6 Dec 2013 | KNMI, News report. De Zware storm van 5 december. 06 Dec 2013, https://www.knmi.nl/over-het-knmi/nieuws/de-zware-storm-van-5-december |

(TEXT) peak gusts

| UK: Aonach Mor; Germany: Sylt, Kiel Leuchtturm, Rostock-Warnemuende, List, Norderney, Brocken, Feldberg/Black Forest | 6 Dec 2013 | Kunz M, B Muehr, K Schroeter, T Bessel, S Moehrle, T Muenzberg, S Brink, H-M Schmidt, Winterstorm Xaver - Report. 06Dec2013 - Report No.1, Situation Report - 19:00CET, CEDIM Forensic Disaster Analysis Group (FDA), Center for Disaster Management and Risk Reduction Technology. |

[FIG] Time series wind speed

| Norderney Riffgat, Borkum Fischerhalje | 4-6 Dec 2013 | Mills, Ian, Remko Scharoo, Luciana Fenoglio, Xaver affected much of northern Europe on 5 and 6 December and caused worst storm surge for decades in the North Sea. https://www.eumetsat.int/home/News/DAT_20870_62.html (last accessed: 19Nov2019, 28Jun2020) |

[FIG] Time series of wind speed and direction and gust

| Zeelugge Meteopark, Zeelugge Daminstrumentatie (Westelijke Dam) | 5-6 Dec 2013 | Oceanografisch Meteorologisch Stasjon, Stormverslag 05-06 december 2013, 26pp, 2013 [pdf document properties: author=Myriam Sys; datestamp=15Dec2013] |

[TABLE] Tabulated peak gusts

| Many stations in Germany | 5-6 Dec 2013 | Unwetterzentrale, Orkantief XAVER - ein weiterer schwerer Wintersturm der letzten Jahrzehnte, Thomas Savert and Stefan Laps, Dec. 2013 http://www.unwetterzentrale.de/uwz/928.html |

[MAP] 1 hour peak gusts

| Iceland, UK, Netherlands, northern Germany, Denmark, southern Norway | 5 Dec 2013 0700-0800 MEZ | Unwetterzentrale, Orkantief XAVER - ein weiterer schwerer Wintersturm der letzten Jahrzehnte, Thomas Savert and Stefan Laps, Dec. 2013 http://www.unwetterzentrale.de/uwz/928.html |

[MAP] 24 h peak gusts

| Germany | 5 Dec 2013 0700 MEZ to 6 Dec 2013 0700 MEZ | Unwetterzentrale, Orkantief XAVER - ein weiterer schwerer Wintersturm der letzten Jahrzehnte, Thomas Savert and Stefan Laps, Dec. 2013 http://www.unwetterzentrale.de/uwz/928.html |

[MAP] 24 h peak gusts

| Germany | 6 Dec 2013 0700 MEZ to 7 Dec 2013 0700 MEZ | Unwetterzentrale, Orkantief XAVER - ein weiterer schwerer Wintersturm der letzten Jahrzehnte, Thomas Savert and Stefan Laps, Dec. 2013 http://www.unwetterzentrale.de/uwz/928.html |

[MAP] 24 h snowfall accumulations

| Germany | 5 Dec 2013 0700 MEZ to 6 Dec 2013 0700 MEZ | Unwetterzentrale, Orkantief XAVER - ein weiterer schwerer Wintersturm der letzten Jahrzehnte, Thomas Savert and Stefan Laps, Dec. 2013 http://www.unwetterzentrale.de/uwz/928.html |
[TABLE] Wind speed and gust.

| Location                      | Date          | Reference                                                                 |
|-------------------------------|---------------|---------------------------------------------------------------------------|
| Northeast Atlantic and North Sea | 5 Dec 2013    | Bancroft, George P. Marine Weather Review - North Atlantic Area, September through December, Mariners Weather Log, volume 58, No.1, April 2014, pp.33-40 |

[MAP] 24 h snowfall accumulations

| Germany, 6 Dec 2013 0700 MEZ | Stefan Laps, Dec. 2013 | http://www.unwetterzentrale.de/uwz/928.html |

[TEXT] mention of met-ocean measurements available through COSYNA project

| Station Watt (Pile at Spiekeroog) | 7 Dec 2013, 0700 MEZ | Badewiën T., Long-term observatory @ Pile Spiekeroog ICBM,COSYNA Progress Report 2013, p.24. Helmholtz-Zentrum Geesthacht, June 2014 |

[FIG] Time series of wind speed and wind direction

| Time series graph of wind speed and wind direction | 1-31 Dec 2013 | FUGRO GEOS Ltd. Ormen Lange Monthly reports of wavescan data: December. Reporting period: I December 2013 to 31 December 2013, Report Number: C70101/8177/R0, Issue date: 23 January 2014, prepared by Heather Holt, Checked by Donald Brockie, approved by Mark Jones |

[FIG] Time series of wind speed and wind direction

| AWO platform | 5-7 Dec 2013 | Gautier C, A Camarena, J van Nieuwkoop, SWAN hindcasts Wadden Sea, December 2013. Tidal inlet of Ameland and eastern Wadden Sea. Deltares, 2014, 197pp. Project 1209433-007, Reference 1209433-007-HYE-0005 |

[FIG] Time series of wind speed and direction

| UITHZWD | 5-7 Dec 2013 | Gautier C, A Camarena, J van Nieuwkoop, SWAN hindcasts Wadden Sea, December 2013. Tidal inlet of Ameland and eastern Wadden Sea. Deltares, 2014, 197pp. Project 1209433-007, Reference 1209433-007-HYE-0005 |

[FIG] Time series of wind speed and direction at Scharboern

| Scharboern | 4-8 Dec 2013 | Goennert G, O Mueller, M Schaper, K Sossidi, Die Sturmflut nach dem Tief Xaver von 5. bis 7. Dezember 2013. Berichte des Landesbetriebes Strassen, Bruecken und Gewasser (LSBG), Freie und Hansestadt Hamburg, Nr. 16/2014, 26pp. |

[MAP] 24 hour maximum gusts

| Northwest Europe | 5Dec2013 0000-2400 UTC | Hewson T, L Magnusson, O Brevik, F Prates, I Tsonesvky, HJW de Vries, Windstorms in northwest Europe in late 2013, ECMWF Newsletter, No 139, pp 22-28, Spring 2014 |

[TEXT] Maximum average wind speed 118km/h

| Norderney | 5-6 Dec 2013 | Knaack H and H Heyken, Xaver hatte sehr schwere Stumflut im Gepaeck, Jahresbericht 2013. Der Zukunft verplichtet, pp.8-9, document date stamp 24Apr2014 |

[MAP] maximum gusts at 10m;

| northern Germany, North Sea and Baltic Sea | 5-6 Dec 2013 | Leiding T, B Tinz, G Rosenhagen, C Lefevre, S Haeseler, S Hagemann, I Bastigkeit, D Stein, P Schwenk, S Mueller, O Outzen, K Herlhotz, F Kinder, T Neumann, Meteorological and Oceanographic Conditions at the FINO platforms during the severe storms Christian and Xaver, DEWI Magazin, No.44, p.16-25, 2014 |

[FIG] Time series graph of wind direction and atmospheric pressure at 100m height

| FINO1, FINO2, FINO3 | 5-7 Dec 2013 | Leiding T, B Tinz, G Rosenhagen, C Lefevre, S Haeseler, S Hagemann, I Bastigkeit, D Stein, P Schwenk, S Mueller, O Outzen, K Herlhotz, F Kinder, T Neumann, Meteorological and Oceanographic Conditions at the FINO platforms during the severe storms Christian and Xaver, DEWI Magazin, No.44, p.16-25, 2014 |

[FIG] Time series graph of wind speed, wind gust, wind direction

| Messpflah Westerland | 1-9Dec2013 | Luecht, Fabian and Ove Peters, Bericht ueben die Sturmflut vom 05.-06.12.2013 an der Westküste Schleswig-Holsteins, Landesbetrieb fuer Kuestenschutz, Nationalpark und Meeresschutz Schleswig-Holstein, Husum 26Feb2014, 19pp. [pdf document properties: title=Lfd; Author=Thorsten Nommensen; datestamp=11Dec2018] |

[TEXT] highest wind speed at FINO1 platform (30m/s)

| FINO1 | 4-7 Dec 2013 | Mai, S., Sea state at the research platform FINO1 during the winter storm 'Xaver', BFG, Bundesamt fuer Gewasserkunde, document properties: author=Mai, date=16May2014 |

[FIG] Time series of wind speed and wind direction with gust indicated

| Hallig Hooge, Buesum, Strucklahnungshoern | 4-7 Dec 2013 | Matelski, Birgit, Freck Jensen, Peter Voss, Jorg Peters, Maria Blumel, Auswertung zur Hydrologie des Sturmtiefs Xaver 05.12.2013 bis 06.12.2013, Statusbericht vom 01.10.2014, Landesbetrieb fuer Kuestenschutz, Nationalpark und Meeresschutz, Schleswig-Holstein, Husum, 01.10.2014, 25pp. |

[FIG] Time series of 10 min wind speed reduced to 10m.

| Draugen | 1-31 Dec 2013 | MIROS, Monthly Report, Draugen, December 2013, Doc. No. ND/1022/13/12 (prepared by SRS, checked by OO, |

[TABLE] list of monthly minimum temperatures during cold air outbreak

| UK and Europe | Month list | Eden, Phillip, Weather Log December 2013, Weather, Feb 2014, pp-i |

[FIG] Time series of wind gust, wind speed, wind direction, air temperature, atmospheric pressure
| FIG | Time series of 10 min wind speed reduced to 10m, 3second gust reduced to 10m, air temperature, relative humidity, air pressure, sea temperature, cloud height, visibility | approval by CNE | [pdf document properties: author=MIROS AS; datestamp=30Jan2014] |
| FIG | Time series of 10 min wind speed reduced to 10m, 3second gust reduced to 10m, air temperature, relative humidity, air pressure, sea temperature, cloud height, visibility | Ekofisk | 1-31 Dec 2013 | MIROS, Monthly report, Ekofisk, December 2013, Doc. No. ND/1024/13/12, (prepared by SRS) 34pp, 9Jan2014 | [PDF document properties: author=Miros AS; datestamp=13Jan2014] |
| FIG | Time series of 10 min wind speed reduced to 10m, 3second gust reduced to 10m, air temperature, relative humidity, air pressure, sea temperature, cloud height, visibility | Gullfaks | 1-31 Dec 2013 | MIROS, Maanedsrapport Gullfaks C, Desember 2013, Dok. Nr ND/1013/13/12, carried out by SRS, controlled by CNE, approved by CO | [pdf document properties: author=Miros AS; date stamp: 13Jan2014] |
| FIG | Time series of 10 min wind speed reduced to 10m, 3second gust reduced to 10m, air temperature, relative humidity, air pressure, sea temperature, cloud height, visibility | Heidrun | 1-31 Dec 2013 | MIROS, Maanedsrapport Heidrun, Desember 2013, Dok. Nr. ND/1010/13/12, 21 pp, 07Jan2014, carried out by SRS, controlled by CNE, approved by OO | [pdf properties: author=Miros AS; date stamp: 08/01/2014] |
| FIG | Time series of 10 min wind speed reduced to 10m, 3second gust reduced to 10m, air temperature, relative humidity, air pressure, sea temperature, cloud height, visibility | Heimdal | 1-31 Dec 2013 | MIROS, Maanedsrapport Heimdal, Desember 2013, Dok. Nr. ND/1047/13/12 (carried out be SRS, controlled by CNE, approved by OO) | [pdf properties: author=Miros AS; datestamp=06Jan2014] |
| FIG | Time series of 10 min wind speed reduced to 10m, 3second gust reduced to 10m, air temperature, relative humidity, air pressure, sea temperature, cloud height, visibility | Nome | 1-31 Dec 2013 | MIROS, Maanedsrapport Nome, Desember 2013, Dok. Nr. ND/1087/13/12, 21pp, carried out by SRS, controlled by CNE, approved by OO | [pdf properties: Author=Miros AS; datestamp=06Jan2014] |
| FIG | Time series of 10 min wind speed reduced to 10m, 3second gust reduced to 10m, air temperature, relative humidity, air pressure, sea temperature, cloud height, visibility | Sleipner A | 1-31 Dec 2013 | MIROS, Maanedsrapport Sleipner A, Desember 2013, Dok. Nr. ND/1012/13/12, (prepared by SRS) 21pp, 7Jan2014 | [PDF document properties: author=Miros AS; datestamp=10Jan2014] |
| FIG | Time series of 10 min wind speed reduced to 10m, 3second gust reduced to 10m, air temperature, relative humidity, air pressure, sea temperature, cloud height, visibility | Troll A | 1-31 Dec 2013 | MIROS, Maanedsrapport Troll A, Desember 2013, Dok. No. ND/1012/13/12, (prepared by SRS) 21pp, 7Jan2014 | [PDF document properties: author=Miros AS; datestamp=10Jan2014] |
| TEXT | Highest average wind and gust | Terneuzen, Hansweert | 5 Dec 2013 | Nossent J, L Boeckx, E Taverniers, M Deschamps, T Verwaest, F Mostaert, Sinterklaasstorm 6 december 2013. Beschrijving van de hydrometrische gebeurtenissen, Versie 4.0. WL Rapporten, 00-119, Waterbouwkundig Laboratorium, Antwerpen, Belgie. October 2014, WL2014R00_119_5 [document date stamp: 15Oct2014; author= Deschamps, Maarten] |
| TEXT | Highest wind and highest gust | Europalifeform, Platform K13a, IJmuiden, Lauwersoog, Lichteiland Goeree, Hoek van Holland | 5-6 Dec 2013 | RWS, Stormvloedrapport van 5 t/m 7 december (SR91) Sint-Nicolaasvloed 2013, Watermanagementcentrum Nederland, Rijkswaterstaat, prepared by Ing. J. Kroos, 19 Mar 2014, 48 pp |
| TEXT | Highest hourly average wind speed | Vardøarna | 5-6 Dec 2013 | SMHI, Simone, Hilde, Sven och Ivar okt-dec 2013, 3 Jul 2014, https://www.smhi.se/kunskapsbanken/meteorologi/simonshilde-sven-och-ivar-okt-dec-2013-1.76183 |
| TEXT | Highest hourly average wind speed | Vitieland | 5-6 Dec 2013 | van Dorland, R, Zware storm op 5 december, Zenit, p43, Januari 2014 |
| FIG | Map with highest gusts values written | Station in the Netherlands and offshore | 5 Dec 2013 | van Dorland, R, Zware storm op 5 december, Zenit, p43, Januari 2014 |
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Ruck Sturm dokumentation 2013 Deutschland, 2013,
Deutsche Rueckversicherung Aktiengesellschaft,
Hansaallee 177, 40549 Duesseldorf, www.deutscherrueck.de [pdf document information: author=filiz; datestamp=07Aug2015]

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Sinterklaas storm at Het Zwin. Numerical modelling with
Xbeach, M.Sc. Civil Engineering, Delft University of
Technology, 2015.

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Shelf Science, 164, 301-312, 2015b.

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Becker, J Lilibrige, Cyclone Xaver seen by geodetic
observations, Geophys Research Letters, 42, 9925-9932,
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Letters, 11, 2016, 054001

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Southern North Sea storm surge event of Dec.5, 2013: Water levels, waves, and coastal impacts, Earth Science
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wind energy analysis of Cyclone Xaver over North Europe,
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Energy Procedia, 94, 37-44, 2016.

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Matelski, Birgit, Erfahrungen aus der Sturmflut Xaver vom 5.
| Title | Speed and Direction | Pressure | Author(s) | Date |
|-------|---------------------|----------|-----------|------|
| [TEXT] maximum gusts | Strucklahnungsohren, Hallig Hooge | 5-6 Dec 2013 | Matelski, Birgit, Erfahrungen aus der Sturmflut Xaver von 5-6 Dec 2013 und dem Weihnachtschwohwarz 2014 in Sleswigh-Holstein, IWASA 2016 Tagungsbeitrag. (46. IWASA, 7-8 Januar 2016; Internationales Wasserbau-Symposium Aachen. [pdf document properties: autors=sonja; datestamp=26Apr2016]) |
| [FIG] Time series graph of wind magnitude, wind direction and sea level pressure | Elbe station | 1-8 Dec 2013 | Staneva J, K Wahle, W Koch, A Behrens, L Fenoglio-Marc, EV Stanev, Coastal flooding: impact of waves on storm surge during extremes - a case study for the German Bight, Nat. Hazards Earth Syst. Sci., 16, 2373-2389, 2016 |
| [FIG] Time series graph of wind speed; maximum 25m/s 05Dec2013 12:00 | FINO1 at 60m | 2-9 Dec 2013 | Peter Frohle & Norman Dreier, EarlyDike - Sensor - und risiko basiertes Fruhwarntystem fuer Seeledeehe, Teilprojekt: Wellenmonitoring und Wellenbelastungsssimulator (AP2), Hamburg, April 2017 |
| [FIG] Time series graph of wind speed: maximum 21m/s 05Dec2013 12:00 | Helgoland at 14m | 2-9 Dec 2013 | Frohle P & N Dreier, EarlyDike - Sensor - und risiko basiertes Fruhwarnsystem fuer Seeledeehe, Teilprojekt: Wellenmonitoring und Wellenbelastungsssimulator (AP2), Hamburg, April 2017 |
| [TEXT] Maximum wind speed and gust | Kolo, Leszno, Kalisz, Leba, Kasprowy Wierch, Ustka, Sniezka | 6-10 Dec 2013 | Ribeiro R, R Rudge, D Rucinska, Analysis of physical factors of the windstorm Xaver in Poland: post-hazard review, Weather, 72, 2017, pp.378-382 |
| [FIG] Time series of wind speed and gust | FINO1 | 1 Oct 2013-31 Dec 2013, 1-8 Dec 2013 | Staneva J, H Guenheimer, O Krueger, C Schrum, V Alart, O Brevik, J-R Bidlot, K Mogensen, Impact of wind waves on the air-sea momentum fluxes for different wind and sea state conditions and oceanic responses, 1st International Workshop on waves, storm surges and coastal hazards, Liverpool, UK 10-15 Sep2017 [pdf document properties: title=Anlass; author=Patrick Kalb-Anlass, datestamp=20/09/2017] |
| [FIG] Time series of wind speed | Helgoland | 3-8 Dec 2013 | Staneva J, C Schrum, A Behrens, S Grayeck, H Ho-Hagemann, V Alan, O Breivik, J-R Bidlot, A North Sea-Baltic Sea Regional Coupled Models: Atmosphere, wind waves and ocean, in Proceedings of the Eighth EuroGOOS International Conference (Operational Oceanography. Serving Sustainable Marine Development), 3-5 October 2017, Bergen, Norway, 2017b. |
| [FIG] Time series graph of wind speed at 100m height | FINO1 | 3-7 Dec 2013 | Wahle K, J Staneva, W Koch, L Fenoglio-Marc, HTM Ho-Hagemann, EV Stanev, An atmosphere-wave regional coupled model: improving prediction of wave heights in the southern North Sea, Ocean Sci., 13, 289-301, 2017. (doi:10.5194/os-13-289-2017) |
| [FIG] Latitude profile graph of altimeter-derived wind speed from SARAL-Altika | North Sea axis 53 - 60N | 6 Dec 2013 04:46:55 UTC | Wahle K, J Staneva, W Koch, L Fenoglio-Marc, HTM Ho-Hagemann, EV Stanev, An atmosphere-wave regional coupled model: improving prediction of wave heights in the southern North Sea, Ocean Sci., 13, 289-301, 2017. (doi:10.5194/os-13-289-2017) |
| [FIG] Time series graph of measured wind speed | Helgoland and Westerland | 3-8 Dec 2013 | Wahle K, J Staneva, W Koch, L Fenoglio-Marc, HTM Ho-Hagemann, EV Stanev, An atmosphere-wave regional coupled model: improving prediction of wave heights in the southern North Sea, Ocean Sci., 13, 289-301, 2017. (doi:10.5194/os-13-289-2017) |
| [FIG] Time series graph of 10m wind speed | FINO1 | 2 weeks across storm period | Wahle K, J Staneva, W Koch, L Fenoglio-Marc, HTM Ho-Hagemann, EV Stanev, An atmosphere-wave regional coupled model: improving prediction of wave heights in the southern North Sea, Ocean Sci., 13, 289-301, 2017. (doi:10.5194/os-13-289-2017) |
| [TEXT] highest average wind speed and highest gust | Nissum Fjord | 5-6 Dec 2013 | Danish Emergency Management Agency DEMA, National Risk Profile for Denmark, April 2018 |
| [FIG] Time series of 10m wind speed | Hallig Hooge | 5-6 Dec 2013 | Dreier, Norman and Peter Froehle, Operational wave forecast in the German Bight as part of a sensor- and risk based early warning system, In: J-S Shum, I Chun, HS Lim (ed.), Proceedings from the International Coastal Symposium (ICS) 2018 (Busan, Republic of Korea), Journal of Coastal Research, Special Issue No. 85, 1161-1165, 2018 |
| [FIG] Time series of wind speed and wind direction | FINO1 | 1-9 Dec 2013 | Fery, Natascha, Birger Tinz, Lydia Gates, Reproduction of storms over the North Sea and the Baltic with the regional analysis COSMO-REA6 ISPR 2018, 17-19 July 2018, Bonn [pdf document properties: datestamp=1607/2018] |
### Table S12. Significant wave height and sea state (arranged by year and then alphabetically)

| Data type | Location | Time Interval | Full Reference and Notes |
|-----------|----------|---------------|--------------------------|
| [FIG] High frequency water level measurements from radar gauge array (14m) | FINO1 | 6Dec2013 00:09:00:11 | BFG, Orkan Xaver: BFG beobachtet extreme Wellen in der Nordsee (06.12.2013) |
| [MAP] ABB10. Gridded significant wave height of combined waves and swell | North Sea and Western Approaches; Baltic Sea | 6 Dec 2013 00:00UTC | Deutschlander T, K Frerich, S Haeseler, C Lefebvre, Orkantief XAVER uber Nordeuropae von 5, bis 7. Dezember 2013, Deutscher Wetterdienst DWD, Stand 30. Dezember 2013, 19pp. |
| [FIG] ABB11. Time series of significant wave height, period, wave direction, and sea temperature | Station Elbe | 2 Dec 2013 – 9 Dec 2013 09:59UTC | Deutschlander T, K Frerich, S Haeseler, C Lefebvre, Orkantief XAVER uber Nordeuropae von 5, bis 7. Dezember 2013, Deutscher Wetterdienst DWD, Stand 30. Dezember 2013, 19pp. |
| [FIG] Saral-AltiKa strip map of significant wave height | North-south transect of North Sea | 06Dec2013 04:47UTC | Mills, Ian, Remko Scharroo, Luciana Fenoglio, Xaver affected much of northern Europe on 5 and 6 December and caused worst storm surge for decades in the North Sea. https://www.eumetsat.int/website/home/News/DAT_2087062.html (last accessed: 19Nov2019, 28Jun2020) |
| [FIG] Time series of significant wave height, height of highest 1% and 10% of waves, wave direction (period 2-5s and >10s), wave low frequency energy, equivalent wave height for period >10s | Westhinder, Akkaert, Bol van Heist, Oostende, Scheur Wielingen | 5-6 Dec 2013 | Oceanografisch Meteorologisch Station, Stormverslag 05-06 december 2013, 26pp, 2013 [pdf document properties: author=Myriam Sys; datestamp=15Dec2013] |
| [TEXT] Maximum significant wave height and maximum wave height | Waverider at Vadovaorna | 5Dec2013 | SMHI, Stormen Sven gav nya vattenstandsrekord i Oresund, https://www.smhi.se/hyhetssarkiv/stormen-sven-gav-nya-vattenstandsrekord-i-oresund-1.34732, updated 20Mar2017; original datestamp 10Dec2013. |
| [TEXT] record sea state of 6 m | North Sea area of Sylt | 5-6 Dec 2013 | Suedddeutsche Zeitung, Xaver holte sich Land. Sturmschaden auf Sylt, 15Dec201315:36 https://www.sueddeutsche.de/panorama/sturmschaeden-auf-sylt-xaver-holte-sich-land-1.1844100 |
| [TABLE] Significant wave height | Northeast Atlantic and North Sea | 5 Dec 2013 | Bancroft, George P, Marine Weather Review - North Atlantic Area, September through December, Mariners Weather Log, volume 58, No.1, April 2014, pp.33-40 |
| [FIG] Time series of significant wave height, maximum significant wave height 9.04m; maximum trough to crest wave height 15.5m | FINO1 | 4-9 Dec 2013 | Blasi C, S Mai, J Wilhelmi, T Zenz, U Barjenbruch, A powerful method of measuring sea wave spectra and their direction, ICHE 2014, Hamburg - Lehfeldt and Kopmann (eds), Bundesanstalt fuer Wasserbau, 2014, ISBN 978-3-939230-32-8 |
| [TABLE] Significant wave height at peak | Newbiggin Ness, Tyne | 5-6 Dec 2013 | CH2MHill Halcrow, Cell 1 Regional Coastal Monitoring Programme, Wave Data Analysis Report 2: 2013-2014, Final Report, March 2014 [document properties: author=Andy.Parson@ch2m.com; datestamp; 04/04/2014] |
| [FIG] Time series of significant wave height and maximum wave height; tables of maximum values | Ormen Lange Norwegian Sea Platform | 1-31 Dec 2013 | FUGRO GEOS Ltd, Ormen Lange Monthly reports of wavescan data: December. Reporting period: 1 December 2013 to 31 December 2013, Report Number: C70101/8177/R0, Issue date: 23 January 2014, prepared by Heather Holt, Checked by Donald Brockie, approved by Mark Jones |
| [FIG] Time series of significant wave height | Buoy array in Ameland inlet area | 5-7 Dec 2013 | Gautier C, A Camarena, J van Nieuwkoop, SWAN hindcasts Wadden Sea, December 2013. Tidal inlet of Ameland and eastern Wadden Sea. Deltares, 2014, 197pp. Project 1209433-007, Reference 1209433-007-HYE-0005 |
| [FIG] Time series of significant wave height | Buoy array in eastern Wadden Sea | 5-7 Dec 2013 | Gautier C, A Camarena, J van Nieuwkoop, SWAN hindcasts Wadden Sea, December 2013. Tidal inlet of Ameland and eastern Wadden Sea. Deltares, 2014, 197pp. Project 1209433-007, Reference 1209433-007-HYE-0005 |
| [FIG] Time series of significant wave height and maximum wave height; FINO1 Hs=10m and Hmax=16m; FINO3 Hs=9.1m and | FINO1, FINO2, FINO3 | 5-7 Dec 2013 | Leiding T, B Tinz, G Rosenhagen, C Lefevre, S Haeseler, S Hagemann, I Bastigkeit, D Stein, P Schweng, S Mueller, O Outzen, K Herklots, F Kinder, T Neumann, Meteorological and Oceanographic Conditions at the FINO platforms during the severe storms Christian and Xaver, DEWI Magazin, No.44, p16-25, 2014. |
Hmax=13.5m

**[FIG]** Time series of significant wave height
- wave measurement buoy Westerland
  - 2-9 Dec 2013
- Luecht, Fabian and Ove Peters, Bericht uebet die Sturmflut vom 05.-06.12.2013 an der Westkuste Schleswig-Holsteins, Landesbetrieb fuer Kuestenschutz, Nationalpark und Meeresenschutz Schleswig-Holstein, Husum 26Feb2014, 19pp. [pdf document properties: title=Lfd; Author=Thorsten Nommensen; datestamp: 11Dec2018]

**[FIG]** Radar gauge half-hour time series of Hs, mean period, direction, spread; max Hs=9.04m; max wave height 15.5m
- FINO1
  - 4-7 Dec 2013
- Mai, S., Sea state at the research platform FINO1 during the winter storm 'Xaver', BFG, Bundesamt fuer Gewasserkunde, document properties: author=Mai, date=16May2014

**[FIG]** Time series of significant wave height and maximum wave height
- FINO1, Borkum-Suedstrand
  - 4-9 Dec 2013
- Mateiska, Birgit, Frek Jensen, Peter Voss, Jorg Peters, Maria Blumel, Auswertung zur Hydrologie des Sturmtiefs Xaver 05.12.2013 bis 06.12.2013, Statusbericht vom 01.10.2014, Landesbetrieb fuer Kuestenschutz, Nationalpark und Meeresenschutz, Schleswig-Holstein, Husum, 01.10.2014, 25pp.

**[FIG]** Time series of significant wave height and maximum wave height
- Draugen
  - 1-31 Dec 2013
  - MIROS, Monthly Report, Draugen, December 2013, Doc. No. ND/1022/13/12 (prepared by SRS, checked by OO, approved by CNE) [pdf document properties: author=MIROS AS; datestamp=30Jan2014]

**[FIG]** Time series of significant wave height and maximum wave height from spectral analysis and time series data; waverider and altimeter
- Ekofisk
  - 1-31 Dec 2013
  - MIROS, Monthly report, Ekofisk, December 2013, Doc. No. ND/1024/13/12, (prepared by SRS) 34pp, 9Jan2014 [PDF document properties: author=Miros AS; datestamp=13Jan2014]

**[FIG]** Time series of significant wave height and maximum wave height
- Heidrun
  - 1-31 Dec 2013
  - MIROS, Manedssrappor Heidrun, Desember 2013, Dok. Nr. ND/1010/13/12, 21 pp, 07Jan2014, carried out by SRS, controlled by CNE, approved by OO [pdf properties: author=MIROS AS; date stamp=08/01/2014]

**[FIG]** Time series of significant wave height and maximum wave height
- Nome
  - 1-31 Dec 2013
  - MIROS, Manedssrappor Nome, Desember 2013, Dok. Nr. ND/1087/13/12, 21pp, carried out by SRS, controlled by CNE, approved by OO [pdf properties: Author=Miros AS; datestamp=06Jan2014]

**[FIG]** Time series of significant wave height and maximum wave height from spectral analysis and time series data; waverider and altimeter
- Sleipner A
  - 1-31 Dec 2013
  - MIROS, Manedssrappor Sleipner A, Desember 2013, Dok. Nr. ND/1017/13/12, 06Jan2014, prepared by SRS, controlled by CNE, approved by OO.

**[FIG]** Time series of significant wave height
- Scheur West Wandelaar, Europlatform, Platform K13a, If muiden
  - 5-6 Dec 2013
  - RWS, Stormvloedrapport 5 tm 7 december (SR91) Sint-Nicolaasvloed 2013, Watermanagementcentrum Nederland, Rijkswaterstaat, prepared by Ing. J. Kroos, 19 Mar 2014b, 48 pp

**[FIG]** Time series of maximum wave height
- Scheur West Wandelaar, Europlatform, Platform K13a, If muiden
  - 5-6 Dec 2013
  - RWS, Stormvloedrapport 5 tm 7 december (SR91) Sint-Nicolaasvloed 2013, Watermanagementcentrum Nederland, Rijkswaterstaat, prepared by Ing. J. Kroos, 19 Mar 2014b, 48 pp

**[TABLE]** Table of maximum 'globally corrected' significant wave height in ranked storm list
- Scheur west Wandelaar, Euro platform, If muiden runtestortplaats, Eierlandse Gat, Schiermonnikoog Nord
  - 5-6 Dec 2013
  - RWS, Stormvloedrapport 5 tm 7 december (SR91) Sint-Nicolaasvloed 2013, Watermanagementcentrum Nederland, Rijkswaterstaat, prepared by Ing. J. Kroos, 19 Mar 2014b, 48 pp

**[TEXT]** Maximum wave height
- Vadoeorna
  - 5-6 Dec 2013
  - SMHI, Simone, Hilde, Sven och Ivar okt-dec 2013, 3 Jul 2014, https://www.smhi.se/kunskapsbanken/meteorologi/simone-hilde-sven-och-ivar-okt-dec-2013-1.76183

**[TEXT]** Maximum significant wave height 3.8m
- Blakeney Overfalls Waverider
  - 5-6 Dec 2013
  - Spencer, T., S.M. Brooks, I. Moller, B.R. Evans, Where local matters: Impacts of a major North Sea storm surge, EOS, 95, 269,270, 29July2014

**[FIG]** Time series significant wave height
- Wave buoy 1_1 Amelander Zeebat
  - 5-7 Dec 2013
  - van Rooijen A. A Oost, Memo: Regionale advisering Ameland Noordwest, Deltares, 1209381-008-ZKS-0008, 43pp, 18Dec2014 [PDF document properties: title=Regional advisering: Ameland NW; author=Arnold van Rooijen; keywords: 1209381-008-ZKS-0008; date stamp=18/12/2014]

**[FIG]** Time series significant wave height
- SCHW, SCHO, WIEL
  - 5-7 Dec 2013
  - Carrion Aretxabala, BI, Morphological impact of the Sinterklaas storm at Het Zwin, Numerical modelling with Xbeach, M.Sc.
| FIG] Time series of significant wave height and maximum wave height from Nortek AWAC instrument 600m from shore | Beach profile 104 south of Ostend Belgium | 4-8 Dec 2013 | Dan, Sebastian, Anne-Lise Montreuil, Rosalía Delgado, Tomas van Oyen, Large storm impact on a beach under sand nourishments, The Proceedings of the Coastal Sediments 2015, edited by Ping Wang, Julie D Rosati, and Jun Cheng, Coastal Sediments 2015, San Diego, USA, 11-15May2015 |
| [FIG] Time series of significant wave height | Liverpool Bay Wavenet waverider | 5 Dec 2013 | Dissanayake P and H Karunaratna, Effect of storm clustering on beach/dune erosion, E-proceedings of the 36th IAHR World Congress, 28June-3July, 2015, The Hague, The Netherlands |
| [FIG] Time series of significant wave height | Liverpool Bay Wavenet waverider | 1 Dec 2013 - 31 Jan 2014 | Dissanayake P, J Brown, P. Wisse, H Karunaratna, Comparison of storm cluster vs isolated event impacts on beach.dune morphodynamics, Estuarine, Coastal, and Shelf Science, 164, 301-312, 2015b. |
| [STRIP PROFILE] AltiKa satellite altimetry significant wave height | Strip profile through North Sea | 6 Dec 2013 0447UTC | Fenoglio-Marc L, R Scharroo, A Annuiziato, L Mendoza, M Becker, J Lillibridge, Cyclone Xaver seen by geodetic observations, Geophys Research Letters, 42, 9925-9932, 2015 |
| [FIG] Time series data FINO1 | FINO1 | 3-7 Dec 2013 | Fenoglio-Marc L, R Scharroo, A Annuiziato, L Mendoza, M Becker, J Lillibridge, Cyclone Xaver seen by geodetic observations, Geophys Research Letters, 42, 9925-9932, 2015 |
| [FIG] Time series of significant wave height from RADAC, Waverider buoy, AWAC | FINO1 | 4-7 Dec 2013 | Fischer, JG, C Senet, A Schneelhorst, O Outzén, S Schirmel, K Herklots, Sea state measurements in Germanys first offshore wind farm "alpha ventus", in the south-eastern parts of the North Sea, 2015 IEEE/OES Eleventh Current, Waves and Turbulence Measurement (CWTM), 2015 [PDF document properties: datestamp: 14/01/2015] |
| [FIG] Significant wave height, wave period and wave direction; maximum Hs 4.5m (instrument failure) | Fjaltring | 7 Nov 2013 – 7 Dec 2013 | Gierlevenst T, H Lauridsen, F Langhans, J Bejdic, Met-ocean and wind resource related studies for nearshore windfarms in Denmark, seminar at the Danish Energy Agency, 27 February 2015. |
| [FIG] Significant wave height, wave period and wave direction; maximum Hs 4.5m (instrument failure) | Bornholm, Baltic Sea | 7 Nov 2013 – 7 Dec 2013 | Gierlevenst T, H Lauridsen, F Langhans, J Bejdic, Met-ocean and wind resource related studies for nearshore windfarms in Denmark, seminar at the Danish Energy Agency, 27 February 2015. |
| [TEXT] combined wave height 8–10 m | North Sea buoy or platform at 56.3N, 02.4E | 5–6 Dec 2013 | Sibley A, D Cox, H Titley, Coastal flooding in England and Wales from Atlantic and North Sea storms during the 2013/2014 winter, Weather, 70, 62-70, 2015 |
| [TEXT] maximum significant wave height of 4.7m and period of 14s | Tyne Tees WaveNet buoy | 5–6 Dec 2013 | Sibley A, D Cox, H Titley, Coastal flooding in England and Wales from Atlantic and North Sea storms during the 2013/2014 winter, Weather, 70, 62-70, 2015 |
| [FIG] Time series of significant wave height | Blakeney Overfalls, Chapel Point, North Well, Hapisburgh, Felixstowe, Sizewell, South Knock | 5-6 Dec 2013 | Spencer T, SM Brooks, BR Evans, JA Tempest, I Moeller, Southern North Sea storm surge event of Dec-5, 2013: Water levels, waves, and coastal impacts, Earth Science Reviews, 146, 120-145, 2015 |
| [FIG] Time series of significant wave height | Liverpool, Sizewell | 4-6 Dec 2013 | Wadey MP, JM Brown, ID Haigh, T Dolphin, P Wisse, Assessment and comparison of extreme sea levels and waves during the 2013/2014 storm season in two UK coastal regions, Nat. Hazards Earth Syst. Sci. Discuss., 3, 2665-2708, 2015b. |
| [FIG] Time series significant wave height | Blakeney | 2-7 Dec 2013 | Brooks SM, T Spencer, A McIvor, I Möller, Reconstructing and understanding the impacts of storms and surges, southern North Sea, Earth Surface Processes and Landforms, 41, 855-864, 2016. |
| [FIG] Time series of Hmax and significant wave height | Lighthouse Alte Weser, Borkum Suedstrand | 5-8 Dec 2013 | Maß S and U Barjenbruch, Water level measurements with radar gauges at the German North Sea coast, [PDF document properties: author=IOC; subject: IOC/2016/MG/14 vol.5; datestamp: 18/04/2017] |
| [FIG] Time series of significant wave height | Seegangmessstation Westerland | 4-8 Dec 2013 | Mateški, Birgit, Erfahrungen aus der Sturmmittel Xaver von 5. und 6.12.2013 und dem Weihnachtssturm Xaver 2014 in Schleswig-Holstein, IWASA 2016 Tagungsbeitrag. (46. IWASA, 7-8 Januar 2016; Internationales Wasserbau-Symposium Aachen. [pdf document properties: author=sonja; datestamp: 26Apr2016] |
| [FIG] Time series of measured wave conditions in 20m deep water | Amelander Zeegat buoy 1_1 | 5-8 Dec 2013 | Nederhoff K, E Elias, T Vermaas, Erosie op Ameland Noordwest. Modelstudie: simulaties met Delft3D en XBeach, Deltares, 117pp, July, 2016. |
**Time series of significant wave height**

**Helgoland wave buoys**

3-8 Dec 2013

Staneva J, C Schrum, A Behrens, S Grayek, H Ho-Hagemann, V Alan, O Breivik, J-R. Buiot, A North Sea-Baltic Sea Regional Coupled Models: Atmosphere, wind waves and ocean, in: Proceedings of the Eight EuroGOOS International Conference (Operational Oceanography. Serving Sustainable Marine Development), 3-5 October 2017, Bergen, Norway, 2017b.

**Latitude profile**

North Sea axis 53 - 60N

6 Dec 2013 04:46:55UTC

Wahle K, J Staneva, W Koch, L Fenoglio-Marc, HTM Ho-Hagemann, EV Stanov, An atmosphere-wave regional coupled model: improving prediction of wave heights in the southern North Sea, Ocean Sci., 13, 289-301, 2017. (doi:10.5194/os-13-289-2017).

**Time series of significant wave height**

FINO1 waverider buoy

3-7Dec2013

Wahle K, J Staneva, W Koch, L Fenoglio-Marc, HTM Ho-Hagemann, EV Stanov, An atmosphere-wave regional coupled model: improving prediction of wave heights in the southern North Sea, Ocean Sci., 13, 289-301, 2017. (doi:10.5194/os-13-289-2017).

**Time series of significant wave height**

FINO1 waverider buoy

5Dec2013 22:44UTC

Peter Frohle & Norman Dreier, EarlyDike - Sensor - und risiko basiertes Frühwarnsystem fuer Seedeiche, Teilprojekt: Wellenmonitoring und Wellenbelastungssimulator (AP2), Hamburg, April 2017.

**Time series of significant wave height**

Elbe station, Westerland station

2-8 Dec 2013

Staneva J, K Wahle, W Koch, A Behrens, L Fenoglio-Marc, EV Stanov, Coastal flooding: impact of waves on storm surge during extremes - a case study for the German Bight, Nat. Hazards Earth Syst. Sci., 16, 2373-2389, 2016.

**Time series of significant wave height**

FINO1 waverider buoy

2-9 Dec 2013

Peter Frohle & Norman Dreier, EarlyDike - Sensor - und risiko basiertes Frühwarnsystem fuer Seedeiche, Teilprojekt: Wellenmonitoring und Wellenbelastungssimulator (AP2), Hamburg, April 2017.

**Time series of significant wave height**

Aussen Elbe buoy

2-9 Dec 2013

Peter Frohle & Norman Dreier, EarlyDike - Sensor - und risiko basiertes Frühwarnsystem fuer Seedeiche, Teilprojekt: Wellenmonitoring und Wellenbelastungssimulator (AP2), Hamburg, April 2017.

**Time series of wave energy; wind waves at 11s, swell at 13s (highest), highest observable energy at 20s**

FINO1 waverider buoy

2-9 Dec 2013

Peter Frohle & Norman Dreier, EarlyDike - Sensor - und risiko basiertes Frühwarnsystem fuer Seedeiche, Teilprojekt: Wellenmonitoring und Wellenbelastungssimulator (AP2), Hamburg, April 2017.

**Time series of significant wave height**

FINO1

8 Dec 2013

Peter Frohle & Norman Dreier, EarlyDike - Sensor - und risiko basiertes Frühwarnsystem fuer Seedeiche, Teilprojekt: Wellenmonitoring und Wellenbelastungssimulator (AP2), Hamburg, April 2017.

**Time series of significant wave height**

Helgoland wave buoys

3-8 Dec 2013

Staneva J, C Schrum, A Behrens, S Grayek, H Ho-Hagemann, V Alan, O Breivik, J-R. Buiot, A North Sea-Baltic Sea Regional Coupled Models: Atmosphere, wind waves and ocean, in: Proceedings of the Eighth EuroGOOS International Conference (Operational Oceanography. Serving Sustainable Marine Development), 3-5 October 2017, Bergen, Norway, 2017b.

**Time series of significant wave height**

FINO1

3-7 Dec 2013

Wahle K, J Staneva, W Koch, L Fenoglio-Marc, HTM Ho-Hagemann, EV Stanov, An atmosphere-wave regional coupled model: improving prediction of wave heights in the southern North Sea, Ocean Sci., 13, 289-301, 2017. (doi:10.5194/os-13-289-2017).

**Time series of significant wave height**

North Sea axis 53 - 60N

6 Dec 2013 04:46:55UTC

Wahle K, J Staneva, W Koch, L Fenoglio-Marc, HTM Ho-Hagemann, EV Stanov, An atmosphere-wave regional coupled model: improving prediction of wave heights in the southern North Sea, Ocean Sci., 13, 289-301, 2017. (doi:10.5194/os-13-289-2017).

**Time series of significant wave height**

Helgoland and Westerland

3-8 Dec 2013

Wahle K, J Staneva, W Koch, L Fenoglio-Marc, HTM Ho-Hagemann, EV Stanov, An atmosphere-wave regional coupled model: improving prediction of wave heights in the southern North Sea, Ocean Sci., 13, 289-301, 2017. (doi:10.5194/os-13-289-2017).

**Time series of significant wave height**

FINO1

2 weeks across storm period

Wahle K, J Staneva, W Koch, L Fenoglio-Marc, HTM Ho-Hagemann, EV Stanov, An atmosphere-wave regional coupled model: improving prediction of wave heights in the southern North Sea, Ocean Sci., 13, 289-301, 2017. (doi:10.5194/os-13-289-2017).

**Time series of significant wave height**

FINO1

2-9 Dec 2013

Peter Frohle & Norman Dreier, EarlyDike - Sensor - und risiko basiertes Frühwarnsystem fuer Seedeiche, Teilprojekt: Wellenmonitoring und Wellenbelastungssimulator (AP2), Hamburg, April 2017.

**Time series of significant wave height**

Untjeboern wave gauge

5-6 Dec 2013

Dreier, Norman and Peter Froehle, Operational wave forecast in the German Bight as part of a sensor- and risk based early warning system, In: J-S Shim, I Chun, HS Lim (ed), Proceedings from the International Coastal Symposium (ICS) 2018 (Busan, Republic of Korea), Journal of Coastal Research, Special Issue No. 85, 1161-1165, 2018.

**Highest significant wave height**

Nynindegab

5-9 Dec 2013

Kystdirektoratet, Shoreface nourishment effects. An analysis of the 2011 nourishment performed at Skodsborge, Kystdirektoratet, Hopboje 1, 7620 Lemvig, Dec 2018 [pdf document properties: title=Shoreface nourishment effects Skodsborge 2012-2018, datestamp=20/12/2018].
average wave period 11.1s

[FIG] Time series of wave period and energy
Newbiggin Ness, Tyne Tees, Whithy waverider
5-6 Dec 2013
CH2M Hill Halcrow, Cell 1 Regional Coastal Monitoring Programme, Wave Data Analysis Report 2: 2013-2014, Final Report, March 2014 [document properties: author=Andy.Parson@ch2m.com; datestamp: 04/04/2014]

[FIG] Time series of mean period, peak period, and wave direction
Ormen Lange Norwegian Sea Platform
1-31 Dec 2013
FUGRO GEOS Ltd, Ormen Lange Monthly reports of waves data: December. Reporting period: 1 December 2013 to 31 December 2013, Report Number: C70101/8177/80, Issue date: 23 January 2014, prepared by Heather Holt, Checked by Donald Brookie, approved by Mark Jones

[FIG] Wave spectra graphs at 2-5 hour intervals
Buoys near Ameland inlet
5-6 Dec 2013
Gautier C, A Camarena, J van Nieuwkoop, SWAN hindcasts Wadden Sea, December 2013. Tidal inlet of Ameland and eastern Wadden Sea. Deltares, 2014, 197pp. Project 1209433-007, Reference 1209433-007-HYE-0005

[FIG] Wave spectra graphs at 2-5 hour intervals
Buoys in eastern Wadden Sea
5-6 Dec 2013
Gautier C, A Camarena, J van Nieuwkoop, SWAN hindcasts Wadden Sea, December 2013. Tidal inlet of Ameland and eastern Wadden Sea. Deltares, 2014, 197pp. Project 1209433-007, Reference 1209433-007-HYE-0005

[FIG] Time series of wave peak period and wave direction
Wave measurement buoy Westerland
2-9 Dec 2013
Luecht, Fabian and Ove Peters, Bericht ueber die Sturmflut vom 05.-06.12.2013 an der Westkueste Schleswig-Holsteins, Landesbetrieb fuer Kuestenschutz, Nationalpark und Meereschutz Schleswig-Holstein, Husum 26Feb2014, 19pp. [pdf document properties: title=Lfd; Author=Thorstien Nommensen; datestamp: 11Dec2018]

[FIG] Time series of average wave period and wave peak period
FINO1, Borkum-Suedstrand
4-9 Dec 2013
Mai S, J Wilhelmi, T Zenz, U Barjenbruch, Orkan 'Xaver' - Seegangstatistik an den Stationen FINO1 und Borkum-Suedstrand, 19, KFKI-Seminar, BREMERHAVEN 11.11.2014 (presentation slides)

[FIG] Spectrograms of wave energy on axes of frequency versus time
FINO1, Borkum-Suedstrand
4-9 Dec 2013
Mai S, J Wilhelmi, T Zenz, U Barjenbruch, Orkan 'Xaver' - Seegangstatistik an den Stationen FINO1 und Borkum-Suedstrand, 19, KFKI-Seminar, BREMERHAVEN 11.11.2014 (presentation slides)

[FIG] Time series of wave period
Westerland
4-8 Dec 2013
Matěški, Birgit, Freerk Jensen, Peter Voss, Jorg Peters, Maria Blumel, Auswertung zur Hydrologie des Sturmtiefs Xaver 05.12.2013 bis 06.12.2013, Statusbericht vom 01.10.2014, Landesbetrieb fuer Kuestenschutz, Nationalpark und Meereschutz Schleswig-Holstein, Husum 01.10.2014. 25pp.

[FIG] Time series of average upcrossing period and wave peak period
Drakenen
1-31 Dec 2013
MIROS, Monthly Report, Drakenen, December 2013, Doc. No. ND/1022/13/12 (prepared by SRS, checked by OOE, approved by CNE) [pdf document properties: author=MIROS AS; datestamp=30Jan2014]

[FIG] Time series of average wave period from spectral analysis and time series data; wave rider and altimeter
Ekofisk
1-31 Dec 2013
MIROS, Monthly report, Ekofisk, December 2013, Doc. No. ND/1024/13/12, (prepared by SRS) 34pp, 9Jan2014 [PDF document properties: author=MIROS AS; datestamp=13Jan2014]

[FIG] Average upcrossing period and primary wave peak period
Heidrun
1-31 Dec 2013
MIROS, Manedsrapport Heidrun, Desember 2013, Dok. Nr. ND/1010/13/12, 21 pp, 07Jan2014, carried out by SRS, controlled by CNE, approved by OOE [pdf properties: author=MIROS AS; datestamp: 08/01/2014]

[FIG] Average upcrossing period and primary wave peak period
Norne
1-31 Dec 2013
MIROS, Manedsrapport Norne, Desember 2013, Dok. Nr. ND/1087/13/12, 21 pp, carried out by SRS, controlled by CNE, approved by OOE [pdf properties: Author=MIROS AS; datestamp: 06Jan2014]

[FIG] Time series of average wave period from spectral analysis and time series data; wave rider and altimeter
Sleipner A
1-31 Dec 2013
MIROS, Manedsrapport Sleipner A, Desember 2013, Dok. Nr. ND/1017/13/12, 06Jan2014, prepared by SRS, controlled by CNE, approved by OOE.

[FIG] Time series of average upcrossing wave period, peak period of primary wave, average wave direction
Troll A
1-31 Dec 2013
MIROS, Manedsrapport, Troll A, Desember, 2013, Doc. No. ND/1012/13/12, (prepared by SRS) 21pp, 7Jan2014 [PDF document properties: author=MIROS AS; datestamp=10Jan2014]

[FIG] Time series of wave period
Scheur west Wandelajaer, Euro platform, IJmuiden, Platform K13a
5-6 Dec 2013
RWS, Stormvoedrapport van 5 t/m 7 december (SR91) Sint-Nicolaasvloed 2013, Watermanagementcentrum Nederland, Rijkswaterstaat, prepared by Ing. J. Kroos,
TABLE] Table of maximum 'globally corrected' wave periods in ranked storm list

| Location                        | Period       |
|---------------------------------|--------------|
| Scheur west Wandelaar, Euro platform, Ilmuiden municiestorplaats, Eielandse Gat, Schiermonnikoog Nord | 2013-Dec-5 |

19 Mar 2014b, 48 pp

[FIG] Time series of wave peak period

Wave buoy 1_1 Amelander Zeegat

5-Dec-2013

van Rooijen A, A Oost, Memo: Regionale advisering Ameland Noordwest, Deltas, 1209381-008-ZKS-0008, 43pp, 18-Dec-2014 [PDF document properties: title=Regional advisering: Ameland NW; author=Arnold van Rooijen; keywords: 1209381-008-ZKS-0008; date stamp: 18/12/2014]

[FIG] Time series of peak period and wave direction

SCHW, SCHO, WIEL

5-7-Dec-2013

Carron Aretxabala, BL Morphological impact of the Sinterklaas storm at Het Zwin. Numerical modelling with XBeach, M.Sc. Civil Engineering, Delft University of Technology, 2015.

[FIG] Time series of wave period and wave direction from Nortek AWAK instrument 600m from shore

Beach profile 104 south of Ostend

4-8-Dec-2013

Dan, Sebastian, Anne-Lise Montreuil, Rosalía Delgado, Tomas van Oven, Large storm impact on a beach under sand nourishments, The Proceedings of the Coastal Sediments 2015, edited by Ping Wang, Julie D Rosati, and Jun Cheng, Coastal Sediments 2015, San Diego, USA, 11-15-May-2015

[TEXT] reference to peak period and wave direction information for 2012 to 2013 across storm period

FINO1

7

Fischer, JG, C Senet, A Schneeboorst, R Outzzen, S Schirmel, K Herklotz, Sea state measurements in Germanys first offshore wind farm "alpha ventus", in the south-eastern parts of the North Sea, 2013 IEEE/OES Eleventh Current, Waves and Turbulence Measurement (CWTM), 2015 [PDF document properties: datestamp: 14/01/2015]

[FIG] Time series of wave period

Liverpool, Sizewell

4-6-Dec-2013

Wadey MP, JM Brown, ID Haigh, T Dolphin, P Wisse, Assessment and comparison of extreme sea levels and waves during the 2013/2014 storm season in two UK coastal regions, Nat. Hazards Earth Syst. Sci. Discuss., 3, 2665-2708, 2015b.

[FIG] Time series of average wave period

Lighthouse Alte Weser, Borkum Suedstrand

4-8-Dec-2013

Mai S and U Barjenbruch, Water level measurements with radar gauges at the German North Sea coast, [PDF document properties: author=ROC; subject: IOC/2016/MG/14 vol.5; datestamp: 18/04/2017]

[FIG] Time series of wave period

Seegeassonsssstation Westerland

4-8-Dec-2013

Mateiski, Birgit, Erfahrungen aus der Sturmflut Xaver von 5, und 6.12.2013 und dem Weihnachtschwoasser 2014 in Shleswig-Holstein, IWASA 2016 Tagungsbeitrag, (46. IWASA, 7-8 Januar 2016; Internationales Wasserbau-Symposium Aachen. [pdf document properties: author=sonja; datestamp: 26-Apr-2016]

[FIG] Wave period and direction

Amelander Zeegat buoy

5-8-Dec-2013

Nederhoff K, E Elias, T Vermaas, Erosie op Ameland Noordwest. Modelstudie: simulaties met Delft3D en XBeach, Deltas, 117pp, July, 2016

[TEXT] wave peak period 10s from ADCP

Hornbaek

5-Dec-2013

Sorensen CS, NK Drønen, P Knudsen, J Jensen, P Sorensen, An extreme event as a games changer in coastal zone management, Journal of Coastal Research, (Special Issue, No 75), 700-704, 2016. Proceedings of the 14th International Coastal Symposium (Sydney, Australia) ed by A Vila-Concejo, E Bruce, DM Kennedy, RJ McCartney

[FIG] Two dimensional graph of wave spectral density versus frequency and time

Elbe buoy and FINO1 buoy

2-8-Dec-2013

Stanoea J, K Wahl, W Koch, A Bohrens, L Fenoglio-Marc, EV Stanoev, Coastal flooding: impact of waves on storm surge during extremes - a case study for the German Bight, Nat. Hazards Earth Syst. Sci., 16, 2373-2389, 2016

[FIG] Two dimensional graph of wave spectral density versus frequency and time

Elbe buoy

1-8-Dec-2013

Stanoe J, C Schrum, A Bohrens, S Grayek, H Ho-Hagemann, V Alan, O Breivik, J-R. Biblot, A North Sea-Baltic Sea Regional Coupled Models: Atmosphere, wind waves and ocean, in Proceedings of the Eighth EuroGOOS International Conference (Operational Oceanography, Serving Sustainable Marine Development), 3-5 October 2017, Bergen, Norway, 2017b.

[FIG] Energy spectrum from wave buoy for different directions

FINO1

5 Dec 2013 22:44UTC

J Jensen, S Niehuser, A Arns, S Dangendorf, Sensor- and risikobasiertes Fruhwaran-system fuer Seeedche (EarlyDike), API - Sturmflutmonitoring und Sturmflutssimulatort - Fuchbericht 2016, Siegen, April 2017

[TABLE] peak period

Nymindegab

5-9-Dec-2013

Kystdirektoratet, Shoreface nourishment effects. An analysis of the 2011 nourishment performed at
| Table S14. Surge reports and quantitative water levels (arranged by year and then alphabetically) |
|-----------------------------------------------|
| **Data type** | **Location** | **Time Interval** | **Full Reference and Notes** |
| [TABLE] MHW, true surge, skew surge on each semidiurnal tidal cycle | Helgoland, Borkum, Emden, Wilhelmshaven, Bremerhaven, Bremen, Cuxhaven, Brunsbüttel, Hamburg, Zollenspieker, Buesum, Eidersperwerk, Husum, Dagebüll | 5-7 Dec 2013 | BSH, Die Nordseesturmfuturen von 5. und 6.12.2013, 3pp, prepared by Stockmann.K. (title: Sturmflut 2011 bm1101; author stamp: bm1101; document time stamp: 12/10/2013 12:5136PM) |
| [FIG] ABB12. Time series of water level with lines for MThw and MTnw | Husum and Norderney-Riffgat | 5-8 Dec 2013 | Deutschlander T, K Frierich, S Haeseler, C Lefebvre, Orkantief XAVER ueber Nordeuropea von 5. bis 7. Dezember 2013, Deutscher Wetterdienst DWD, Stand 30. Dezember 2013. 19pp. |
| [FIG] ABB13. Time series of water level with lines for MThw and MTnw | Flensburg and Warnemunde | 5-8 Dec 2013 | Deutschlander T, K Frierich, S Haeseler, C Lefebvre, Orkantief XAVER ueber Nordeuropea von 5. bis 7. Dezember 2013, Deutscher Wetterdienst DWD, Stand 30. Dezember 2013. 19pp. |
| [FIG] ABB13. Time series of water level with lines for MThw and MTnw | Hamburg St. Pauli | 5-8 Dec 2013 | Deutschlander T, K Frierich, S Haeseler, C Lefebvre, Orkantief XAVER ueber Nordeuropea von 5. bis 7. Dezember 2013, Deutscher Wetterdienst DWD, Stand 30. Dezember 2013. 19pp. |
| [TEXT] Maximum water levels | Hamburg, Dagebüell, Husum, Buesum, Eidersperwerk, Cuxhaven | 5-6 Dec 2013 | Kunz M, B Muehr, K Schroeter, T Bessel, S Moehlre, T Muenzberg, S Brink, H-M Schmidt, Winterstorm Xaver - Report. 06Dec2013 - Report No.1. Situation Report - 19:00CET, CEDIM Forensic Disaster Analysis Group (FDA), Center for Disaster Management and Risk Reduction Technology. |
| [TABLE] Water level maximum and minimum; true surge maximum and minimum | Aberdeen, Cromer, Dover, Harwich, Immingham, Leith, Lerwick, Lowestoft, North Shields, Sheerness, Whitby, Wick | 5-7 Dec 2013 | McGarricke P (ed), UK coastal monitoring and forecasting: Annual report for 2013 for the UK National Tide Gauge Network, NERC 100017897, 2013 [pdf document properties: author=panmec; created=16Apr2014] |
| [FIG] SARal-Altika strip map of water level | North-south transect of North Sea | 06Dec2013 04:47UTC | Mills, Ian, Remko Scharow, Luciana Fenoglio, Xaver affected much of northern Europe on 5 and 6 December and caused worst storm surge for decades in the North Sea. https://www.eumetsat.int/websate/home/News/DAT_20870 62.html (last accessed: 19Nov2019, 28Jun2020) |
| [FIG] Time series of water level anomaly | Helgoland Suedhaven, Leuchtturm Alte Weser | 4-6 Dec 2013 | Mills, Ian, Remko Scharow, Luciana Fenoglio, Xaver affected much of northern Europe on 5 and 6 December and caused worst storm surge for decades in the North Sea. https://www.eumetsat.int/webseite/home/News/DAT_20870 62.html (last accessed: 19Nov2019, 28Jun2020) |
| [TEXT] Maximum water level NAP | Vissingen | 6Dec2013 04:00MEST | NOS, Hoogste waterstand sinds 1953, 06/12/2013, 09:52, [https://nos.nl/artikel/583218-hoogste-waterstand-sinds-1953.html](https://nos.nl/artikel/583218-hoogste-waterstand-sinds-1953.html) |
| [FIG] Time series of water level, astronomical tide and true surge residual | Oostende, Zeebrugge | 5-6 Dec 2013 | Oceanografisch Meteorologisch Station, Stormvorslag 05-06 december 2013, 26pp, 2013 [pdf document properties: author=Myriam Sys; datestamp=15Dec2013] |
| [TABLE] water level of the midnight flood of 6Dec2013 (values over average high water) | Borkum, Norderney, Langeoog, Spiekeroog, Wangeroog West, Leyhoern, Bensersiel, Emsperwerk, Knock,Emden, Varel Schlesse, Fedderwardersiel, Wilhelmshaven, Cuxhaven, Huntesperwerk, Ochtumsperrwerk, Spieka Neufeld, Otterndorf, Stader Sand | Midnight flood, 6 Dec 2013 | NLIWKN, Schwere Sturmflut gut Uebertanden, Wasserstanden zwischen Zweiinhale und Knap vier metern registriert // presensoinformation von 6. Dezember 2013, (Ansprechpartnerin: Herma Heyken), 06/12/2013. |
| [TEXT] Maximum water levels | Woken, Barseback, Halmstad, Malmo | 5-6 Dec 2013 | SmHI, Stormen Sven gav nya vattenstandsrekord i Oresund. [https://www.smhi.se/nyhetsarkiv/stormen-sven-gav-nya-vattenstandsrekord-i-oresund-1.34732](https://www.smhi.se/nyhetsarkiv/stormen-sven-gav-nya-vattenstandsrekord-i-oresund-1.34732) updated 20Mar2017; original datestamp 10Dec2013. |
| [TEXT] Minimum water level | Skanoor | 5-6 Dec 2013 | SmHI, Stormen Sven gav nya vattenstandsrekord i Oresund. [https://www.smhi.se/nyhetsarkiv/stormen-sven-gav-nya-vattenstandsrekord-i-oresund-1.34732](https://www.smhi.se/nyhetsarkiv/stormen-sven-gav-nya-vattenstandsrekord-i-oresund-1.34732) updated 20Mar2017; original datestamp 10Dec2013. |
| [TEXT] Maximum flood | Hamburg-St Pauli | 6 Dec 2013 | Unwetterzentrals, Orkantief XAVER - ein weiterer schwerer |
The table contains information about water levels and surge events in various locations. Here is a summary of the key points:

- **Water level at 6.09m NN and skew surge at 3.98m uMH**
  - Location: Cuxhaven
  - Date: 6 Dec 2013
  - Source: Wintersturm der letzten Jahrzehnte, Thomas Savert and Stefan Laps, December 2013, Associated British Ports, Marine Environmental Research, July, 2014

- **Table**
  - Water level, expected, tide, residual surge
  - Locations: Lerwick, Wick, Aberdeen, Leith, North Shields, Immingham, Cromer, Lowestoft, Dover.
  - Dates: 5-6 Dec 2013
  - Source: Unwetterzentrale, Orkantief XAVER - ein weiterer schwerer Wintersturm der letzten Jahrzehnte, Thomas Savert and Stefan Laps, December 2013, Associated British Ports, Marine Environmental Research, July, 2014

- **Text**
  - Base of water 20 feet above normal with 15 feet above that.
  - Location: Hemsby UK
  - Date: Night 5-6 Dec 2013
  - Source: BBC, East coast surge: what happened next? (report by Richard Haugh), 5Dec2014

- **Text**
  - Highest storm flood water levels
  - Locations: North Shields, Whitby, Scarborough
  - Date: 5-6 Dec 2013
  - Source: CH2M Halcrow, Cell 1 Regional Coastal Monitoring Programme, Wave Data Analysis Report 2: 2013-2014, Final Report, March 2014

- **Figure**
  - Time series of tide gauge water level
  - Locations: North Shields, Whitby, Scarborough
  - Date: 5-6 Dec 2013
  - Source: CH2M Halcrow, Cell 1 Regional Coastal Monitoring Programme, Wave Data Analysis Report 2: 2013-2014, Final Report, March 2014

- **Map with data**
  - Maximum water levels
  - Locations: Immingham, Cromer, Lowestoft, Harwich, Sheerness, Dover, Kingston Upon Hull
  - Date: 5-6 Dec 2013
  - Source: Dunbar I, N Phipps, M Szonyi, Risk Nexus. After the storm: how the UK's flood defences performed during the surge following Xaver, Flood resilience review 09.14, Zurich Insurance Company Ltd., Mythenquai 2, 8002, Zurich, Switzerland

- **Text**
  - Highest storm flood water levels
  - Locations: North Shields, Whitby, Scarborough
  - Date: 5-6 Dec 2013
  - Source: CH2M Halcrow, Cell 1 Regional Coastal Monitoring Programme, Wave Data Analysis Report 2: 2013-2014, Final Report, March 2014

- **Timeseries**
  - Water level
  - Locations: Holbaek and Roskilde
  - Date: 6-7 Dec 2013
  - Source: Erikson J, Rekordextindestande i Isfjorden og Roskilde Fjord, Vejet, 138, 2 40-48, 2014

- **Text**
  - Highest surge water level
  - Location: Borkum
  - Date: 6 Dec 2013
  - Source: FINO1, 15-m wave damaged FINO1, 08Jan2014, http://www.fino1.de/meldungen/alle-meldungen/137-15-meter-welle-beschadigt-fino1

- **Figure**
  - Time series of measured water level
  - Locations: Terschelling Noordzee, Nes, Wierumerwad, Laurwersoog, Eemshaven, Nieuw Staatensjl
  - Date: 5-7 Dec 2013
  - Source: Gautier C, A Camarena, J van Nieuwkoop, SWAN hindcasts Wadden Sea, December 2013. Tidal inlet of Ameland and eastern Wadden Sea. Deltas, 2014, 197pp. Project 1209433-007, Reference 1209433-007-HYE-0005

- **Timeseries**
  - Observed water level and astronomical tide
  - Location: Vlissingen
  - Date: 2Dec2013 0000UTC to 12Dec2013 0000UTC
  - Source: Hewson T, L Magnusson, O Breivik, F Prates, I Tsonvevsky, HJW de Vries, Windstorms in northwest Europe in late 2013, ECMWF Newsletter, No. 139, pp 22-28, Spring 2014

- **Text**
  - Maximum water level over average high water 2.83m
  - Location: Nordemey
  - Date: 5-6 Dec 2013
  - Source: Knaack H and H Heyken, Xaver hatte sehr schwere Stumflut im Gepaeck, Jahresbericht 2013. Der Zukunft verplichtet, 2014

- **Text**
  - Maximum water level over average high water 2.83m
  - Location: Nordemey
  - Date: 5-6 Dec 2013
  - Source: Kristandt, J., B. Brectt, H. Frank, H. Knaack, Optimization of empirical storm surge forecast-modeling of high resolution wind fields, Die Kueste, 81, 301-348, 2014

- **Table**
  - Highest absolute water levels and MTHW skew surges
  - Locations: List, Hoernum, Wittduen, Dagebueil, Hooge Anleger, Husum, Eidersperrwerk, Cuxhaven, Buesum, Stoersperrwerk, Glueckstadt, Schulau, St. Pauli
  - Date: 5-6 Dec 2013
  - Source: Luecht, Fabian and Ove Peters, Bericht ueber die Sturmflut vom 05.-06.12.2013 an der Westkueste Schleswig-Holsteins, Landesbetrieb fuer Kuestenschutz, Nationalpark und Meeresschutz Schleswig-Holstein, Husum 26Feb2014, 19pp. [pdf document properties: title=Lfd; Author=Thorsten Nommensen; datestamp=11Dec2018]

- **Timeseries**
  - Water level
  - Location: FINO1, FINO2, FINO3
  - Date: 1-8 Dec 2013
  - Source: Leiding T, B Tint, G Rosenhagen, C Lefevre, S Haeseler, S Hagemann, I Bastigkeit, D Stein, P Schwenk, S Mueller, O Outzen, K Herklotz, T Neumann, Meteorological Wind fields, Insurance Company Ltd. Zurich, Mythenquai 2, 8002, Zurich, Switzerland

- **Figure**
  - Time series of water level
  - Location: FINO1, Borkum-Suedstrand
  - Date: 4-9 Dec 2013
  - Source: Mai S, T Wilhelmi, T Zenz, U Barjenbruch, Orkan ‘Xaver’ - Seegangstatistik an den Stationen FINO1 and Borkum-Suedstrand, 19. KFKI-Seminar, Bremerhaven 11.11.2014 (presentation slides)

- **Figure**
  - Time series of the measured water level, modelled tide, and surge residual
  - Locations: Wyk, Hamburg St. Pauli, Husum
  - Date: 5-6 Dec 2013
  - Source: Mateiski, Birgit, Frerk Jensen, Peter Voss, Jorg Peters, Maria Blumel, Auswertung zur Hydrologie des Sturmstiefs Xaver 05.12.2013 bis 06.12.2013, Statusbericht vom 01.10.2014, Landesbetrieb fuer Kuestenschutz, Nationalpark und
Highest water levels

| Table | Maximum water levels, MThw levels |
|-------|-----------------------------------|
|       | 62 stations in Schleswig-Holstein |
| 5-6 Dec 2013 | Matelski, Birgit, Frerk Jensen, Peter Voss, Jorg Peters, Maria Blumel, Auswertung zur Hydrologie des Sturmtiefs Xaver 05.12.2013 bis 06.12.2013, Statusbericht vom 01.10.2014, Landesbetrieb fuer Kuestenschutz, Nationalpark und Meeresschutz, Schleswig-Holstein, Husum, 01.10.2014, 25pp. |

| Figure | Time series of water level |
|--------|-----------------------------|
| Dragen | MIROS, Monthly Report, Dragen, December 2013, Doc. No. ND/1022/13/12 (prepared by SRS, checked by OO, approved by CNE) [pdf document properties: author=MIROS AS; datestamp=30Jan2014] |
| 1-31 Dec 2013 | |

| Figure | Time series of water level from altimeter |
|--------|------------------------------------------|
| Ekofisk | MIROS, Monthly report, Ekofisk, December 2013, Doc. No. ND/1024/13/12, (prepared by SRS) 34pp, 9Jan2014 [PDF document properties: author=MIros AS; datestamp=13Jan2014] |
| 1-31 Dec 2013 | |

| Figure | Time series of water level from altimeter |
|--------|------------------------------------------|
| Heidrun | MIROS, Manedsrapport Heidrun, Desember 2013, Dok. Nr. ND/1010/13/12, 21 pp, 07Jan2014, carried out by SRS, controlled by CNE, approved by OO [pdf properties: author=Miros AS; date stamp: 08/01/2014] |
| 1-31 Dec 2013 | |

| Figure | Time series of water level from altimeter |
|--------|------------------------------------------|
| Sleipner A | MIROS, Manedsrapport Sleipner A, Desember 2013, Dok. Nr. ND/1017/13/12, 06Jan2014, prepared by SRS, controlled by CNE, approved by OO. |
| 1-31 Dec 2013 | |

| Table | Highest storm surge water levels with times |
|-------|--------------------------------------------|
| Vissingen, Zandvliet, Kallo, Prosperpolder, Lietkenshoek, Antwerpen, Boom, Hemiksem, Tielse, Sint-Amands, Walem, Mechelen Benediktslus, Dendemonde, Hombeek, Duffel, Lier Molbrug, Schoonarde, Waasmunster, Manta, Emsalem, Kessel, Wetteren, Melle | Nossent J, L Boeckx, E Taverniers, M Deschamps, T Verwaest, F Mostaert, Sinterklaaslaast storm 6 december 2013. Beschrijving van de hydrometrische gebeurtenissen, Versie 4.0: WL Rapporten, 00-119, Waterbouwkundig Laboratorium, Antwerpen, Belgie. October 2014, WL2014R00_119_5 [document date stamp: 15Oct2014; author=Deschamps, Maarten] |
| 6 Dec 2013 | |

| Figure | Time series of observed water level, astronomical tide, true surge residual |
|--------|-------------------------------------------------------------------------|
| Vissingen | Nossent J, L Boeckx, E Taverniers, M Deschamps, T Verwaest, F Mostaert, Sinterklaaslaast storm 6 december 2013. Beschrijving van de hydrometrische gebeurtenissen, Versie 4.0: WL Rapporten, 00-119, Waterbouwkundig Laboratorium, Antwerpen, Belgie. October 2014, WL2014R00_119_5 [document date stamp: 15Oct2014; author=Deschamps, Maarten] |
| 4-8 Dec 2013 | |

| Text | Highest water levels |
|------|----------------------|
| Roskilde Haven, Torminde, Harbaek, Klapenberg, Tollboen Kobenhavn, Sjaellands Odde, Grenaa, Odense Fjord | Pelt AS, BODIL’s stormflood i de indre dansk farvande, Vejret, 138, 24-29, 2014 |
| 5-6 Dec 2013 | |

| Text | Extreme low water levels |
|------|--------------------------|
| Koge Bugt, Flensborg, Rodby, Ronne og Tegn | Pelt AS, BODIL’s stormflood i de indre dansk farvande, Vejret, 138, 24-29, 2014 |
| 5-6 Dec 2013 | |

| Map Text | Highest coastal water levels |
|---------|-----------------------------|
| Lerwick, Wick, Aberdeen, Lerit, North Shields, Whitby, Immingham, Cromer, Lowestoft, Harwich, Herne Bay, Sheerness, Dover, Ostend, Borkum, Heligoland, Binnenhufen, Cuxhaven, Hirtshals, Gothenburg, Torshamman | RMS, 2013-2014 Winter Storms in Europe. An Insurance and Catastrophe Modeling Perspective. RMS White Paper. [PDF TIMESTAMP 11Mar2014] |
| 5-6 Dec 2013 | |

| Table | Maximum water level, astronomical tide, skew surge for successive storm tides |
|-------|-----------------------------------------------------------------------------|
| Vissingen, Roopont buiten, Dordrecht, Den Helder, Harlingen, Delfzijl | RWS, Watermanagementcentrum Nederland, Stormvloedflits 2013-07 van 5 t/m 7 december 2013, Rijkswaterstaat (document time stamp: 07Jan2014), 2014a |
| 5-7 Dec 2013 | |

| Table | Maximum water level, astronomical tide, skew surge for successive storm tides |
|-------|-----------------------------------------------------------------------------|
| Vissingen, Roopont buiten, Hoek van Holland, Den Helder, Harlingen, Delfzijl | RWS, Stormvloedrapport van 5 t/m 7 december (SR91) Sint-Nicolaasvloed 2013, Watermanagementcentrum Nederland, Rijkswaterstaat, prepared by Ing. J. Kroos, 19 Mar 2014b, 48 pp |
| 5-6 Dec 2013 | |

| Figure | Time series of measured water level, modelled astronomical tide, residual |
|--------|-----------------------------------------------------------------------------|
| Vissingen, Roopont buiten, Hoek van Holland, Dordrecht, Den Helder, Harlingen, Delfzijl | RWS, Stormvloedrapport van 5 t/m 7 december (SR91) Sint-Nicolaasvloed 2013, Watermanagementcentrum Nederland, Rijkswaterstaat, prepared by Ing. J. Kroos, 19 Mar 2014b, 48 pp |
| 5-7 Dec 2013 | |

| Text | Highest water levels |
|------|----------------------|
| Viken, Barseback, Halmstad | SMHI, Simone, Hilde, Sven och Ivar okt-dec 2013, 3 Jul 2014, https://www.smhi.se/kunskapsbanken/meteorologi/simone-hilde-sven-och-ivar-okt-dec-2013-1.76183 |
| 6-7 Dec 2013 | |
[TEXT] Lowest water level
Skanoor
6-7 Dec 2013
SMHI, Simone, Hilde, Sven och Ivar okt-dec 2013, 3 Jul 2014
https://www.smhi.se/kunskapsbanken/meteorologi/simone-hilde-sven-och-ivar-okt-dec-2013-1.76183

[TEXT] Maximum water levels & skew surge from beach survey
Morston, Blakeney, Cley
5-6 Dec 2013
Spencer, T, S.M. Brooks, I. Moller, B.R. Evans, Where local matters: Impacts of a major North Sea storm surge, EOS, 95, 269-270, 29July2014

[TEXT] Maximum water levels from beach survey
Wells-next-the-Sea
5-6 Dec 2013
Spencer, T, S.M. Brooks, I. Moller, B.R. Evans, Where local matters: Impacts of a major North Sea storm surge, EOS, 95, 269-270, 29July2014

[PROFILE] Maximum water levels from beach survey
Holme-next-the-Sea, Thornham, Titchwell, Brancaster Beach, Brancaster Staith, Burnham Deepdale, Burnham Overy Staith, Holkham Gap, Wells Stiffkey, Morston, Blakeney, Cley, Salthouse
5-6 Dec 2013
Spencer, T, S.M. Brooks, I. Moller, B.R. Evans, Where local matters: Impacts of a major North Sea storm surge, EOS, 95, 269-270, 29July2014

[FIG] Time series of surface elevation
Sylt, Grena, Sassnitz
4-10 Dec 2013
Stanev E, J Staneva, S Grayek, J Schulz-Stellenfleth, S. Grashorn, A Behrens, Numerical modelling and data assimilation, COSYNA Progress Report 2013, pp.46-51, Helmholtz-Zentrum Geesthacht, June 2014.

[FIG] Time series of sea surface elevation
4 unlabelled stations in German Bight identified on map only
3-9 Dec 2013
Staneva J, K Wahle, E Stanev. Response of the German Bight Hydro and Sediment Dynamics to Wave, Tidal and Atmospheric Forcing, 3rd GODAE OceanView Coastal Oceans and Shelf Seas Task Team (COSS-TT) International Coordination Workshop, 21-24 January 2014, Rincon Beach Resort, Puerto Rico, 36pp

[FIG] Time series of measured water level and modelled astronomical tide. Highest water level 3.8m; highest corresponding tide 1.4m
Lauperzooog
4-9 Dec 2013
van Rooijen A, A Oost, Memoc Regionale advising Ameland Noordoost, Deltaros, 1209381-008-ZKS-0008, 43pp, 18Dec2014 [PDF document properties: title=Regional advising: Ameland NW; author=Arnold van Rooijen; keywords: 1209381-008-ZKS-0008; date stamp: 18/12/2014]

[FIG] Time series of water level in 20 m depth. Maximum water level 2.6m NAP on 5 Dec 2013 21:00GMT
Terschelling Noordzee
4-7 Dec 2013
van Rooijen A, A Oost, Memoc Regionale advising Ameland Noordoost, Deltaros, 1209381-008-ZKS-0008, 43pp, 18Dec2014 [PDF document properties: title=Regional advising: Ameland NW; author=Arnold van Rooijen; keywords: 1209381-008-ZKS-0008; date stamp: 18/12/2014]

[TEXT] Absolute water level and skew surge
Hamburg-St.Pauli
5-6 Dec 2013
Aker T, T Bistray, M Klaaw, M Mueller, M Suesser, Deutsche Ruck Sturm dokumentation 2013 Deutschland, 2013, Deutsche Ruckversicherung Aktiengesellschaft, Hansasallee 177, 40549 Duesseldorf, www.deutscherueck.de [pdf document information: author=fizl; date stamp=07Aug2015]

[FIG] Time series measured water level, astronomical tide, surge residual
Cadzand
5-7 Dec 2013
Carrion Arextabala, BL Morphological impact of the Sinterklas storm at Het Zwin. Numerical modelling with Xbeach, M.Sc, Civil Engineering, Delft University of Technology, 2015.

[FIG] Water level from tide gauge
Ostend
4-8 Dec 2013
Dan, Sebastian, Anne-Lise Montreuil, Rosalia Delgado, Tomas van Oyen, Large storm impact on a beach under sand nourishment, The Proceedings of the Coastal Sediments 2015, edited by Ping Wang, Julie D Rosati, and Jun Cheng, Coastal Sediments 2015, San Diego, USA, 11-15May2015

[FIG] Time series of water level from tide gauge
Liverpool Gladstone Dock
5 Dec 2015
Dissanyake P and H Karunarathna, Effect of storm clustering on beach/dune erosion, e-proceedings of the 36th IAHR World Congress, 28June-3July, 2015, The Hague, The Netherlands

[FIG] Time series of water level from tide gauge
Liverpool Gladstone Dock
5 Dec 2013
Dissanyake P, J Brown, H Karunarathna, Impacts of storm chronology on the morphological changes of the Formby beach and dune system, UK, Nat. Hazards Earth Syst. Sci., 15,1533-1543, 2015.

[FIG] Time series of water level from tide gauge
Liverpool Gladstone Dock
1 Dec 2013 - 31 Jan 2014
Dissanyake P, J Brown, P. Wisse, H Karunarathna, Comparison of storm cluster vs isolated event impacts on beach/dune morphodynamics, Estuarine, Coastal, and Shelf Science, 164, 301-312, 2015b.

[STRIP PROFILE] AltiKa satellite altimetry detided water level height
Strip profile through North Sea
6 Dec 2013 0447UTC
Fenoglio-Marc L, R Scharroo, A Annuziato, I Mendoza, M Becker, J Lilijbridge, Cyclone Xaver seen by geodetic observations, Geophys Research Letters, 42, 9925-9932, 2015

[FIG] True surge heights
Aberdeen, Lowestoft, Borkum, Suedstrand
5-6Dec 2013
Fenoglio-Marc L, R Scharroo, A Annuziato, I Mendoza, M Becker, J Lilijbridge, Cyclone Xaver seen by geodetic observations, Geophys Research Letters, 42, 9925-9932, 2015
Borkum Fischeralte, Emden, Helgoland, Mellumplate, Leuchtturm Alte Weser, Wilhelmshaven, Dwarsgat, Hoernum/Sylt, Bremerhaven, Dagebuell, Cuxhaven, Busum

observations, Geophys Research Letters, 42, 9925-9932, 2015

[FIG] Time series water level data FIN01 3-7 Dec 2013 Fenoglio-Marc L, R Scharroo, A Annuziato, L Mendoza, M Becker, J Lillibridge, Cyclone Xaver seen by geodetic observations, Geophys Research Letters, 42, 9925-9932, 2015

[FIG] Time series of water level; maximum 1.3m where normal high tide 0.2m Saebj/ Fredrikshavn 1 Nov 2013 – 31 Dec 2013 Gierlevsen T, H Lauridsen, F Langhans, J Bøjde, Met-ocean and wind resource related studies for nearshore windfarms in Denmark, seminar at the Danish Energy Agency, 27 February 2015.

[FIG] Time series of water level Wandelaar 1-31 Dec 2013 Gourgue O, BB Sisih, J Vanlede, H Komjani, M Chen, Modelling tides and storm surges on the European continental shelf, 22nd Telemac & Mascaret User Club, STFC Daresbury Laboratory, UK, 13-16 Oct 2015. [PDF document properties: datestamp: 05/10/2015]

[FIG] Maximum water level in cm Pegel Null PN List, Hoernum, Wittduen, Wyk, Dagebuell, Buesum, Helgoland, Cuxhaven, LT Alte Weser, Wilhelmshaven, Norderney, Emden 5-6 Dec 2013 Jensen, J., A. Arns, T. Wahl, Yet another 100yr storm surge event: the role of individual storm surges on design water levels, Journal of Marine Science and Technology, 23, 882-887, 2015.

[FIG] Maximum water levels Emden, Norderney, Cuxhaven 5-6 Dec 2013 NLWKN, Sturmfludienst der Betreibestelle Norden-Norderney, Niedersaechischer Landesbetrieb fuer Wasserwirtschaft, Kuesten- und Naturschutz, Niedersachsen, 12/2015 [document date stamp 10Dec2015]

[TABLE] Maximum water level, maximum true surge, maximum astronomical tide, skew surge Wick, Aberdeen, North Shields, Whitby, Immingham, Kings Lynn, Wells next the Sea, Lowestoft 5 Dec 2013 Spencer T, SM Brooks, BR Evans, JA Tempest, I Moeller, Southern North Sea storm surge event of Dec., 2013: Water levels, waves, and coastal impacts, Earth Science Reviews, 146, 120-145, 2015

[FIG] Time series of gauge water level, calculated astronomical tide, and true surge residual Liverpool, Lowestoft 4-6 Dec 2013 Wadey MP, JD Haigh, RJ Nichols, JM Brown, K Horsburgh, B Carroll, SL Gallot, T Mason, E Bradshaw, A comparison of the 31 January-1 February 1953 and 5-6 December 2013 coastal flood events around the UK, UK Frontiers in Marine Science, 2, 84, 2015a.

[FIG] Time series of gauge water level, calculated astronomical tide, skew surge Lowestoft 5 Dec 2013 Wadey MP, JM Brown, ID Haigh, T Dolphin, P Wisse, Assessment and comparison of extreme sea levels and waves during the 2013/2014 storm season in two UK coastal regions, Nat. Hazards Earth Syst. Sci. Discuss., 3, 2665-2708, 2015b.

[FIG] Time series of true surge Hoek van Holland 4-8 Dec 2013 F Zylj, J Suni, M Verlaan, Application of data assimilation for improved operational water level forecasting on the northwest European shelf and North Sea, Ocean Dynamics, 65, 1699-1716, 2015

[FIG] Time series of still water levels Immingham and Cromer 5-7 Dec 2013 Brooks SM, T Spencer, A McIvor, I Mollier, Reconstructing and understanding the impacts of storms and surges, southern North Sea, Earth Surface Processes and Landforms, 41, 855-869, 2016.

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| FIG | Time series of water level, astronomical tide, and surge residual | Holmestrandsholm-Halig, Nordstrandsholm | 4-8 Dec 2013 | Matelski, Birgit, Erfahrungen aus der Sturmflut Xaver von 5. und 6.12.2013 und dem Weihnachtsdurchfluss 2014 in Sleswigs-Holstein, IWA/SA 2016 Tagungsbeitrag, (46. IWA/SA, 7-8 Januar | 2016, Internationales Wasserbau-Symposium Aachen. [pdf document properties: autor=sonja; datestamp=26Apr2016] |
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| FIG | Time series of water level | Terschelling, Wierumergronden, Nes | 5-8 Dec 2013 | Nederhoff K, E Elias, T Vermaas, Erosion op Ameland Noordwest. Modelstudie: simulaties met Delt3D en XBeach, Deltares, 117pp, July, 2016 |
| FIG | Time series of water levels with text indicating highest water level 1.96 m DWR| Hornbaek | 4-6 Dec 2013 | Sorensen CS, NK Dronen, P Knudsen, J Jensen, P Sorensen, An extreme event as a games changer in coastal zone management, Journal of Coastal Research, (Special Issue, No 75), 700-704. 2016, Proceedings of the 14th International Coastal Symposium (Sydney, Australia) ed by A Vila-Concejo, E Bruce, DM Kennedy, RJ Mccarroll |
| FIG | Time series of tide gauge water levels | 4 German Bight stations, unidentified but marked on map | 4-9 Dec 2013 | Staneva J, K Wahle, H Guenther, E Stanoe, Coupling of wave and circulation models in coastal-ocean predicting systems: a case study for the German Bight, Ocean Sci., 12, 797-806, 2016a |
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| TEXT | 5.2 m surge; water level 6.08m ODN | Boston UK | 5-6 Dec 2013 | Evans, Sun Yan, EA/13/2 Appendix 1, History of flooding sources, Boston Barrier Transport & Works Act order application, Public Inquiry documents, [pdf document properties: author=BDB; datestamp=16Mar2017] https://consult.environment-agency.gov.uk/engagement/bostonbarriertwoa/results/appendix-i-history-of-flooding-sources.pdf |
| TABLE | Highest flood water levels | Wick, North Shields, Immingham, Boston, Wells, Lowestoft, Sheerness | 5-6 Dec 2013 | Jee, Andrew, EA/13/2 Appendix 1. A summary of flooding events in Boston. [pdf document properties: author=Andrew Jee; Date stamp=17Mar2017] https://consult.environment-agency.gov.uk/engagement/bostonbarriertwoa/ |
| FIG | Time series of the surge residual from ADCP | FINO1 | 4-7 Dec 2013 | Staneva J, H Guenther, O Krueger, C Schrumm, V Alari, O Breivik, J-R Bidlot, K Mogensen, Impact of wind waves on the air-sea momentum fluxes for different wind and sea state conditions and oceanic responses, 1st International Workshop on waves, storm surges and coastal hazards, Liverpool, UK 10-15Sep2017 [pdf document properties: title=Anlass; author=Patrick Kalb-Anlass; datestamp=20/09/2017] |
| FIG | Time series of surge residual | Helgoland? (uncertain if is from ADCP data at FINO1?) | 4-7 Dec 2013 | Staneva J, C Schrum, A Behrens, S Grayek, H Ho-Hagemann, V Alari, O Breivik, J-R Bidlot, A North Sea-Baltic Sea Regional Coupled Models: Atmosphere, wind waves and ocean, in Proceedings of the Eighth EuroGOOS International Conference (Operational Oceanography, Serving Sustainable Marine Development), 3-5 October 2016, Bergen, Norway, 2017b |
| FIG | Time series of water level | Pellworm Anleger | 5-6 Dec 2013 | Dreier, Norman and Peter Froehle, Operational wave forecast in the German Bight as part of a sensor- and risk based early warning system, In: J-S Shim, I Chus, HS Lim (ed), Proceedings from the International Coastal Symposium (ICS) 2018 (Busan, Republic of Korea), Journal of Coastal Research, Special Issue No. 85, 1161-1165, 2018 |
| TEXT | Water level and surge at Southend on two tidal cycles | Southend | 5-6 Dec 2013 | Environment Agency, Thames Barrier Project Pack 2018, January 2018 |
| TABLE | Maximum water level 2.1m | Hvide Sande | 5-9 Dec 2013 | Kystdirektoratet, Shoreface nourishment effects. An analysis of the 2011 nourishment performed at Skodsbjerge, Kystdirektoratet, Højbovej 1, 7620 Lenvig, Dec 2018 [pdf document properties: title=Shoreface nourishment effects_Skodsbjerge_20.12.2018, datestamp=20/12/2018] |
Table S15. Water current information (arranged by year and then alphabetically)

| Data type          | Location                       | Full Reference and Notes |
|--------------------|--------------------------------|--------------------------|
| [FIG] Time series of the ADCP water currents at 4, 6, 14m | FINO1                   | 1-7 Dec 2013; Steineva J, H Guenther, O Krueger, C Schrumm, V Alari, O Breivik, J-R Bidlot, K Mogensen. Impact of wind waves on the air-sea momentum fluxes for different wind and sea state conditions and oceanic responses, 1st International Workshop on waves, storm surges and coastal hazards, Liverpool, UK. 10-15Sep2017 | 
| [FIG] Time series of water level, astronomical tide, surge residual | Hamburg St Pauli         | 5-6 Dec 2013; Schenk, L and S Mueller-Navarra. 3.4.4. Windstaatsstatiken und Häufigkeit von Sturmfluten 2012-2015 https://www.bsh.de/DE/PUBLIKATIONEN/Nordseezustand_Aktuell/Anlagen/Downloads/3_4_4_Windstaatsstatiken.pdf?__blob=publicationFile&v=2 | 
| [TEXT] Maximum water level | Ostend Belgium and Viken Hoganas Kommune | 5-6 Dec 2013; Wikipedia, Stormen Sven, Bodil, https://da.wikipedia.org/wiki/Stormen_Bodil#cite_note-39 (accessed 02Oct2019) | 
| [FIG] Map with maximum water levels printed | Kingston-upon-Hull, Immingham, Cromer, Lowestoft, Harwich, Sheerness, Dover | 5-6 Dec 2013; JBA Risk Management, Storm Xaver 2013. Event Commentary, 2020. [PDF document properties: author=Cameron Whitlam] | 
| [TABLE] Maximum water levels with times | Lerwick, Wick, Aberdeen, Leith, North Shields, Whiteby, Immingham, Cromer, Lowestoft, Harwich, Sheerness, Herne Bay, Dover, Ostend, Borkum, Heligoland Binnenhaven, Cuxhaven, Hirtshals, Gothenburg, Torshaven | 5-6 Dec 2013; WIKI, Cyclone Xaver, https://en.wikipedia.org/wiki/Cyclone_Xaver accessed 24Jan2020 | 
| [TABLE] Maximum water levels with an astronomical tide, skew surge, and return period | Dover, Immingham, Whiteby, North Shields, Lowestoft, Liverpool, Newhaven, Leith, Aberdeen, Llandudno, Portsmouth, Ullapool | 5-6 Dec 2013; Surgewatch, Storm event 6th December 2013, https://www.surgewatch.org/events/1/ (last accessed 04Mar2020) | 
| [TEXT] Maximum water level 1.2m over normal | Goteborg | 6 Dec 2013 1800M; Wikipedia, Stormen Sven, https://sv.wikipedia.org/wiki/Stormen_Sven#cite_note-15, accessed 29Apr2020 | 

Table S16. Return period of water level; ranking of water level

| Source                      | Full Reference and Notes |
|-----------------------------|--------------------------|
| Bloomberg (2013)            | Bloomberg, Hamburg has worst flood in 37 year amid European storms, Nicholas Brautlecht, 6Dec2013, 02:58PM GMT https://www.bloomberg.com/news/articles/2013-12-06/hamburg-has-worst-flood-in-37-years-as-storms-rage-across-europe | 
| Gccapitalideas (20131209)   | gccapitalideas, Windstorm Xaver, 9Dec2013, https://www.gccapitalideas.com/2013/12/09/windstorm-xaver/ | 
| Kunz et al (20131206)       | Kunz M, B Muehr, K Schroeter, T Bessel, S Moehrle, T Muenzberg, S Breivik, H-M Schmidt, Winterstorm Xaver - Report, 06Dec2013 - Report No.1, Situation Report - 19:00CET, CEDIM Forensic Disaster Analysis Group (FDA), Center for Disaster Management and Risk Reduction Technology. -Rank 2 water level Hamburg St Pauli after 03 Jan 1976; measurement start 1825 -New records: Dagebüell, Husum, Buesum, Eidersperwerk, Cuxhaven | 
| N LWKN (2013)               | NLWKN, Schwere Sturmflut gut Ueberstanden, Wasserstaende zwischen Zweieinhalbe und Knapp vier metern registriert // presseinformation von 6. Dezember 2013, (Ansprechpartnerin: Herma Heyken), 06/12/2013. -list of skew surges for station on Niedersachsen coast with comparison ranking with 2006 and 1962 events. | 
| NOS (20131206)              | NOS, Hoogste waterstand sinds 1953, 06/12/2013, 09:52; https://nos.nl/artikel/583218-hoogste-waterstand-sinds-1953.html | 
| Oceanografisch Meteorologisch Station (2013) | Oceanografisch Meteorologisch Station, Stormverslag 05-06 december 2013, 26pp, 2013 | 
| SMHI (20131210)             | SMHI, Stormen Sven gav nyt vattenstandsrekord i Oresund, https://www.smhi.se/nyhetsarkiv/stormen-sven-gav-
Unwetterzentrale (2013/12)

Unwetterzentrale, Orkanvorf XAVER - ein weiterer schwerer Wintersturm der letzten Jahrzehnte, Thomas Saver et al. from Laps, Dec. 2013 http://www.unwetterzentrale.de/uwz/928.html
-Flood level Hamburg-St Pauli was second highest since 3 Jan 1976
-Storm Xaver belongs to the strongest storm occurrence in the past decades

The Lowestoft Journal (2013/12/12)

The Lowestoft Journal, Suffolk MP hits out at environment secretary in statement about the floods, 14Dec2013, correspondent: Annabelle Dickson.
-UK environment minister Owen Patterson claims surge was freak event with 1 in 500y return period
-PM Peter Aldous points out last surge was 6 years previously

ABPmer (2014)

ABP mer, Ensuring Flood Resilience. An overview of the 5/6 December 2013, Associated British Ports, Marine Environmental Research, July, 2014
-water level ranking: Lerwick, Wick, Aberdeen, Leith, North Shields, Immingham, Cromer, Lowestoft, Dover.
-return period: Immingham, Lowestoft

CH2MHill Halcrow (2014)

CH2MHill Halcrow, Cell 1 Regional Coastal Monitoring Programme, Wave Data Analysis Report 2: 2013-2014, Final Report, March 2014 [document properties: author=Andy.Parson@ch2m.com; datestamp: 04/04/2014]
-North Shields tide gauge water level: return period 1 in 200y to 1 in 500y
-Whitby tide gauge water level: 1 in 100y to 1 in 500y
-Scarborough tide gauge water level: 1 in 150y to 1 in 500y

Dunbar et al. (2014)

Dunbar I, N Flippins, M Szymy, Rok Nexus. After the storm: how the UK’s flood defences performed during the surge following Xaver, Flood resilience review 09/14, Zurich Insurance Company Ltd., Mythenquai 2, 8002, Zurich, Switzerland [document properties: date 28Aug2014; author= Zurich] -1953 surge was most serious for at least 250years.
-Thomas Barries designed to handle 1 in 1000y event taking climate change and sea level rise into account
-400 000 people in Hull area no protected for 1 in 100y standard
-Warrington Water Scheme designed to provide protection, at 1 in 100 year standard.

Eriksen (2014)

Eriksen J, Rekordvandstande i Isefjorden og Roskilde Fjord, Vejret, 138, 2 40
-roskilde water level at 100-200y return level

Gautier et al (2014)

Gautier C, A Camarena, J van Nieuwkoop, SWAN hindcasts Wadden Sea, December 2013. Tidal inlet of Ameland and eastern Wadden Sea. Deltaries, 2014, 197pp. Project 1209433-007, Reference 1209433-007- HYE-0005-maximum water level Delfzijl assessed at 1 in 50y to 1 in 100 year recurrence interval

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-Beschilderung van de hydrometrische gebeurtenissen, Versie 4.0. WL Rapporten, 00-119, Waterbouwkundig Laboratorium, Antwerpen, Belgie. October 2014, WL2014R00_119_5 [document date stamp: 15Oct2014; author= Deschamps, Maarten]-Antwerp water level at 4-5 year return level

Nossent et al (2014)

Nossent J, L Boreckx, E Taverniers, M Deschamps, T Verwaest, F Mostaert, Sinterklaasstorm 6 december 2013. Beschrijving van de hydrometrische gebeurtenissen, Versie 4.0. WL Rapporten, 00-119, Waterbouwkundig Laboratorium, Antwerpen, Belgie. October 2014, WL2014R00_119_5 [document date stamp: 15Oct2014; author= Deschamps, Maarten]-Antwerp water level at 4-5 year return level

Pelt (2014)

Pelt AS, BODILs stormflood in de indre dansk farvande, Vejret, 138, 24-29, 2014-
-ranking 1 water levele: Roskilde Havn, Hornbaek, Klampenborg, Tolboden, Sjaellands Odde, Odense Fjord-
-ranking 2 water levele: Grenaa
-5 surge events in Kopenhagen at 1.7m level of Bodil since 1600

RMS (2014)

RMS, 2013-2014 Winter Storms in Europe. An Insurance and Catastrophe Modeling Perspective. RMS White Paper. [PDF TIMESTAMP 11Mar2014]-Overtopping of defences indicates that East Coast defences could not withstand a stronger storm at 1 in 1000 year level

RWS (2014a)

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-Delfzijl: previous water level record exceed 1cm during Storm Xaver; expected 15 times per 1000 years-
-Vissoptingen: highest water level since 1953; expected once in 20y-
-29, 2014-
-ranking 1 water levele: Roskilde Havn, Hornbaek, Klampenborg, Tollboden, Sjaellands Odde, Odense Fjord-
-ranking 2 water levele: Grenaa
-5 surge events in Kopenhagen at 1.7m level of Bodil since 1600

RWS (2014b)

RWS, Stormvloedrapport van 5 t/m 7 december (SR91) Sint-Nicolaaasvloed 2013, Watermanagementcentrum Nederland, Rijkswaterstaat, prepared by Ing. J. Kroos, 19 Mar 2014a, 48 pp-
-high water per 1000 years: Den Helder 240, Harlingen 130, Delfzijl 15, Vlissingen 53, Roomspot buiten 79, Hoek van Holland 120, Dordrecht 130

Van Rooinen and Oost (2014)

Van Rooinen A, A Oost, Memo: Regionale advisering Ameland Noordwest, Deltaries, 1209381-008-ZKS-0008, 18pp, 15Dec2014 [PDF document properties: tril=Regional advisering: Ameland NL; author=Arnold van Rooinen; keywords: 1209381-008-ZKS-0008; date stamp: 18/12/2014]-Xbeach model study of beach erosion for water levels at different return periods to 1 in 1000 year event-
-Storm Xaver was a 10 year storm in the these simulations

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-Emden return period >20y-
-Cuxhaven return period 2-20 years

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-Storm Xaver water level rank 1 even in most tide gauge stations in UK

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-sea level for 5-6Dec2013 and 3Jan2014 were in top 10 water levels of 96 surge events in data base for last century

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-calculated return period of absolute water level

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-FIG15. (return period) Statistical analysis of return periods of extreme water levels at (a) Immingham and (b) Lowestoft. Analysis based on one maximum annual sea level value AMAX (black squares) or skew surge joint probability method (green squares). Open circles show 10 highest water levels on record (documented at http://www.ntlsf.org/data/uk-network-real-time). Central point in circle indicates reported landscape change and/or significant coastal flooding. 1953 and 2013 storm surge maximum water levels indicated by a red circle
-Whitby to Lowestoft: return periods 1 in 200y to 1 in 1000y
-Whitby, Immingham: ~100y flooding events

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-water level for Dec2013 corresponded to 50 year flood event
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-return period of waters referenced to 2008 (because of significant sea level rise; 2008 sea level 0.1m higher than 1953 levels)

Wadey et al (2015b) - Wadey MP, JM Brown, ID Haigh, T Dolphin, P Wise, Assessment and comparison of extreme sea levels and waves during the 2013/2014 storm season in two UK coastal regions, Nat. Hazards Earth Syst. Sci. Discuss., 3, 2665-2708, 2015b.
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-Sizewell: return period waves <1year
-Liverpool: return period water level 44 years
-Liverpool: return period waves 5 years
-Tabulated curve for return periods of water level (Liverpool, Lowestoft) and waves (Sizewell, Lowestoft)

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-return period Immingham=787 years
-return period Lowestoft=188 years

Dangendorf et al (2016) - Dangendorf S, A Arns JG Pinto, P Ludwig, J Jensen, The exceptional influence of storm 'Xaver' on design water levels in the German Bight, Environmental Research Letters, 11, 2016, 054001
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-return period models including Storm Xaver resulted in 40cm increase in 200 year design water levels for stations in Lower Saxony; station in Schleswig-Holstein had slight decrease in design water levels.
-Important to reassess return water levels during lifetime of coastal protection structure.

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-https://confluence.ecmwf.int/pages/viewpage.action?pageId=28315390
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Matelski (2016) - Matelski, Birgit, Erfahrungen aus der Sturmflut Xaver von 5. und 6.12.2013 und dem Weihnachtshochwasser 2014 in Schleswig-Holstein, IWASA 2016 Tagungsbeitrag. (46. IWASA, 7-8 Januar 2016; Internationales Wasserbau-Symposium Aachen. [pdf document properties: author=sonja; datestamp=26/4/2016]
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-highest ever water levels at Hornbaek & Copenhagen (series 1890-2015)

Sorensen et al (2016) - Sorensen CS, NK Dronen, P Knudsen, J Jensen, P Sorensen, An extreme event as a games changer in coastal zone management, Journal of Coastal Research, (Special Issue, No 75), 700-704, 2016. Proceedings of the 14th International Coastal Symposium (Sydney, Australia) ed by A Vila-Concejo, E Bruce, DM Kennedy, RJ McCarron.
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-Storm 'Xaver' water levels presented with return period analysis curves.
Table S17. Return period of wind speed; ranking of wind speed

| Source | Full Reference and Notes |
|--------|-------------------------|
| Winther-Jensen and Jorgensen (1999) | Winther-Jensen, M and ER Jorgensen, When real life wind speed exceeds design wind assumptions, 1999 European Wind Energy Conference, 1-5 March 1999, Nice, France pp.220-223. |
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| Kunz et al (20131206) | Kunz M, B Muehr, K Schroeter, T Bessel, S Moehrle, T Muenzberg, Storm Xaver wind speed reached the 2-10 year level. |
| Pelt (2014) | Pelt AS, BODIL's stormflood i de indre dansk farvande, Vejret, 138, 24-29, 2014 |
| SMHI (20140703) | SMHI, Simone, Hilde, Sven och Ivar okt-dec 2013, 3 Jul 2014, https://www.smhi.se/kunskapsbanken/metereologii/simone-hilde-sven-och-ivar-okt-dec-2013-1.76183 |
| Ribeiro et al (2017) | Ribeiro R, R Rudge, D Rucinska, Analysis of physical factors of the windstorm Xaver in Poland: post-hazard review, Weather, 72, 2017, pp.378-382 |

Table S18. Storm trajectory map (arranged by year and then alphabetically)

| Source | Full Reference and Notes |
|--------|-------------------------|
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| KNMI (2013) | KNMI, News report. De Zware storm van 5 december, 06 Dec 2013, https://www.knmi.nl/over-het-knmi/zieuwde/zieuwde-storm-van-5-december |
| Oceangrafisch Meteorologisch Station (2013) | Oceangrafisch Meteorologisch Station, Stormverslag 05-06 december 2013, 26pp, 2013 [pdf document properties: author=Myriam Sys; dateset=15Dec2013] |
| Unwetterzentrale (2013) | Unwetterzentrale, Orkantief XAVER - ein weiterer schwerer Wintersturm der letzten Jahrzehnte, Thomas Savert and Stefan Lapx, Dec 2013. http://www.unwetterzentrale.de/uwz926.html |
| Goennert et al (2014) | Goennert G, O Mueller, M Schaper, K Sossidi, Die Sturmflut nach dem Tief Xaver von 5. bis 7. Dezember 2013. Berichte des Landesbetriebes Strassen, Bruecken und Gewaesser (LSBG), Freie und Hansestadt Hamburg, Nr. 16/2014, 26pp. |
| RMS (2014) | RMS, 2013-2014 Winter Storms in Europe. An Insurance and Catastrophe Modeling Perspective. RMS White Paper. [PDF TIMESTAMP 11Mar2014] |
| RWS (2014b) | RWS, Stormvloedrapport van 5 t/m 7 december (SR91) Sint-Nicolaasvloed 2013, Watermanagemenntcentrum Nederland, Rijkswaterstaat, prepared by Ing. J. Kroos, 19 Mar 2014b, 46 pp |
| Carrion (2015) | Carrion Aretxabala, BI, Morphological impact of the Sinterklaas storm at Het Zwin. Numerical modelling with Xbeach, M.Sc. Civil Engineering, Delft University of Technology, 2015. |
| Fenoglio-Marc et al (2015) | Fenoglio-Marc L, R Scharroo, A Annuziato, L Mendoza, M Becker, J Lililbridge, Cyclone Xaver seen by geodetic observations, SUPPORTING MATERIAL, Geophys Research Letters, 42, 9925-9932, 2015 |
| Wadey et al. (2015) | Wadey MP, ID Haigh, RJ Nichols, JM Brown, K Horsburgh, B Carroll, SL Gallop, T Mason, E Bradshaw, A comparison of the 31 January-1 February 1953 and 5-6 December 2013 coastal flood events around the UK, UK Frontiers in Marine Science, 2, 84, 2015. |
- FIG1b: Storm Xaver storm track on map with rectilinear latitude-longitude coordinates.

Cheliotis et al (2016)  
Cheliotis, I. G. Varlas, K. Christakos, The impact of cyclone Xaver on hydropower potential in Norway, conference paper, September 2016 In: T Karedas, A Bais, PT Nastos (ed), Perspectives on Atmospheric Sciences, Springer, Cham. 2017 https://doi.org/10.1007/978-3-319-35095-0_25, first online 10Sep2016 [pdf document properties: author=Konstantinos Christakos; dastestamp: 07/09/2016]  
- FIG3. Mean sea level pressure track of cyclone Xaver as simulated by WRF

Christakos et al (2016)  
Christakos K, I Cheliotis, G Varlas, GJ Steeneveld, Offshore wind energy analysis of Cyclone Xaver over North Europe, 13th Deep Sea Offshore Wind R&D Conference, EERA DeepWind2016, 20-22 January 2016, Trondheim, Norway, Energy Procedia, 94, 37-44, 2016.  
-FIG4. Mean sea level pressure in hPa and maximum WPD in kW/m2 at 100m tracks for cyclone Xaver as simulated by the WRF model

Dangendorf et al (2016)  
Dangendorf S, A Arns JG Pinto, P Ludwig, J Jensen, The exceptional influence of storm 'Xaver' on design water levels in the German Bight, Environmental Research Letters, 11, 2016, 054001  
-FIG3. Storm Xaver trajectory from CCLM model and ERA-Interim at 6h intervals on rectilinear coordinates

Table S19. Unusual pressure drop; time series central pressure; explosive characteristics (arranged by year and then alphabetically)

| Source | Full Reference and Notes |
|--------|--------------------------|
| Air Worldwide (20131212) | Air Worldwide, Press Release, Boston, 12Dec2013. https://www.air-worldwide.com/In-the-News/AIR-Estimates-Losses-from-European-Windstorm-Xaver-at-Between-EUR-700-Million-and-EUR-1-4-Billion/ (accessed 02Jan1999) |
| Kunz et al (20131206) | Kunz M, B Muehr, K Schroeter, T Bessel, S Moehrle, T Muenzberg, S Brink, H-M Schmidt, Winterstorm Xaver - Report, 06Dec2013 - Report No.1, Situation Report - 19:00CET, CEDIM Forensic Disaster Analysis Group (FDA), Center for Disaster Management and Risk Reduction Technology, -Xaver started between Newfoundland and Greenland with pressure 1015hPa -pressure 975 hPa 5Dec2013 0700CET; decrease >25hPa in 24h; 17.1hPa in 3h |
| Oceanografisch Meteorologisch Station (2013) | Oceanografisch Meteorologisch Station, Stormverslag 05-06 december 2013, 26pp, 2013 [pdf document properties: author=Myriam Sys; dastestamp=15Dec2013] -description of central pressure evolution |
| Bancroft (2014) | Bancroft, George F, Marine Weather Review - North Atlantic Area, September through December, Mariners Weather Log, volume 58, No.1, April 2014, pp.33-40 -low pressure deepened by 44 hPa in 24h |
| Hewson et al (2014) | Hewson T, L Magnusson, O Breivik, F Praes, T Muenzberg, Winterstorm Xaver - ECWMF Newsletter, No 139, pp 22-28, Spring 2014. -5 h deepening of 13 hPa 5Dec2013 0000-0600UTC -maximum 24h deepening about 44hPa, which is extreme -minimum central pressure 961hPa 1800UTC 5Dec2013 |
| RMS (2014) | RMS, 2013-2014 Winter Storms in Europe. An Insurance and Catastrophe Modeling Perspective. RMS White Paper. [PDF TIMESTAMP 11Mar2014] -Storms Xaver and Christian had low pressure center to east of UK; they were intensifying storms. |
| RWS (2014b) | RWS, Stormversoepers rapport 5 t/m 7 december (SR91) Sint-Nicolaasvlied 2013, Watermanagementcentrum Nederland, Rijkswaterstaat, prepared by Ing. J. Kroos, 19 Mar 2014b, 48 pp -usually fast drop of the central pressure by more than 25hPa in 24h |
| Axer et al (2015) | Axer T, T Bistry, M Klawa, M Mueller, M Suess, Deutsche Ruck Sturm dokumentation 2013 Deutschland, 2013, Deutsche Rueckversicherungs-Aktiengesellschaft, Hansaullee 177, 40549 Duesseldorf, www.deutschereueck.de [pdf document information: author=filiz; date stamp=07Aug2015] -description of rapid pressure drop during Xaver |
| Dan et al (2015) | Dan, Sebastian, Anne-Lise Montreuil, Rosalita Delgado, Tomas van Oyen, Large storm impact on a beach under sand nourishments, The Proceedings of the Coastal Sediments 2015, edited by Ping Wang, Julie D Rosati, and Lise Montreuil, Robert, 2015, pp. 130-139 -atmospheric pressure on 3Dec dropped to 1012 hPa from 1030 hPa one day before |
| Fenoglio-Marc et al (2015b) | Fenoglio-Marc L, R Scharroo, A Annuzziato, L Mendoza, M Becker, J Lillibridge, Cyclone Xaver seen by geodetic observations, SUPPORTING MATERIAL, Geophys Research Letters, 42, 9925-9932, 2015b -map of trajectory of low pressure center with minimum pressures indicated |
| Dangendorf et al. (2016) | Dangendorf S, A Arns JG Pinto, P Ludwig, J Jensen, The exceptional influence of storm 'Xaver' on design water levels in the German Bight, Environmental Research Letters, 11, 2016, 054001 -core pressure decreased from the 999hPa to 961hPa in 24h; explosive characteristics (Sanders and Gyakum, 1980) |
| JBA Risk Management (2020) | JBA Risk Management, Storm Xaver 2013. Event Commentary, 2020. [PDF document properties: author=Cameron Whitmarsh] -reference to explosive cyclogenesis |

Table S20. Squall line, convective thunderstorms, tornadoes (arranged by year and then alphabetically)

| Source | Full Reference and Notes |
|--------|--------------------------|
| Unwetterzentrale (201312) | Unwetterzentrale, Orkantief XAVER - ein weiterer schwerer Wintersturm der letzten Jahrzehnte, Thomas Saxvert and Stefan Laps, Dec. 2013 http://www.unwetterzentrale.de/uxz/928.html -lightning activity in the squall line with extremely strong high (850hPa) 130-170km/h winds to the surface -already on morning Thursday 5Dec2013 convection front with strong lightning activity -05Dec2013 17:00 convection front on line Netherlands to Munsterland & Weserbergland; only few lightning |
### Table S21. Lightning (arranged by year and then alphabetically)

| Source | Full Reference and Notes |
|--------|--------------------------|
| Van Dorland (2014) | van Dorland, R, Zware storm op 5 december, Zenit, p43, Januari 2014 - map showing time of passage of lightning systems across the Netherlands from the KNMI lightning detection network. |
| Caithness Windfarm | Caithness Windfarm, craigdr, Detailed accidents to 31 December 2015. Document time stamp 5Jan2016, 175pp - reference to tornado threat in Poland; worst ever tornado Lublin 20July 1931 with 111 m/s |
| WIKI (20200502) | WIKI, Cyclone Xaver, https://en.wikipedia.org/wiki/Cyclone_Xaver accessed 24Jan2020 |

### Table S22. Meso-vortex (arranged by year and then alphabetically)

| Source | Full Reference and Notes |
|--------|--------------------------|
| Hewson et al. (2014) | Hewson, T, L Magnusson, O Breivik, F Prates, I Tsonevsky, HW de Vries, Windstorms in north-west Europe in late 2013. ECMWF Newsletter, No 139, pp.22-28, Spring 2014. -...intense meso-vortex hanging back to the west of the main low for a time, and this enhanced the strong wind swath running into western Scotland |

### Table S23. Meteotsunami (arranged by year and then alphabetically)

| Source | Full Reference and Notes |
|--------|--------------------------|
| Goennert et al (2001) | Goennert G, SK Dubé, T Murthy, W Siefert (2001): 7. Storm surges generated by extratropical cyclones - case studies. In: Die Kueste 63 Sonderheft. Heide, Holstein: Boyens. pp 455-546 -... -Berwind, N, C Sienkiewicz, A Jönsson, P de Vries, Storm surges generated by extratropical cyclones in the North Sea: northern part of the North Sea - Numerical simulation of storm surge generation in the German Bight using a nested model setup |
| McGarricle et al (2013) | McGarricle P (ed), UK coastal monitoring and forecasting: Annual report for 2013 for the UK National Tide Gauge Network, NERC 100017897, 2013 [pdf document properties: author=pamcg; created=16Apr2014] - Aberdeen: water level max 05Dec2013 15:00; min 06Dec2013 21:30 - Dover: surge max 06Dec2013 00:45; min 05Dec2013 13:00 - Dover: water level max 06Dec2013 00:45; min 07Dec2013 09:15 - Immingham: surge max 05Dec2013 17:30; min 05Dec2013 13:00 - Immingham: water level max 05Dec2013 19:15; min 05Dec2013 13:00 - Leith: surge max 05Dec2013 12:45; min 05Dec2013 08:00 - Leith: water level max 05Dec2013 15:15; min 05Dec2013 09:00 - North Shields: surge max 05Dec2013 15:15; min 05Dec2013 08:30 - North Shields: water level max 05Dec2013 16:15; min 07Dec2013 00:30 - Whitby: surge max 05Dec2013 15:45; min 05Dec2013 09:45 - Whitby: water level max 05Dec2013 17:15; min 07Dec2013 00:30 - Wick: water level max 05Dec2013 12:45; min 06Dec2013 20:00 |
| Pelt (2014) | Pelt AS, BODIL's stormflood i de indre dansk farvande, Vejret, 138, 24-29, 2014 - water rose suddenly with character of little flood wave at Torsminde |
-seiches or svkelper; water masses in motion between Kattegat and Nord Sjælland

RWS (2014b) RWS, Stormvloedrapport van 5 t/m 7 december (SR91) Sint-Nicolaasvloed 2013, Watermanagementcentrum Nederland, Rijkswaterstaat, prepared by Ing. J. Kroos, 19 Mar 2014b, 48 pp
 -burseit/metaotsunami assessed for Hoek van Holland soon after cold front passage; 70 cm amplitude, 1 h FWHM

DEMA (2018) Danish Emergency Management Agency DEMA, National Risk Profile for Denmark, April 2018
 -mention of general metaotsunami threat for Denmark

Wikipedia (20200429) Wikipedia, Stormen Sven, https://sv.wikipedia.org/wiki/Stormen_Sven#cite_note-15, accessed 29Apr2020
 -restaurende in Helsingborg with windows stove in by wave and flooded

Table S24. Infragravity wave (arranged by year and then alphabetically)

| Source | Full Reference and Notes |
|--------|--------------------------|
| Oceanografisch Meteorologisch Station (2013) | Oceanografisch Meteorologisch Station, Stormverslag 05-06 december 2013, 26pp, 2013 | [pdf document properties: author=Myriam Sys; datestamp=15Dec2013] |
| Gautier & al (2014) | Gautier C, A Camarena, J van Nieuwkoop, SWAN hindcasts Wadden Sea, December 2013. Tidal inlet of Ameland and eastern Wadden Sea. Deltares, 2014, 197pp. Project 1209433-007, Reference 1209433-007-HYE-0005 |
| Carrion (2015) | Carrion Aretxabala, BL Morphological impact of the Sinterklaas storm at Het Zwin. Numerical modelling with Xbeach, M.Sc. Civil Engineering, Delft University of Technology, 2015 |
| Wahle & al (2017) | Wahle K, J Staneva, W Koch, I Fenoglio-Marc, HTM Ho-Hagemann, EV Stanev, An atmosphere-wave regional coupled model: improving prediction of wave heights in the southern North Sea, Ocean Sci., 13, 289-301, 2017.(doi:10.5194/os-13-289-2017) |

Table S25. Wave dynamics and dike breaches; wave runup studies (arranged by year and then alphabetically)

| Source | Full Reference and Notes |
|--------|--------------------------|
| Sueddeutsche Zeitung (20131215) | Sueddeutsche Zeitung, Xaver holte sich Land: Sturmschaden auf Sylt, 15Dec201315:36
 -https://www.sueddeutsche.de/panorama/sturmschaden-auf-sylt-xaver-holte-sich-land-1.1844100 |
| Carrion (2015) | Carrion Aretxabala, BL Morphological impact of the Sinterklaas storm at Het Zwin. Numerical modelling with Xbeach, M.Sc. Civil Engineering, Delft University of Technology, 2015 |
| Brooks et al (2016) | Brooks SM, T Spencer, A McIvor, I Möller, Reconstructing and understanding the impacts of storms and surges, southern North Sea, Earth Surface Processes and Landforms, 41, 855-864, 2016 |
| Dreier and Froehle (2018) | Dreier, Norman and Peter Froehle, Operational wave forecast in the German Bight as part of a sensor- and risk based early warning system, In: J-S Shim, I Chun, HS Lim (ed), Proceedings from the International Coastal Symposium (ICS) 2018 (Busan, Republic of Korea), Journal of Coastal Research, Special Issue No. 85, 1161-1165, 2018 |
| Surfegwatch (20200304) | Surfegwatch, Storm event 6th December 2013, https://www.surfegwatch.org/events/1/ (last accessed 04Mar2020) |

Table S26. Precipitation, river level dike breaches (arranged by year and then alphabetically)

| Source | Full Reference and Notes |
|--------|--------------------------|
| Goennert et al (2014) | Goennert G, O Mueller, M Schaper, K Sossidu, Die Sturmflut nach dem Tief Xaver von 5 bis 7. Dezember 2013. Berichte des Landesbetriebes Strassen, Bruecken und Gewaesser (LSBG), Freie und Hansestadt Hamburg, Nr. 162014, 26pp |
| | -precip Hamburg-Fuhlsbuettel 5Dec2013 11.9mm; no information that this contributed to Elbe water levels at Hamburg |
| Nossent et al (2014) | Nossent J, L Boeckx, E Taverniers, M Deschamps, T Verwaest, F Mostaert, Sinterklaastorm 6 december 2013. Beschrijving van de hydrometrische gebeurtenissen, Versie 4.0, WL Rapporten, 00-119, Waterbouwkundig Laboratorium, Antwerpen, België. October 2014, WL2014R00_119_5 | [document date stamp: 15Oct2014; author= Deschamps, Maarten] |
| | -focus on Belgian precipitation and river heights/flow in Antwerp estuary during Storm Xaver |
Table S27. Unusual peak of significant wave height in northern North Sea (arranged by year and then alphabetically)

| Source | Full Reference and Notes |
|--------|--------------------------|
| Wahle et al (2017) | Wahle K, J Staneva, W Koch, L Fenoglio-Marc, HTM Ho-Hagemann, EV Stanev, An atmosphere-wave regional coupled model: improving prediction of wave heights in the southern North Sea, Ocean Sci., 13, 289-301, 2017. (doi:10.5194/os-13-289-2017). - unusual peak in altimeter-derived significant wave height 58-59N in northern North Sea |

Table S28. Double surge peak from wind and travelling wave (arranged by year and then alphabetically)

| Source | Full Reference and Notes |
|--------|--------------------------|
| Wahle et al (2017) | Wahle K, J Staneva, W Koch, L Fenoglio-Marc, HTM Ho-Hagemann, EV Stanev, An atmosphere-wave regional coupled model: improving prediction of wave heights in the southern North Sea, Ocean Sci., 13, 289-301, 2017. (doi:10.5194/os-13-289-2017). - external surge from Aberdeen and Lowestoft caused second storm surge maximum in the German Bight - as demonstrated by Staneva et al (2016), the wave induced mechanisms contributed to a persistent increase in the surge after the first maximum |
| Niehuser et al (2018) | Niehuser S, D Dangendorf, A Arns, J Jensen, A high resolution storm surge forecast for the German Bight, Conference: 9th Chinese-German Joint Symposium on Coastal and Ocean Engineering, Tainan, Taiwan, 2018 - double peak of true surge from wind effect and travelling surge wave |

Table S29. Modelled turbulence kinetic energy in wave model (arranged by year and then alphabetically)

| Source | Full Reference and Notes |
|--------|--------------------------|
| Gautier et al (2014) | Gautier C, A Camarena, J van Nieuwkoop, SWAN hindcasts Wadden Sea, December 2013. Tidal inlet of Ameland and eastern Wadden Sea. Deltares, 2014, 197pp. Project 1209433-007, Reference 1209433-007-HYE-0005 - wave dissipation in the SWAN model of the Wadden Sea |
| Staneva et al. (2016a) | Staneva J, K Wahle, H Guenther, E Stanev, Coupling of wave and circulation models in coastal-ocean predicting systems; a case study for the German Bight, Ocean Sci., 12, 797-806, 2016a - map modelled turbulence kinetic energy produced for Storm Britta with high values along coast |

Table S30. Fatalities & injuries

| Source | Full Reference and Notes |
|--------|--------------------------|
| BBC (20131205) | BBC, In pictures: Winter storm hits UK, 5 December 2013, https://www.bbc.com/news/uk-scotland-25231224 - 2 men killed in UK during the storm FIG4. [PHOTO] Earlier in West Lothian lorry driver dies when vehicle blown over on to two cars (PA) |
| BBC (20131206) | BBC20131206, Deadly storm and tidal surge batter northern Europe, BBC 6 Dec2013 (report by Anna Holligan) - at least 7 people killed - Poland, Poraj: tree blown onto car & 3 people killed - UK: 2 deaths; lorry driver killed when truck overturned near Edinburgh, man crushed by falling tree Nottinghamshire - Denmark: 1 death; woman died after lorry blown over - Sweden: 1 death; 2 sailors swept off ship in southern Sweden, not found by rescue services |
| Bloomberg (2013) | Bloomberg, Hamburg has worst flood in 37 year amid European storms, Nicholas Brautlecht, 6Dec2013, 02:58PM GMT https://www.bloomberg.com/news/articles/2013-12-06/hamburg-has-worst-flood-in-37-years-as-storms- rage-across-europe - 3 people killed Poland |
| Daily Mail (20131206) | Daily Mail, Huge storm strikes Europe causing death and destruction and leading to cancellation of hundreds of flights, 6Dec2013. (correspondent: Nick Enoch), https://www.dailymail.co.uk/news/article-2519517/Huge-storm-strikes-Europe-causing-death-destruction-leading-cancellation-hundreds-flights.html - 7 people killed Europe; 3 in N Poland car accident, 1 in truck overturn Denmark |
| Deutschlander et al (2013) | Deutschlander T, K Frieric, S Haeseler, C Lefebvre, Orkantief XAVER uzeb Nordeuropea von 5. bis 7. Dezember 2013, Deutscher Wetterdienst DWD, Stand 30. Dezember 2013, 19pp. - 10 fatalities across Europe |
| DW (20131205) | DW, Storm Xaver pummels Europe, flood surge feared, 05/12/2013 - driver killed Scotland when truck overturned - scooter rider killed England by falling tree - 72 year old woman killed Denmark when vehicle blown off road |
| Expressen (2013) | Expressen, Flera doda i Sverige efter stormen Sven, 06Dec2013, 17:34 CET - 5 killed in Sweden, mostly by falling trees and branches - two seamen swept off Dutch cargo ship Marietje Andrea off Ystad on Thursday morning; search stopped after 6 h. |
| Gccapitalideas (20131209) | gccapitalideas, Windstorm Xaver, 9Dec2013, https://www.gccapitalideas.com/2013/12/09/windstorm-xaver/ - 8 people killed in storm |
Table S31. Coastal flooding and evacuations (arranged by year and then alphabetically)

| Source | Full Reference and Notes |
|--------|--------------------------|
| BBC (20131205) | BBC, In pictures: Winter storm hits UK, 5 December 2013, https://www.bbc.com/news/uk-scotland-25231224 |
| FIG1 | [PHOTO] Thousands evacuated from homes as storms hit much of UK. Residents on this street in Rhyl, north Wales, rescued by RNLI (Reuters) |
FIG2. [PHOTO] British Red Cross set up rescue centre in the Denbighshire town of Rhyl where 500 people could still be in need of help (Reuters).

FIG10. [PHOTO] Elsewhere in England, high tides followed the storm's tidal surges, battering coastal towns including Blackpool (AP).

FIG11. [PHOTO] The famous Blackpool beach was battered by the tide (AP).

FIG12. [PHOTO] In Merseyside, the storm claimed a pirate ship build earlier this year out of drift wood on New Brighton beach. (Bob Warwick)

FIG13. [PHOTO] This dramatic shot captures the scene on the Wirral as the storm hit the north west of England (Laurra Steen)

BBC (20131206)

BBC20131206, Deadly storm and tidal surge batter northern Europe; BBC 6 Dec 2013 (report by Anna Holligan - BBC, East coast surge: what happened next? (report by Richard Haugh), 5Dec2014)

- Western England: 10000 homes evacuated, Norfolk & Suffolk, houses collapse, Hemsby;
- North Wales: residents rescued by lifeboats on Wednesday and Thursday in Liverpool and Manchester;
- Hamburg: Fish Market and some streets near river flooded;
- Netherlands: limited flooding, sea dykes held; some flooding in Dordrecht and Rotterdam;

Bloomberg (2013)

Bloomberg, Hamburg has worst flood in 37 years amid European storms, Nicholas Brautlecht, 6Dec2013, 02:58PM GMT. https://www.bloomberg.com/news/articles/2013-12-06/hamburg-has-worst-flood-in-37-years-as-storms-rage-across-europe

- Thousands evacuated from coastal areas of UK during night 5-6 Dec 2013;
- Port flooded plus quayside streets & squares;

Daily Mail (20131206)

Daily Mail, Huge storm strikes Europe causing death and destruction and leading to cancellation of hundreds of flights, 6Dec2013. (Correspondent: Nick Enoch), https://www.dailymail.co.uk/news/article-2519517/Huge-storm-stricks-Europe-causing-death-destruction-leading-cancellation-hundreds-flights.html

- Flooding in Hallig area of Germany;

Deutschlander et al (2013)

Deutschlander T, K Frierich, S Haeseler, C Lefebvre, Orkantief XAVER über Nordeuropa von 5. bis 7. Dezember 2013, Deutscher Wetterdienst DWD, Stand 30. Dezember 2013, 19pp.

- Flooding in Hallig area of Germany;

GCCapitalideas (20131209)

gccapitalideas, Windstorm Xaver, 9Dec2013, https://www.gccapitalideas.com/2013/12/09/windstorm-xaver/
- UK: 1400 properties flooded in UK: 400 Humber region, 300 Rhyl North Wales, 300 Boston Lincolnshire, 200 Whithby; also Scarborough, Great Yarmouth, Lowestoft;
- Germany: damage from coast flooding in Hamburg; historic fish market flooded;
- Netherlands: some flooding in Dordrecht, Rotterdam, Vlaardinghen;

Kunz (20131206)

Kunz M, B Muehr, K Schroeter, T Bessel, S Moehrle, T Muenzberg, S Brink, H-M Schmidt, Winterstorm Xaver - Report 06/Dec2013 - Report No.1, Situation Report – 19:00CET, CEDIM Forensic Disaster Analysis Group (FDA), Center for Disaster Management and Risk Reduction Technology;
- Thousands evacuated from lowland areas in UK;
- Fish Market and Elbstrasse in Hamburg completely flooded;
- pollutant release hazard;
- Borkum: evacuation of residents of the roadstead prepared;

Spiegel International (20131206)

Spiegel International, Winter storm Xaver' batters northern Europe; 6 Dec 2013, 12:56PM GMT. https://www.spiegel.de/international/europe/tidal-surge-winter-storm-xaver-batters-northern-europe-a-937576.html

- Fig2. The storm brought rain, hail and snow with the tidal surge, and the German port city of Hamburg seen its worst flooding in decades, forcing authorities to close off parts of the city center on Thursday night.
- Here, woman passes by the storm surge in central Hamburg (DPA);

FIG3. People stand on benches in Hamburg's historic fish market which has been flooded by the Elbe River due to the storm (AP);

FIG4. Floodwaters in Hamburg early on Friday morning. City officials closed off flooded areas and some reportedly had trouble reaching work in the morning (DPA);

FIG6. Streets also flooded in the northern German town of Norddeich on Friday morning (Reuters);

FIG7. Water levels reached what was expected to be their high point in Hamburg on Friday morning, some 6m above level (Reuters);

FIG8. Waves overtake ferry station in the northern German city of Danbeugel on Thursday night (DPA);

FIG9. The pier at the Bensersiel port of lower Saxony was also flooded by the storm surge (DPA);

FIG16. Here waves batter the promenade in Blackpool England on Thursday as the storm hit the UK;

FIG17. Homes on the tiny German island of Langeness as the North Sea rose on Thursday (DPA);

FIG18. Traffic signs on the beach in the German village of Norddeich on Thursday were nearly submerged by the storm surge. (Reuters)

Unwetterzentrale (201312)

Unwetterzentrale, Orkantief XAVER – ein westlicher schwerer Wintersturm der letzten Jahrzehnte, Thomas Savert and Stefan Laps, Dec. 2013 http://www.unwetterzentrale.de/uwz/928.html

- Hamburg hafen: streets & quays flooded

ABPmer (2014)

ABPmer, Ensuring Flood Resilience. An overview of the 5/6 December 2013, Associated British Ports, Marine Environmental Research, July, 2014

- International port flooded;
- Lowestoft flood damage;
- Hull frontage flooded; 115 businesses & 149 residential properties; water level 5.8mODN, 0.4m below crest of Hull Tidal Surge Barrier.

BBC (20141205)

BBC, East coast surge: what happened next? (report by Richard Haugh), 5Dec2014
- Home evacuations: Kent: 500 homes; Lincolnshire: 600 homes; Humber: 400 homes; Jaywick, Essex: 2500 homes
evacuated; Lowestoft, Suffolk: town center flooded
-Hugh Drake, farmer, lost 25 acres of farmland; 2 years before crops can grow because of salt

CH2M Hill Halcrow (2014)

Dunbar et al (2014)

Dunbar I, P Flinn, M Szonyi, Rik Nieuws. After the storm: how the UK’s flood defences performed during the surge following Xaver, Flood resilience review 09.14, Zurich Insurance Company Ltd., Mythenquai 2, 8002, Zurich, Switzerland [document properties: date 28Aug2014; author= Zurich]
-thousands of people evacuated
-XAVER: 1400 flooded homes, 1000 businesses, 3200 ha farmland
-Kingston-upon-Hull new record: 5.8m: significant flooding
-2013 flood: 100 properties flooded & flood protection structures damaged

Eden (201402)

Eden, Phillip, Weather Log December 2013, Weather, Feb 2014, pp.1-iv
-coastal flooding at Boston (Lincs), Jaywick (Essex), Ryhyl (Denbighshire),

Eriksen (2014)

Sorensen J, Rekordvandstande i Isefjorden og Roskilde Fjord, Vejret, 138, 2 40-48, 2014
-map of coastal flooding Roskilde

Goennert et al. (2014)

Goennert G, O Mueller, M Schaper, K Sossidi, Die Sturmflut nach dem Tief Xaver von 5. bis 7. Dezember 2013. Berichte des Landesbetriebes Strassen, Bruecken und Gewaesser (LSBG), Freie und Hanstad Hamburg, Nr. 16/2014, 26pp.
-flooding in Hamburg

Leiding et al (2014)

Leiding T, B Timz, G Rosenhagen, C Lefevre, S Haeseler, S Hagemann, I Bastigkeit, D Stein, P Schwenk, S Mueller, O Outz, K Herklotz, F Kinder, T Neumann, Meteorological and Oceanographic Conditions at the FinO platforms during the severe storms Christian and Xaver, DEWI Magazin, No.44, p16-25, 2014.
-'Hallig lowlands were flooded’

Nossent et al (2014)

Nossent J, L Boeckx, E Taverniers, M Deschamps, T Verwaest, F Mostaert, Sinterklaas-Rapport, March 2014 [document properties: author=filiz; date stamp=07Aug2015]

RMS (2014)

RMS. 2013-2014 Winter Storms in Europe. An Insurance and Catastrophe Modeling Perspective. RMS White Paper. [PDF TIMESTAMP 11Mar2014]
-1400 properties flooded in England and Wales
-flooding on low-lying North Sea islands of Langeness and Hooge near Denmark

Thorne (2014)

Thorne, Colin, Geographies of UK flooding in 2013/4, The Geographical Journal, 180, 297-309, 2014.
-brief outline of east coast areas flooded during storm surge

Axer et al (2015)

Axer T, T Bistry, M Klawo, M Mueller, M Suesser, Deutsche Ruck Sturm dokumentation 2013 Deutschland, 2013,
-Deutseh Ruckversicherung Aktiengesellschaft, Hanssaale 177, 40459 Duesseldorf, www.deutscherueck.de [pdf document information: author=filiz; date stamp=07Aug2015]

Haigh and Bradshaw (2015)

Haigh I and E Bradshaw, A century of UK coastal flooding, Planet Earth, Winter 2015, (pdf document properties: 13Jan2016)
-flooded 2800 homes and 1000 businesses

Kendon and McCarthy (2015)

Kendon M and M McCarthy, The UK’s wet and stormy winter of 2013/2014, Weather, 70, 40-47, 2015
-'several hundred properties on the coasts of eastern England and North Wales were inundated'

Sibley et al (2015)

Sibley A, D Cox, H Tiley, Coastal flooding in England and Wales from Atlantic and North Sea storms during the 2013/2014 winter, Weather, 70, 62-70, 2015
-Newcastle quayside under water at high tide
-Scarborough, Whitby; seafront properties flooded
-* power outages to Whitby making recovery difficult
-Humber estuary towns flooded: Reedness & Goole
-* River Haven at Boston Linolshirne had breaches of sea defences with 200 people evacuated
-thousands of people evacuated East Anglia
-flooding: Great Yarmouth, Lowestoft, Wells-next-the-Sea, Blakeney, Cley
-Hemsby: cliff collapse & lifeboat station destroyed
-several hundred homes evacuated Kent
-risk of flooding Sandwich & Sealsster

Wadey et al (2015a)

Wadey MP, ID Haigh, RJ Nichols, JM Brown, K Horsburgh, B Carroll, SL Gallop, T Mason, E Bradshaw, A comparison of the 31 January-1 February 1953 and 5-6 December 2013 coastal flood events around the UK, UK Frontiers in Marine Science, 2, 84, 2015a.
-listing of flooded areas and evacuations in Wales. Liverpool area, eastern England, Susess/Kent

Wadey et al (2015b)

Wadey MP, JM Brown, ID Haigh, T Dolphin, P Wisse, Assessment and comparison of extreme sea levels and waves during the 2013/2014 storm season in two UK coastal regions, Nat. Hazards Earth Syst. Sci. Discuss., 3, 2665-2708, 2015b.
->2800 properties across UK flooded including >800 in Boston, Lincolnshire
-Suffolk: total of 22 breaches reported across county causing severe flooding; failure of sea defences at Blythburgh
-floods in Mersea estuary: 19 businesses flooded and 4 domestic properties
-Lowestoft: 143 commercial properties, 90 residential properties flooded
-Waveney distric: 170 properties flooded

Sorensen (2016)

Sorensen CS, Water NOT wanted - Coastal floods and flood protection in Denmark, In RA Herrmann & J Jensen (eds), Sicherung von Daemmen, Deichen und Stauanlagen: Handbuch fuer Theorie und Praxis (Vol V pp3-21). Siegen: Universitut Siegen, 2016
-Xaver impacted other parts of Denmark compared with Britta 2006
-some houses uninhabitable for some time and still are
Evans (2017) Evans, Sun Yan, EV2/2 Appendix 1, History of flooding sources, Boston Barrier Transport & Works Act order application, Public Inquiry documents, [pdf document properties: author=BDB; datestamp=16Mar2017] https://consult.environment-agency.gov.uk/engagement/bostonbarriertwo/results/appendix-1—history-of-flooding-sources.pdf -description of flood in Boston UK

DEMA (2018) Danish Emergency Management Agency DEMA, National Risk Profile for Denmark, April 2018 -600 homes destroyed by flooding Denmark -water 2m above normal Roskilde Fjord -major flooding and destruction Holbaek Fjord, Odense Fjord, Isfjord, Copenhagen

Giannopoulos et al. (2019) Giannopoulos G, L Peake, B Reid, J Andrews, A Grant, I Lorenzoni, M Goulden, J Waters, T Dolphin, J Brenner, TJ Tofhurst, Environmental and social impacts of the 2013 storm surge on the North Norfolk coast, powerpoint presentation date stamp 15May2019, unknown conference -coastal floodgates and ecosystem impacts

Rucinska (2019) Rucinska D, Describing Storm Xaver in disaster terms, International Journal of Disaster Reduction, 34, 147-153, 2019 -10000 people evacuated in UK

JBA Risk Management (2020) JBA Risk Management, Storm Xaver 2013. Event Commentary, 2020, [PDF document properties: author=Cameron Whitatham] -Map of number of houses flooded in different areas of UK, Boston worst and & then Humber -1000 businesses & 1400 houses (4200) people flooded in UK

Surgewatch (20200304) Surgewatch, Storm event 6th December 2013, https://www.surgewatch.org/events/1/ (last accessed 04Mar2020) -seawater inundation 1400 homes & 1000 businesses, 3200ha farmland -10000 people evacuated along coast

WIKI (20200124) WIKI, Cyclone Xaver, https://en.wikipedia.org/wiki/Cyclone_Xaver accessed 24Jan2020 -evacuations: Rhyl Wales; Belgium: Bredevene evacuated 2083 residents along Bruges-Ostend canal, people in Great Yarmouth told to prepare to evacuate in case River Yare flooded -flood: Rhyl Wales, Kinmel Bay, Llandulas, Conway, Oban, Port Clarence, Whitby, Scarborough, Bridlington, Cleethorpes, Hull, Paull, N Lincolnshire, Boston, Wells-Next-the-Sea, Lowestoft, Snape on Alde-Ore estuary; Waldringfield on River Deben, Rotterdam, Dordrecht, Vlaardingen

Wikipedia (20200429) Wikipedia, Stormen Bodil, https://sv.wikipedia.org/wiki/Stormen_Bodil#:cite_note-39 (accessed 02Oct2019) -flood of Viking ship museum in Roskilde -Frederikssum & Jyllinge Nordmark 600 families lost their home -in low lying areas was being fought up to a week after the storm -Belgium: evacuation of 2083 people from Bredevene kommune between Sas Slijkens & Spuikeon -flooding: Rotterdam, Dordrecht, Vlaardingen -Tyne flooded its banks -flooding at Port Clarence on Tees -dike break at Greatham Creek report with CH-47 Chinook from RAF -parts of Hamburg flooded

Wikipedia (20200502) Wikipedia, Orkan Xaver, https://de.wikipedia.org/wiki/Orkan_Xaver (accessed 2 May 2020) -parts of Bremen susceptible to surge flooding evacuated -police closed off parts of Hamburg -`Mehrere Halligen meldeten Land unter’- offshore winds Baltic cause low water levels in Flensburger Foerde and Schleimundung -Badewanneeffekt later caused high water levels of 2m above normal Roskilde Fjord

Table S32. Coastal dike heights and protection levels (arranged by year and then alphabetically)

| Source | Full Reference and Notes |
|--------|-------------------------|
| Horner (1979) | Horner RW, The Thames Barrier Project, The Geographical Journal, 145, 242-253, 1979. -Thames Barrier height 7.2 mODN; designed to protect at 1000year return period |
| Goennert et al. (2012) | Goennert G, B Gerkensmeyer, J-M Mueller, Ermittlung des Sturmflutbemesungswasserstandes fuer den offentlichen Hochwasserschutz in Hamburg, Berichte des Landesbetriebes Strassen, Bruecken und Gewaesser Nr 12/2012. -maps of surge flooding protection levels around the North Sea expressed in terms of return period: present and future -London at 1000y level; Netherlandsmajor cities at 10000y level, Belgium at 1000y, UK unknown, Germany unknown, Denmark at 2.5-300 year except Thaboron (1000 year) |
| Gautier et al (2014) | Gautier C, A Camarena, J van Nieuwkoop, SWAN hindcasts Wadden Sea, December 2013. Tidal inlet of Ameland and eastern Wadden Sea. Deltareas, 2014, 197pp. Project 1209433-007, Reference 1209433-007-0005 -maps of the Netherlands showing protections levels expressed as recurrence interval |
| Van Rooijen and Oosten (2014) | van Rooijen A, A Oost, Memo: Regionale advisering Ameland Noordwest, Deltareas, 1209381-008-ZKS-0008, 43pp, 18Dec2014 [PDF document properties: title=Regional advisering: Ameland NW; author=Arnold van Rooijen; keywords: 1209381-008-ZKS-0008; date stamp: 18/12/2014] -lowest level in protective dune line in NW Ameland at 6.5m; 7m summit at east end of dunes |
| Carrion (2015) | Carrion Aretxabal, BI, Morphological impact of the Sinterklaas storm at Het Zwin. Numerical modelling with Xbeach, M.Sc. Civil Engineering, Delft University of Technology, 2015. |
Table S33. Surge barrier closures (arranged by year and then alphabetically)

| Source | Full Reference and Notes |
|--------|--------------------------|
| Air Worldwide (20131212) | Air Worldwide, Press Release, Boston, 12Dec2013. [https://www.air-worldwide.com/In-the-News/AIR-Estimates-Losses-from-European-Windstorm-Xaver-at-Between-EUR-700-Million-and-EUR-1-4-Billion/](https://www.air-worldwide.com/In-the-News/AIR-Estimates-Losses-from-European-Windstorm-Xaver-at-Between-EUR-700-Million-and-EUR-1-4-Billion/) (accessed 02Jan1990) -Thames Barrier closed for 2 days -2m water level difference between front and back of Thames barrier -Hamburg closes all 38 flood gates |
| BBC (20131210) | BBC20131226, Deadly storm and tidal surge batter northern Europe, BBC 6 Dec 2013 (report by Anna Holligan) -Thames Barrier closed for second day to protect London -eastern Scheldt storm surge barrier closed |
| Gccapitalideas (20131209) | gccapitalideas, Windstorm Xaver, 9Dec2013, [https://www.cccapitalideas.com/2013/12/09/windstorm-xaver/](https://www.cccapitalideas.com/2013/12/09/windstorm-xaver/) -Thames Barrier closed -all 38 flood-gates in Hamburg closed -several barriers closed in the Netherlands including the Eastern Scheldt Barrier |
| DW (20131205) | DW, Storm Xaver pummels Europe, flood surge feared, 05/12/2013 -eastern Scheldt barrier closed for the first time in 6 years |
| GVA (20131205) | GVA, Vrij containers even op drift op de Schelde, 05/12/2013 20:57. [https://www.gva.be/cnt/ad1500792/vrij-containers-op-drift-op-de-schelde-2](https://www.gva.be/cnt/ad1500792/vrij-containers-op-drift-op-de-schelde-2) -warnings that storm gates will be closed in Antwerp |
| Kunz et al (20131206) | Kunz M, B Muehr, K Schroeter, T Bessel, S Moehrle, T Muenzberg, S Brink, H-M Schmidt, Winterstorm Xaver - Report, 06Dec2013 - Report No.1, Situation Report - 19:00CET, CEDIM Forensic Disaster Analysis Group (FDA), Center for Disaster Management and Risk Reduction Technology. -Bremen: 50 gates and dike openings closed and flood barrages at Kennedy Bridge; dike being monitored; 28000 sandbags prepared; new Weser dike recently enhanced -Lower Saxony: 9 barrages at Ems, Hunte, Weser, Unterelbe closed; since 2008 >400 million EUR for coast protection -East Frisian Islands: all dike openings closed -Hamburg 38 flood gates closed |
| NLWKN (20131206) | NLWKN, Schwere Sturmflut gut Uberstanden, Waserstaende zwischen Zweineinhalte und Knapp vier metern |
Xaver' batters northern Europe, -m: how the UK's flood defences
haft, Hansaallee 177, 40549 Duesseldorf, -6
-6 barriers on the Elbe closed
-Hunte and Ochturnsperrwerke close
-many barriers to remain closed for next high tide or to be closed again (Emssperrwerke)

NOS (20131206) NOS, Hoogste waterstand sinds 1953, 06/12/2013, 09:52, https://nos.nl/artikel/583218-hoogste-waterstand-sinds-1953.html
-closure of Oosterscheldekering with its 62 gates for first time since 2007

Spiegel International (20131206) Spiegel International, Winter storm Xaver batters northern Europe, 6 Dec 2013, 12:56
https://www.spiegel.de/international/europe/tidal-surge-winter-storm-xaver-batters-northern-europe-a-937576.html
-Thomas Barrier closed late Thursday

ABPmer (2014) A BP mer, Ensuring Flood Resilience. An overview of the 5/6 December, Associated British Ports, Marine Environmental Research, July, 2014
-Thomas Barrier protected 380,000 properties from surge
-tidal defenses at Hull protected 19,000 properties
-’water levels at Hull were recorded as reaching 5.8mODN, 0.4m below crest of the Hull Tidal Surge Barrier’

Nossent et al (2014) Nossent J, L Boeckx, E Taverniers, M Deschamps, T Verwaest, F Mostaert, Sinterklaasstorm 6 december 2013. Beschrijving van de hydrometrische gebeurtenissen, Versie 4.0. WP. Rapporten, 00-119, Waterbouwkundig Laboratorium, Antwerpen, Belgie. October 2014, WL2014R00_119_5 [document date stamp: 15Oct2014; author= Deschamps, Maarten]
-water level threshold exceeded for Antwerp flood gates to close

RWS (2014b) RWS, Stormvloedrapport van 5 t/m 7 december (SR91) Sint-Nicolaasvloed 2013, Watermanagementcentrum Nederland, Rijkswaterstaat, prepared by Ing. J. Kroos, 19 Mar 2014b, 48 pp
-water level threshold for Maeslant- & Hartelkering for Dordrecht & Rotterdam not met
-Hollandse IJssel Stormvloedkering closed
-Emssperrwerk closed
- Oosterscheldekering

Slingo et al (2014) Slingo J, S Belcher, A Scaife, M McCarthy, A Saultter, K McBeath, A Jenkins, C Huntingford, T Marsh, J Hannaford, S Parry, The Recent Storms and Floods in the UK, 29pp, Met Office, Fitzroy Road, Exeter, Devon, EX1 3PB, UK, February, 2014 [pdf document properties: author=hw.lewis; date stamp=11Feb2014]
-Thomas barrier closed during surge 5-6 Dec 2013

Thorne (2014) Thorne, Colin, Geographies of UK flooding in 2013/4, The Geographical Journal, 180, 297-309, 2014.
-Thomas and Hull barriers closed during surge; 800000 properties protected from flooding

Axer et al (2015) Axer T, T Bistry, M Klawa, M Mueller, M Suesser, Deutsche Ruck Sturm dokumentation 2013 Deutschland, 2013, Deutsche Ruckversicherung Aktiengesellschaft, Hansallee 177, 40549 Duesseldorf, www.deutscherueck.de [pdf document information: author=filiz; date stamp=07Aug2015]
-Thomas barrier closed
- Oosterscheldekering closed
-Niedersachsen: all barriers closed: Ems, Hunte, Weser, Underelbe

Kendon and McCarthy (2015) Kendon M and M McCarthy, The UK’s wet and stormy winter of 2013/2014, Weather, 70, 40-47, 2015
-Thomas Barrier closed

Sibley et al. (2015) Sibley A, D Cox, H Titley, Coastal flooding in England and Wales from Atlantic and North Sea storms during the 2013/2014 winter, Weather, 70, 62-70, 2015
-'hundreds of thousands of properties and around 2000km2 of agricultural land are now protected , including by the Hull and Thomas Barriers’

Wadey et al (2015) Wadey MP, ID Haugh, RJ Nichols, JM Brown, K Horsburgh, B Carroll, SL Gallop, T Mason, E Bradshaw, A comparison of the 31 January-1 February 1953 and 5-6 December 2013 coastal flood events around the UK, UK Frontiers in Marine Science, 2, 84, 2015.
-Thomas barrier closed for 2 days with 2 m water level difference between ront and back.

Environment Agency (2018) Environment Agency, Thames Barrier Project Pack 2018, January, 2018
-Thomas Barrier, Dartford Creek Barrier, Barking Barrier, Royal Docks

North Norfolk District Council Coastal Team (2018) North Norfolk District Council Coastal Team, Refurbishment of sea walls and groynes 2013–2015; Cromer Coast Protection, (picture of plaque on wall taken 27Dec2018) www.northnorfolk.org/coastal
-highest water level at Thomas Barrier since start of operation in 1982

North Norfolk District Council Coastal Team (2019) North Norfolk District Council Coastal Team, Sheringham Sea Defences; Repair and Recovery from the December 2013 storm surge, www.northnorfolk.org/coastal, photo of plaque on wall taken 30Dec2019
-highest water level at Thomas Barrier since start of operation in 1982

Wikipedia (202001002) Wikipedia, Stormen Bodil, https://da.wikipedia.org/wiki/Stormen_Bodil#cite_note–39 (accessed 02Oct2019)
-62 gates of Oosterscheldekering, Thomas Barrier, Hanham 38 flood gates

WIKI (20200124) WIKI, Cyclone Xaver, https://en.wikipedia.org/wiki/Cyclone_Xaver accessed 24Jan2020
-Thomas Barrier, -Eastern Scheldt storm surge barrier closed 62locks Thursday night, -Hamburg closed all 38 flood gates

Wikipedia (20200502) Wikipedia, Orkan Xaver, https://de.wikipedia.org/wiki/Orkan_Xaver (accessed 2 May 2020)
-Thomas Barrier closed
-Deltawerke closed
Table S34. Beach damage and coastal issues; salt water contamination of groundwater; sewer systems (arranged by year and then alphabetically)

| Source | Full Reference and Notes |
|--------|--------------------------|
| BBC (20131206) | BBC20131206, Deadly storm and tidal surge batter northern Europe, BBC 6 Dec 2013 (report by Anna Holligan) - houses fall off sand cliff at east Hemsby UK |
| BT (20131208) | BT, Offer for Bodil: Koebbe huset 15 august – nu er det vaek, 08Dec2013, 16:44, (contributor: Morten Eggert) https://www.bt.dk/danmark/offre-for-bodil-koebbe-huset-15-august-nu-er-det-vaek - summer house over sand cliff at Norlev Strand in Denmark on 06Dec2013 during Storm Bodil |
| Deutschlander et al (2013) | Deutschlander T, K Frierich, S Haeseler, C Lefebvre, Orkantief XAVER uber Nordeuropa von 5. bis 7. Dezember 2013, Deutscher Wetterdienst DWD, Stand 30. Dezember 2013, 19pp. - Auf den Inseln gab es Duvenaabbruche und Sandabtragungen - houses in Helgoland toppled over cliff due to coast erosion |
| Gccapitalideas (20131209) | gccapitalideas, Windstorm Xaver, 9Dec2013, https://www.gccapitalideas.com/2013/12/09/windstorm-xaver/ - waves erodes cliffs at Hemsby |
| Kunz et al (20131206) | Kunz M, B Muehr, K Schroeter, T Bessel, S Moehrle, T Muenzberg, S Brink, H-M Schmidt, Winterstorm Xaver - Report, 06 Dec 2013 - (report on 06 Dec 2013, Situation Report - 19:00 CET, CEDIM Forensic Disaster Analysis Group (FDA), Center for Disaster Management and Risk Reduction Technology. - dune destruction expected at Juist, Spiekeroog, Wangeroog, Norderney |
| Liverpool Echo (20131211) | Liverpool Echo, Formby sand dunes hit by stormy seas, 11Dec2013, (correspondent: Eleanor Barlow) https://www.liverpoolecho.co.uk/news/liverpool-news/formby-sand-dunes-hit-stormy-6397344, accessed 19Apr2020 - 10m of sand cliff cutback at Formby, Merseyside coast, Irish Sea - last worst storm Feb2002 with 12m of sand cliff cutback |
| NLWKN (20131206) | NLWKN, Schwere Sturmflut gut Uberstanden, Wasserstaende zwischen Zweieinhalbe und Knapp vier metern registriert // presseinformation von 6. Dezember 2013, (Ansprechpartnerin: Herma Heyken), 06/12/2013. - on the islands first estimates of NLWKN leaders of significant dune collapse - Hammersee auf Juist und Zehlendorf auf Spiekeroog - Harlehoern dune on Wangerooge hit - Westmangroden was under water; seawater streaming over the deckwork - precise damage not yet finally assessed; water levels still too high to survey damage - detailed measurements of the beach and dunes to be carried out in the coming weeks - Spiekeroog and Wangerooge protection dunes strengthened in 2012 - Langeoog dunes strengthened at Priotal in 2013 - no great damage to the mainland coastal protection structures - Niedersachsen spent 400 millionen Euro in coastal protection since 2008. (Stefan Wenzel minister) |
| NOS (20131206) | NOS, Hoogste waterstand sinds 1953, 06/12/2013, 09:52, https://nos.nl/artikel/583218-hoogste-waterstand-sinds-1953.html - dune damage in North Sea |
| Sueddeutsche Zeitung (20131215) | Sueddeutsche Zeitung, Xaver holte sich Land; Sturmschaden auf Sylt, 15Dec201315:36 https://www.sueddeutsche.de/panorama/sturmschaeden-auf-sylt-xaver-holte-sich-land-1.1844100 - 40m of coastline retreat at Hoernum Odde - dune line broken through in 5 places - dune collapse at 57m+ 21km stretch at west side of Sylt |
| Syller Rundschau (20131209) | Syller Rundschau, Folgen des Orkans. Xaver 'knabberte' Sylt massiv an, 09Dec2013 06:00 (from Friederike Reussner) https://www.shz.de/lokales/zyler-rundschau/xaver-knabberte-sylt-massiv-an-id5098481.html - Sylt west coast beaten on 23 km stretch, 11.5km of coast without damage - worst stretch 1.2km at Hoernumer Odde; 20m lost in places - average coastline loss 2-3m - wave breathrough in one location with water staning in dune valley. - Dikken Deel; dunes broken - List Moovenberg Dike: some damage to concrete plate armour that started several months previously. |
| Unwetterzentrale (201312) | Unwetterzentrale, Orkantief XAVER - ein weiterer schwerer Wintersturm der letzten Jahrzehnte, Thomas Savert and Stefan Laps, Dec. 2013 http://www.unwetterzentrale.de/uwz/928.html - Sudspitze on Sylt Island devastated & Unterfeuer destroyed |
| ABPmer (2014) | ABB mar, Ensuring Flood Resilience: An overview of the 5/6 December 2013, Associated British Ports, Marine Environmental Research, July, 2014 -’the storm surge caused considerable cliff and dune retreats (e.g., Hemsby and Covehythe) and barrier breaches (e.g., Benacre), whilst waves battered the shoreline causing damage to other coastal defences and other coastal infrastructure’ - FIG, p.3. [PHOTO] Coastal erosion at Hemsby [Albanpix] - FIG, p.3. [PHOTO] Wave damage to Cromer frontage [David Tilting] |
| BBC (20141205) | BBC, East coast surge: what happened next? (report by Richard Haugh), 5Dec2014 - houses over cliff edge at Hemsby |
| Knaack and Heyken (2014) | Knaack H and H Heyken, Xaver hatte sehr schwere Sturmflut im Gepaeck, Jahresbericht 2013. Der Zukunft verplichtet, NLWKN, Niedersaechsischer Landesbetrieb fuer Wasserwirtschaft, Kuesten- und Naturschutz, pp.9-9, document date stamp 24Apr2014. - significant dune collapse: Wangerooge, Spiekeroog, Juist - no significant damage to mainland coast - response: summer 2.5million Euro & 180000 m3 sand for strengthening |
| Luecht and Peters (2014) | Luecht, Fabian and Ove Peters, Bericht uber die Sturmflut vom 05.-06.12.2013 an der Westkueste Schleswig-Holsteins, Landesbetrieb fuer Kuestenschutz, Nationalpark und Meeresschutz Schleswig-Holstein, Husum 26Feb2014, 19pp. [pdf document properties: title=Lfd; Author-Thorsten Nommensen; datestamp: 06/12/2013] |
- catalog of coastal damage Schleswig-Holstein
- two places of wave overtopping of main land protection dike in Helgoland
- loss of sand nourishment put in place in 2000
- erosion of sand cliffs on west coast of Sylt; more in south than north
- list of costs for damage repair and clear debris

NOZ (2014/0129)
NOZ Nach Xaver: 9.4 Millionen Euro fuer Juist, Spiekeroog and Wangerooge, 29Jan2014
https://www.noz.de/deutschland-welt/niedersachsen/artikel/446888/nach-xaver-9-4-millionen-euro-fuer-juist-spiekeroog-und-wangerooge-1
-Hammermee on Juist, coast retreat 7m
-Wangerooge: coast retreat of 13m at Harleshoerduenen
-Spiekeroog: 10m of coastline retreat at Zeltplatz

Pelt (2014)
Pelt AS, BODIL's stormflod i de indre dansk farvande. Vejret, 138, 24-29, 2014
-FIG4. [PHOTO] During the storm surge Nordjaellands Kattegatkyst experienced large erosion and damage. Photo of Ragleje Strandvej, which was closed to through traffic because waves swept over the road.

Van Rooijen and Oost (2014)
van Rooijen, A, A Oost, Memo: Regionale adviserings Ameland Noordwest, Deltares, 1209381-008-ZKS-0008, 43pp, 18Dec2014 [PDF document properties: title=Regional adviserings: Ameland NW; authors=Arnold van Rooijen; keywords=1209381-008-ZKS-0008; date stamp: 18/12/2014]
-cutback of steep dune face 10-20m for some profiles
-loss of height of dune line at these points 9-7m and 11-9m
-water recharge area of Ameland groundwater reservoir threatened.

Thorne (2014)
Thorne, Colin, Geographies of UK flooding in 2013/4, The Geographical Journal, 180, 297-309, 2014.
-map of damaged coastal defences on East Coast and Irish sea that required repair.
-2800km of linear defences required repair

Axe et al (2015)
Axe T, T Bistry, M Klawa, M Mueller, M Suess, Deutsche Ruck Sturm dokumentation 2013 Deutschland. 2013, Deutsche Rueckversicherung Aktiengesellschaft, Hansaalle 177, 40549 Duesseldorf, www.deutscherueck.de [pdf document information: author=filiz; date stamp=17Aug2015]
-significant dune losses Juist & Spiekeroog; Wangerooge beach part washed away
-significant sand loss from Sylt, Fohr, Amrum
-dike damaged at a few places: Buesum

Carrion (2015)
Carrion Arexabalba, BI, Morphological impact of the Sinterklaas storm at Het Zwin. Numerical modelling with Xbeach, M.Sc. Civil Engineering, Delft University of Technology, 2015.
-belgian dunes cut back 4-10m: Netherlands dunes 2-20m

Dan et al (2015)
Dan, Sebastian, Anne-Lise Montreuil, Rosalia Delgado, Thomas van Oyen, Large storm impact on a beach under sand nourishments, The Proceedings of the Coastal Sediments 2015, edited by Ping Wang, Julie D Rosati, and Jun Cheng, Coastal Sediments 2015. San Diego, USA, 11-15May2015
-dune scarp cut back 8.9m at beach profile 100 and 13.5m at beach profile 104 near Ostend

Dissanayake and Karunartha (2015)
Dissanayake P and H Karunaratha, Effect of storm clustering on beach/dune erosion, E-proceedings of the 36th IAHR World Congress, 28June-3July, 2015, The Hague, The Netherlands
-Xbeach model of dune damage at Formby Point

Dissanayake et al (2015)
Dissanayake P, J Brown, H Karunaratha, Impacts of storm chronology on the morphological changes of the Formby beach and dune system, UK. Nat. Hazards Earth Syst. Sci., 15,1533-1543, 2015.
-4m dune retreat at Formby Point in Liverpool Bay

Dissanayake et al (2015b)
Dissanayake P, J Brown, P. Wisse, H Karunaratha, Comparison of storm cluster vs isolated event impacts on beach.dune morphodynamics, Estuarine, Coastal, and Shelf Science, 164, 301-312, 2015b.
-Xbeach model study of beach damage at Selton coast on Liverpool Bay

Sibley et al (2015)
Sibley A, D Cox, H Titley, Coastal flooding in England and Wales from Atlantic and North Sea storms during the 2013/2014 winter, Weather, 70, 62-70, 2015
-‘with erosion to coastal cliffs a number of dwellings were undermined as cliffs collapsed, for instance near Hemsby, Norfolk where a lifeboat station was destroyed.’

Spencer et al (2015)
Spencer T, SM Brooks, BR Evans, JA Tempest, I Moeller, Southern North Sea storm surge event of Dec.5, 2013: Water levels, waves, and coastal impacts, Earth Science Reviews, 146, 120-145, 2015
-10 y of shoreline retreat during storm
-cliff top edge cut back by 12 m at some places.
-large differences in wave runup measured in some places
-cliff collapse/promenade damage Weybourne to Happisburgh;
-Bacton-Walcott 72 clifftop homes damaged/destroyed, washover aprons, breaching Benacre-Easton Bavents & Walberswick-Dunwich;
-cliff front notch between BenacreBroad Suffolk to Covehithe, Suffolk
-two major breaches at Blakeney-Cley-Salthouse;
-TAB3. Short term (Net Shoreline Movement NSM) and longer term (End Point Rate) rates of shoreline change on the Suffolk, North Lincolnshire and North Norfolk coasts as determined by Digital Shoreline Analysis
-Covehithe, 5.87; Donna Nook, 13.59; Holkham Gap west, 19.37; Holkham Gap east, 11.52; Scolt Head Is, 5.49

Wadey et al (2015a)
Wadey MP, ID Haigh, RJ Nichols, JM Brown, K Horsburgh, B Carroll, SL Gallop, T Mason, E Bradshaw, A comparison of the 31 January-1 February 1953 and 5-6 December 2013 coastal flood events around the UK, UK Frontiers in Marine Science, 2, 84, 2015a.
-'substantial coastal erosion’ in the UK
-1953 storm was worse than Storm Xaver 2013 for erosion
-2013 storm created new desolated landscape at Spurn Head
waves during the 2013/2014 storm season in two UK coastal regions, Nat. Hazards Earth Syst. Sci. Discuss., 3, 2665-2708, 2015b.  
-Formby (Sefton) with notoriously fast eroding dune system 4m/year; 13m of dune lost during 2013-2014 storms  
 -previous bad case of dune loss at Sefton, 13.6m during Feb 1990 storm

Brooks et al (2016)  
Brooks SM, T Spencer, A Mclvor, I Moller, Reconstructing and understanding the impacts of storms and surges, southern North Sea, Earth Surface Processes and Landforms, 41, 855-864, 2016.  
-average shoreline retreat Scott Head Island 8.14±0.39m; maximum retreat 13m  
-FIG 4. aerial photo interpretation shows large along shore differences with characteristic spatial scale 100-1000m

Matelski (2016)  
Matelski, Birgit, Erfahrungen aus der Sturmflut Xaver von 5. und 6.12.2013 und dem Weihnachtssturmtief 2014 in Schleswig-Holstein, IWASA 2016 Tagungsbeitrag. (46. IWASA, 7-8 Januar 2016, Internationales Wasserber-Symposium Aachen). [pdf document properties: autor=sonja; datenstamp: 26April2016]  
-coastline retreat up to 40m at Hoernum Odde on southern point of Sylt  
-FIG7. [PHOTO] Aerial photo showing retreat of southern tip of Sylt (Hoernum Odde)  
-dunes subject to wave damage during 9h period when the water covered the sand

Nederhoff et al (2016)  
Nederhoff K, E Elias, T Vermaas, Erosion at Ameland Nordwest. Modelstudie: simulaties met Delft3D en XBeach, Deltares, 117pp, July, 2016  
-Delft3D and XBeach model study of threat of seawater contamination of Amelander water catchment area

Sorensen (2016)  
Sorensen CS, Water NOT wanted - Coastal floods and flooding protection in Denmark, In RA Herrmann & J Jensen (eds), Sicherung von Daemmen, Deichen und Stauanlagen: Handbuch fuer Theorie und Praxis (Vol V pp3-21). Siegen: Universitats Siegen, 2016.  
-Jutland west coast: for centuries people moved inland as coast receded; harbours from late 19C  
-Jutland west coast: erosion stopped by sand nourishment 2-3 million m3/year along 110km coastline since 1980s

Sorensen et al (2016a)  
Sorensen CS, NK Dronen, P Knudsen, J Jensen, P Sorensen, An extreme event as a games changer in coastal zone management, Journal of Coastal Research, (Special Issue, No 75), 700-704, 2016. Proceedings of the 14th International Coastal Symposium (Sydney, Australia) ed by A Vila-Concejo, E Bruce, DM Kennedy, RJ McCarroll, 2016a  
-Storm Xaver caused as much coastal erosion damage in the NE Zeeland, Denmark as all the storm events of the past 100y.

Sorensen et al (2016b)  
Sorensen C, NH Broge, MR Molgaard, CS Schow, PThomsen, K Vognsen, P Knudsen, Assessing future flood hazards for adaptation planning in a northern European Coastal Community, Frontiers in Marine Science, 3, 69, doi:10.3389/fmars.2016.00069, 2016b  
-Thyboron: monitoring of well water and geologic modeling to assess saltwater contamination of groundwater  
-Thyboron: storm surge flooding makes sewage system non-operational  
-leveling surveys to assess uplift and tilting of Thyboron.

Staneva et al (2016a)  
Staneva J, K Wahle, H Guenther, E Stanev, Coupling of wave and circulation models in coastal-ocean predicting systems: a case study for the German Bight, Ocean Sci., 12, 797-806, 2016a  
-Xaver: Besides extreme high water levels along the coasts, extreme sea state conditions have been observed causing serious erosion of dunes and sand displacement on the barrier islands'  

Staneva et al (2016)  
Staneva J, K Wahle, W Koch, A Behrens, L Fenoglio-Marc, EV Stanev, Coastal flooding: impact of waves on storm surge during extremes - a case study for the German Bight, Nat. Hazards Earth Syst. Sci., 16, 2373-2389, 2016  
-... serious damage to the southern North Sea coastal areas'

Brooks et al (2017)  
Brooks SM, T Spencer, EK Christie, Storm impacts and shoreline recovery: Mechanisms and controls in the southern North Sea, Geomorphology, 283, 48-60, 2017.  
-*FIG5. End point rate (m/uy) for the barrier coast for the storm periods 2006-2007 (blue), 2007-2008 (pink), and 2013-2014 (orange) for (a) Brancaster Bay (14m), (b) Scoll Head Island (18m), (c) Holkham Bay (16m). Also shown are the cross shore profile locations. (d) end point rate (m/au) for the summer period 2008 to summer 2013, a period of no storm activity along the barrier for Brancaster Bay (blue), Scoll Head Island (red) and Holkham Bay (green).

Jensen et al (2017)  
Jensen J, S Nielsen, A Arn, S Dangendorf, Sensor- und risikobasieretes Fruehwarn-system fuer Sueddeiche (EarlyDike), AP1 - Sturmflumonitoring und Sturmflutsimulator - Fachbericht 2016, Siegen, April 2017  
-FIG5.1. Map of coastline dikes along German North Sea coast with heights; open coastline dikes between 8-10m

World Bank Group (2017)  
World Bank Group, Coastal Protection on the West Coast of Jutland, West Africa Coastal Areas Management Program, Case Study 02 [PDF document date stamp: 14/11/2017]  
-Backg 211. Information on heightened erosion and sand nourishment counter measures on Danish west coast  
-defining regional storm took place Nov1981 with >10m of coastline retreat  
-Danish west coast only region with government supported coastal protection

Breder and Froehle (2018)  
Breder, Norman and Peter Froehle, Operational wave forecast in the German Bight as part of a sensor- and risk based early warning system, In: J-S Shim, I Chun, HS Lim (ed), Proceedings from the International Coastal Symposium (ICS) 2018 (Busan, Republic of Korea), Journal of Coastal Research, Special Issue No. 85, 1161-1165, 2018  
-wave runup investigation at Untjehoern

Kystdirektoratet (2018)  
Kystdirektoratet, Shoreface nourishment effects. An analysis of the 2011 nourishment performed at Skodberge. Kystdirektoratet, Hojbovej 1, 7620 Lemvig, Dec 2018 [pdf document properties: title=Shoreface nourishment effects_Skodberge_20.12.2018, datenstamp=2012/12/2018]  
-largest coastal erosion volume loss in winter 2013-2014 with Storm Bodil as the most serious storm.

Li (2018)  
Li, H., The Ameland Inlet during the Sinterklaas Storm: the role of flooding of watersheds, ZDH model study in Delft3D-FLOW, M.Sc. Thesis, Utrecht University, 01May2018  
-modelling study of flow Dutch Waddensee at Ameland and sediment transport
**North Norfolk District Council Coastal Team (2018)**

North Norfolk District Council Coastal Team, Refurbishment of sea walls and groynes 2013-2015; Cromer Coast Protection, (picture of plaque on wall taken 27Dec2018) [www.northnorfolk.org/coastal](http://www.northnorfolk.org/coastal)

-some damage to Cromer sea defences; there had been no refurbishment for some years

-[FIG6. PHOTO] Photo damaged sea wall Cromer after Dec2013 storm Xaver

**Giannopoulos et al (2019)**

Giannopoulos G, L Peake, B Reid, J Andrews, A Grant, I Lorenzoni, M Goulden, J Waters, T Dolphin, J Bremner, TJ Tolhurst, Environmental and social impacts of the 2013 storm surge on the North Norfolk coast, powerpoint presentation date stamp 15May2019, unknown conference

-natural and manmade defences breached; coastal ecosys flooded

-significance of seawater flooding and soil salization investigated

-dune overtopping and rollback at Blakeney and Cley

**North Norfolk District Council Coastal Team (2019)**

North Norfolk District Council Coastal Team, Sheringham Sea Defences; Repair and Recovery from December 2013 storm surge, www.northnorfolk.org/coastal, photo of plaque on wall taken 30Dec2019

-serious damage to section of Sheringham sea defence wall

**Andrews (2020)**

Andrews, JE, Sp extension and barrier rollover at Blakeney Point and Salthouse: historic map and field observations, Bull. geol. Soc. Norfolk, 69, 35-63, 2020

-mean landward shoreline movement:
  -Brancaster Bay 4.39pm0.22m
  -Scolt Head Island 4.81pm0.24m
  -Holkham Bay 7.36pm0.97m

**JBA Risk Management (2020)**

JBA Risk Management, Storm Xaver 2013. Event Commentary, 2020. [PDF document properties: author=Cameron Whitwham]

-Jersey houses at Hemsby fell into sea because of excessive cliff erosion.

**WIKI (20200502)**

WIKI, Cyclone Xaver, [https://en.wikipedia.org/wiki/Cyclone_Xaver accessed 24Jan2020](https://en.wikipedia.org/wiki/Cyclone_Xaver)

-Happisburgh, Hemsby; holiday homes Norlev strand Denmark undermined

**Wikipedia (20200124)**

Wikipedia, Orkan Xaver, [https://de.wikipedia.org/wiki/Orkan_Xaver accessed 2 May 2020](https://de.wikipedia.org/wiki/Orkan_Xaver)

-[FIG6. PHOTO] Coast damage at Hemsby, Norfolk

-25m of dune retreat at Hammeurse/Juist

-significant dune damage Langeoog, Spiekeroog, Wangerooge

-Nordfriesischen Inseln: land loss at Sylt, Föhr, Amrum; most Halligen flooded; dike break on Keitum/Sylt; damaged dune landscape on 23m of Sylt coast; 20m cliff retreat at Hornumer Odde/Sylt; Duene next to Helgoland had massive dune loss and water in-breaks

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### Table S35: Power interruptions (arranged by year and then alphabetically)

| Source | Full Reference and Notes |
|--------|-------------------------|
| Air Worldwide (20131212) | Air Worldwide, Press Release, Boston, 12Dec2013. [https://www.air-worldwide.com/In-the-News/AIR-Estimates-Losses-from-European-Windstorm-Xaver-at-Between-EUR-700-Million-and-EUR-1-4-Billion/](https://www.air-worldwide.com/In-the-News/AIR-Estimates-Losses-from-European-Windstorm-Xaver-at-Between-EUR-700-Million-and-EUR-1-4-Billion/)(accessed 02Jan1990) |
| BBC (20131205) | BBC, In pictures: Winter storm hits UK, 5 December 2013, [https://www.bbc.com/news/uk-scotland-25231224](https://www.bbc.com/news/uk-scotland-25231224) |
| BBC (20131206) | BBC20131206, Deadly storm and tidal surge batter northern Europe, BBC 6 Dec2013 (report by Anna Holligan) |
| Bloomberg (2013) | Bloomberg, Hamburg has worst flood in 37 year amid European storms, Nicholas Brautlecht, 6Dec2013, 02:58PM GMT [https://www.bloomberg.com/news/articles/20130205/hamburg-has-worst-flood-in-37-years-as-storms-rage-across-europe](https://www.bloomberg.com/news/articles/20130205/hamburg-has-worst-flood-in-37-years-as-storms-rage-across-europe) |
| Daily Mail (20131206) | Daily Mail, Huge storm strikes Europe causing death and destruction and leading to cancellation of hundreds of flights, 6Dec2013. (correspondent: Nick Enoch), [https://www.dailymail.co.uk/news/article-2519517/Hage-storm-strikes-Europe-causing-death-destruction-leading-cancellation-hundreds-flights.html](https://www.dailymail.co.uk/news/article-2519517/Hage-storm-strikes-Europe-causing-death-destruction-leading-cancellation-hundreds-flights.html) |
| Gccapitalideas (20131209) | gccapitalideas, Windstorm Xaver, 9Dec2013, [https://www.gccapitalideas.com/2013/12/09/windstorm-xaver/](https://www.gccapitalideas.com/2013/12/09/windstorm-xaver/) |
| GP (20131206) | GP, Fortsatt risk for halka, 6Dec2013 (correspondent: D Henriksson, K Viklander, P Sydvin, TA Akerblom) |
| Kristeligt Dagblad (20131205) | Kristeligt Dagblad, Stormen blæser Skotland omkuld: Bøddsfald og nebrud, (contributor: Ritzau), 05Dec2013 12:50 [https://www.kristeligt-dagblad.dk/dk/danland/stormen-bl%C3%A6ser-skotland-omkuld-d%C3%B8dsfald-og-nebrud](https://www.kristeligt-dagblad.dk/dk/danland/stormen-bl%C3%A6ser-skotland-omkuld-d%C3%B8dsfald-og-nebrud) (at least 25000 households without power in Scotland and Northern Ireland) |
| Kanz et al (20131206) | Kanz M, B Muther, K Schoeter, T Bessed, S Moehlie, T Marenberg, S Brink, H-M Schmidt, Winterstorm Xaver - Report. 06Dec2013 - Report No.1, Situation Report - 19:00CET, CEDIM Forensic Disaster Analysis Group (FDA), Center for Disaster Management and Risk Reduction Technology. |
Spiegel International (20131206) Spiegel International, Winter storm ‘Xaver’ batters northern Europe, 6 Dec 2013, 12:56 https://www.spiegel.de/international/europe/tidal-surge-winter-storm-xaver-batters-northern-europe-a-937576.html# -power loss to 100000 households in Poland

TheJournal (20131205) TheJournal, Homes remain without electricity after high winds batter power lines, 05Dec2013 08:20PM, https://www.thejournal.ie/storm-ireland-1207783-Dec2013/ -Northern Ireland, -Donegal, Ballybofey, Buncrana, border near Derry, Meath, Dublin, Trim, Dublin coastal area Malahide & East Wall

Unwetterzentrale (201312) Unwetterzentrale, Orkantief XAVER - ein weiterer schwerer Wintersturm der letzten Jahrzehnte, Thomas Savert and Stefan Laps, Dec. 2013 http://www.unwetterzentrale.de/uzw/928.html -tens of thousands of houses in Poland without power

ABPmer (2014) ABP mer, Ensuring Flood Resilience. An overview of the 5/6 December 2013, Associated British Ports, Marine Environmental Research, July, 2014 -storm caused loss of power to more than 100,000 homes

Dunbar et al (2014) Dunbar I, N, N, M, S, N, Risk Nexus. After the storm: how the UK's flood defences performed during the surge following Xaver, Flood resilience review 09.14, Zurich Insurance Company Ltd., Mythenquai 2, 8002, Zurich, Switzerland [document properties: date 28Aug2014; author= Zurich] -10 000s UK & 100 000s Europe left without power -normal public activities came to standstill

RMS (2014) RMS, 2013-2014 Winter Storms in Europe. An Insurance and Catastrophe Modeling Perspective. RMS White Paper. [PDF TIMESTAMP 11Mar2014] -...'downing power lines...' -...with 200 properties affected in Whitby and power outages to the town making recovery difficult’

SMHI (20140703) SMHI, Simone, Hilde, Sven och Ivar okt-dec 2013, 3 Jul 2014, https://www.smhi.se/kunskapsbanken/meteorologi/simone-hilde-sven-och-ivar-okt-dec-2013-1.76183 -50 000 households without power

Sibley et al. (2015) Sibley A, D Cox, H Titley, Coastal flooding in England and Wales from Atlantic and North Sea storms during the 2013/2014 winter. Weather, 70, 62-70, 2015 -'...with 200 properties affected in Whitby and power outages to the town making recovery difficult’

Wadey et al (2015a) Wadey MP, ID Haigh, RJ Nichols, JM Brown, K Horsburgh, C Carroll, E Bradshaw, A comparison of the 31 January-1 February 1953 and 5-6 December 2013 coastal flood events around the UK, UK Frontiers in Marine Science, 2, 84, 2015a. -Electricity substation flooded in Middlesbrough

Wadey et al (2015b) Wadey MP, JM Brown, ID Haigh, T Dolphin, P Wisse, Assessment and comparison of extreme sea levels and waves during the 2013/2014 storm season in two UK coastal regions, Nat. Hazards Earth Syst. Sci. Discuss., 3, 2665-2708, 2015b. -listing of nuclear reactors Sizewell -dune damage in Sizewell area worse in 1953 compared with 2013

Ribeiro et al (2017) Ribeiro R, R Rudge, D Rucinska, Analysis of physical factors of the windstorm Xaver in Poland: post-hazard review, Weather, 72, pp.378-382 -downed electricity lines left many people without power

Rucinska (2019) Rucinska D, Describing Storm Xaver in disaster terms, International Journal of Disaster Reduction, 34, 147-153, 2019 -Poland: blackout in 400 000 homes affecting 1.11 million people -people without power northern Germany -10 000’s without power in UK

Wikipedia (20191002) Wikipedia, Stormen Bodil, https://da.wikipedia.org/wiki/Stormen_Bodil#cite_note-39 (accessed 02Oct2019) -Scotland: 20000 houses without power -Northern Ireland: 6000 houses without power

JBA Risk Management (2020) JBA Risk Management, Storm Xaver 2013. Event Commentary, 2020. [PDF document properties: author=Cameron Whitwham] -130,000 homes/businesses without power

WIKI (20200124) WIKI, Cyclone Xaver, https://en.wikipedia.org/wiki/Cyclone_Xaver accessed 24Jan2020 -Scotland: 20000 houses -N Ireland: 6500 houses -N England: 20000 houses without power across Cumbria and Teeside; 135000 properties across Northeast, Yorkshire, North Lincolnshire had power disruptions -Sweden: 50000 houses without power -Poland: 400000 households with blackout -power outage Middlesbrough -Whitby: electrical substation shut out

Wikipedia (20200429) Wikipedia, Stormen Sven, https://sv.wikipedia.org/wiki/Stormen_Sven#cite_note-15, accessed 29Apr2020 -E.ON power company engaged 4 helicopters and 200 extra staff -most of 1600 people working at Ringhals Nuclear Power station sent home 6Dec2013 -power cuts to 20000 houses Scotland and 6000 houses Ireland

Wikipedia (20200502) Wikipedia, Orkan Xaver, https://de.wikipedia.org/wiki/Orkan_Xaver (accessed 2 May 2020) -power cuts to 20000 houses Scotland and 6000 houses Ireland

Table S36. List bridge closures, cancelled ferry crossings, port closures, airport cancel, rail interruptions, traffic accidents (arranged by year and then alphabetically)

Source Full Reference and Notes
Aftenposten (20131206) Aftenposten, Varsler full storm i Sor-Norge, 5Dec2013 15:03 (correspondent Per Annar Holm) https://www.aftenposten.no/norge/s/kBEij/varsler-full-storm-i-soer-norge
- cancelled flights in Avinor network in southern Norway
- Bodø airport closed due to heavy snowfall
- closed mountain pass roads southern Norway
- cancelled ferries Norway west coast to Denmark
- cancelled ferry: Larvik/Kristiansand and Hirtshals
- cancelled ferry: Sandefjord-Stromstad
- cancelled ferry: Bergen-Stavanger-Hirtshals-Langesund
- cancelled ferry: Hirtshals-Sorlandskysten
- Basto gerry normal
- no cancellation information on ferry Oslo-Kiel
- no indication of cancelled ferry Oslo-Kiel

BBC (20131205)

BBC. In pictures: Winter storm hits UK, 5 December 2013, https://www.bbc.com/news/uk-scotland-25231224
FIG4. [PHOTO] Earlier in West Lothian lorry driver dies when vehicle blown over on to two cars (PA)
FIG5. [PHOTO] High winds brought down this lorry near Hamilton (PA).
FIG6. [PHOTO] Many roads have been closed across Scotland due to fallen trees (AP)
FIG7. [PHOTO] This HGV overturned and came to rest in a precarious position on the M90 Friarton Bridge near Perth (PA)

BBC (20131206)

BBC20131206. Deadly storm and tidal surge batter northern Europe, BBC 6 Dec 2013 (report by Anna Holligan)
- dozens of flights cancelled at Berlin Tegel, Copenhagen & smaller airports
- many rail and ferry services cut in Germany and Scandinavia
- Sweden all rail services cancelled in Skane
- planes grounded at Sturup and Gothenburg’s Landvetter airport
- heavy snow affected roads
- Denmark: 1000 people spent night in Copenhagen airport; Oresund bridge connecting Copenhagen to Denmark closed on night of 5 Dec
- Hamburg port closed overnight; handles huge amount of European trade
- Netherlands Schipol airport: dozens flights cancelled 5Dec, airport okay on 6Dec
- Germany: many rail services stopped; fallen trees on railway lines

Bloomberg (2013)

Bloomberg. Hamburg has worst flood in 37 year amid European storms, Nicholas Brautlecht, 6Dec2013, 02:58PM GMT https://www.bloomberg.com/news/articles/2013-12-06/hamburg-has-worst-flood-in-37-years-as-storms-rage-across-europe
- ship traffic at Hamburg port halted overnight
- Hamburg airport cancelled 100 of 400 take-offs & landings
- DB halted long distance trains via Schleswig-Holstein and cross border Denmark traffic
- DB stopped Hannover-Bremen line
- Scotland rail net work paralyzed 5Dec2013
- extreme flooding caused repeated closing locks at both ends Kiel Canal, world’s busiest artificial waterway
- commuter traffic Berlin & Potsdam interrupted by damage along tracks
- Poland LOT airline some cancelled flights

Daily Mail (20131206)

Daily Mail, Huge storm strikes Europe causing death and destruction and leading to cancellation of hundreds of flights, 6Dec2013. (correspondent: Nick Enoch), https://www.dailymail.co.uk/news/article-2519517/Huge-storm-strikes-Europe-causing-death-destruction-leading-cancellation-hundreds-flights.html
- Copenhagen airport closed overnight; 1000 people spend night in airport
- LOT airline Poland cancels some international and domestic flights
- traffic accidents kill 3 in Poland and 1 in Denmark by wind gusts

Deutschlander et al (2013)

Deutschlander T, K Frierich, S Haeseler, C Lefebvre, Orkantief XAVER ueber Nordeuropa von 5. bis 7. Dezember 2013, Deutscher Wetterdienst DWD, Stand 30. Dezember 2013, 19pp.
- schools and Weihnachtsmarkten in northern Germany closed
- cancelled flights
- interruptions of ship and train traffic.

DW (20131205)

DW, Storm Xaver pummels Europe, flood surge feared, 05/12/2013
- Oresund Bridge linking Denmark and Sweden closed
- transport services stopped ahead of storm: flight, ferry, rail

Gccapitalideas (20131209)

gccapitalideas, Windstorm Xaver, 9Dec2013, https://www.gccapitalideas.com/2013/12/09/windstorm-xaver/
- UK: all forms of transportation severely disrupted due to downed trees
- Germany: disruption rail traffic across northern Germany; dozens of flight cancellations Hamburg, Duesseldorf, Cologne
- Netherlands: widespread travel disruption
- Denmark: Copenhagen airport closed

GP (20131206)

GP, Fortsatt risk for halka, 6Dec2013 (correspondent: D Henriksen, K Vikingsson, P Sydvik, TA Akerblom)
- http://www.gp.se/nyster/goteborg/1.2201325-fortsatt-risk-for-halka (accessed 1May2020)
- trains stopped west Goteland; replacement bus services
- road blockages mostly by fallen trees
- ferry to Knippla and Hyppeln in north Skagarden stopped for carrying cars because of high water levels
- flight cancellations and delays at Landvetter and Arlanda

Kristeligt Dagblad (20131205)

Kristeligt Dagblad, Stormen blæser Skotland omkuld: Doodsfald og nebrud, (contributor: Ritzaau), 05Dec2013 12:50 https://www.kristeligt-dagblad.dk/udland/stormen-bl%2C%26skotland-omkuld-d%2C%26dodsfaled og-nebrud
- cancelled departures from airports at Glasgow, Edinburgh, Aberdeen
- trains cancelled in Scotland
- police warns driver against going on roads

Kunz (20131206)

Kunz M, B Muehr, K Schroeter, T Bessel, S Moehrlne, T Muenzberg, S Brink, H-M Schmidt, Winterstorm Xaver - Report. 06Dec2013 - Report No.1, Situation Report - 19:00CET, CEDIM Forensic Disaster Analysis Group (FDAG), Center for Disaster Management and Risk Reduction Technology.
- Hamburg port closed night 5-6 Dec 2013
- St Pauli Elbtunnel closed
- locks in Kiel Canal at Holtenau and Brunsbuttel closed
- ferries cancelled in Kiel
- German-Danish ferry Scandlines stopped serice between Rostock and Gedser until 6 Dec 2013
- ferry traffic to East and North Frisian islands nearly shut down 5-6 Dec 2013
- ferry companies operating trips to other countries in North and Baltic Sea affected (e.g. Stena)
- Hamburg and Bremen airport: 50% cancellations 5 Dec 2013; 20% cancellations 6 Dec 2013
- Hannover, Duesseldorf, Koeln airport: minor impact
- DB cancelled 20 intercity trains night 5-6 Dec 2013 and 6-7 Dec 2013
- cancellation of Schleswig-Holstein trains from afternoon 5 Dec 2013
- no severe rail infrastructure damage

Rtv Oost (20131205)

rtv Oost, Trainverkeer ten noorden van Zwolle stijlegt vanwege storm 5 Dec 2013 14:02,
https://www.rtvoost.nl/nieuws/1177568/Treinverkeer-ten-noorden-van-Zwolle-stijlegt-vanwege-storm
train traffic shut down from 14:00 5 Dec 2013 from Zwolle to Lelystad, Leeuwarden, Groningen, Emmen

Spiegel International (20131206)

Spiegel International, Winter storm 'Xaver' batters northern Europe, 6 Dec 2013, 12:56
https://www.spiegel.de/international/europe/dtZQ-surge-winter-storm-xaver-batters-northern-europe-a-937576.html#

FIG1. The UK, Germany, Netherlands, Scandinavia most heavily affected by the severe storm, but cancelled flights and trains caused problems across Europe.

- By Thursday night, officials reported three storm-related deaths in the UK and Denmark. Here, planes await takeoff at the Hamburg airport on Thursday (DPA)
- FIG15. Snow from Xaver gnailed traffic near Olpe in the state of Nord Rhein Westphalia
- on Friday morning (DPA)

The Local (20131205)

The Local, Home's remain without electricity after high winds batter power lines, 05 Dec 2013 08:20PM,
https://www.thelocal.se/20131205/stormen-bodil-sweeps-southern-sweden
Oresund Bridge closed to train traffic
- Malmo-Ystad trains stopped at midday; south Sweden trains stopped at 1500
- some ferry routes to/rom south Sweden cancelled

ABPmer (2014)

ABPmer, Ensuring Flood Resilience. An overview of the 5/6 December 2013, Associated British Ports, Marine Environmental Research, July, 2014
- storm caused shutdown of Scotland’s rail network
- Immingham: ‘storm caused damage to critical infrastructure, assets and disrupted port operations’
- Lowestoft: ‘supply damage/interruption to the Bascule Bridge, which in turn was non-operational for approximately 4 days’

Leiding et al (2014)

Leiding T, B Tinz, G Rosenhagen, C Lefevre, S Haeßler, S Hagemann, T Bastiglert, D Steen, P Schwenk, S Mueller, O Outzen, K Herklotz, T Neumann, Meteorological and Oceanographic Conditions at the FNO platforms during the severe storms Christian and Xaver, DEWI Magazin, No.44, p16-25, 2014.
- shipping, rail, air traffic shut down

Axer et al (2015)

Axer T, T Bistro, M Klawo, M Mueller, M Suesser, Deutsche Ruck Sturm dokumentation 2013 Deutschland, 2013, Deutsche Rueckversicherung Aktiengesellschaft, Hansallee 177, 40549 Duesseldorf, www.deutscherueck.de [pdf document information: author=filiz; date stamp=07Aug2015]
- all islands of Niedersachsen and Schleswig Holstein cut off from ferry traffic

Sibley et al. (2015)

Sibley A, D Cox, H Tiley, Coastal flooding in England and Wales from Atlantic and North Sea storms during the 2013/2014 winter, Weather, 70, 62-70, 2015
- ‘On the North Sea coast pats of Newcastle’s quayside were underwater at high tide as the Tyne estuary overflowered’

Wadey et al. (2015a)

Wadey MP, ID Haigh, RJ Nichols, JM Brown, K Horsburgh, B Carroll, SL Gallop, T Mason, E Bradshaw, A comparison of the 31 January-1 February 1953 and 5-6 December 2013 coastal flood events around the UK, UK Frontiers in Marine Science, 2, 84, 2015a.
- TABLE3. List of flooded roads and rails in 1953 and 2013

Wadey et al (2015b)

Wadey MP, JM Brown, ID Haigh, T Dolphin, P Wisse, Assessment and comparison of extreme sea levels and waves during the 2013/2014 storm season in two UK coastal regions, Nat. Hazards Earth Syst. Sci. Discuss., 3, 2665-2708, 2015b.
- Lowestoft train station flooded; lines Lowestoft-Norwich and Lowestoft-Ipswich cut
- Lowestoft-Ipswich line closed for 11 days

Ribeiro et al (2017)

Ribeiro R, R Rudge, D Rucinska, Analysis of physical factors of the windstorm Xaver in Poland: post-hazard review, Weather, 72, 2017, pp.378-382
- some flights cancelled in Poland

Rucinska (2019)

Rucinska D, Describing Storm Xaver in disaster terms, International Journal of Disaster Reduction, 34, 147-153, 2019
- cancelled ferry services across English Channel from Netherlands
- no severe rail infrastructure damage

Wikipedia (20191002)

Wikipedia, Stormen Bodil, https://da.wikipedia.org/wiki/Stormen_Bodilcite_note-39 (accessed 02Oct2019)
- UK: Glasgow: Central train station evacuated 5Dec when flying debris came through roof
- UK: Scotland suspended all rail services later in the day; trampolines & trees on track
- Denmark: 5Dec Banedanmark shut rail services Jyllands 14:00, Fyn 16:00, Funen 18:00
- Denmark: bridges shut: Storebaeltsbron, Vejlefordbron, nye Lillebaeltsbron, gamle lillebaeltsbron, Svendborgsundbron, Oresundsbron, Limfordsbron, Assensbron
structural damage to wind farms and wind energy impacts

Table S37. Structural damage to wind farms and wind energy impacts (arranged by year and then alphabetically)

| Source | Full Reference and Notes |
|--------|--------------------------|
| WIKI (20200124) | WIKI, Cyclone Xaver, https://en.wikipedia.org/wiki/Cyclone_Xaver accessed 24Jan2020 |
| Wikipedia (20200429) | Wikipedia, Stormen Sven, https://sv.wikipedia.org/wiki/Storm_en_Sven#cite_note-15, accessed 29Apr2020 |
| Wikipedia (20200502) | Wikipedia, Orkan Xaver, https://de.wikipedia.org/wiki/Orkan_Xaver (accessed 2 May 2020) |
| Gray (2013) | Gray, Tom, Into the Wind, The AWEA Blog, Ireland, U.K., Germany set new wind generation records, https://www.aweablog.org/ireland-u-k-germany-set-new-wind-generation-records/, 11Dec2013 |
| IWR (20131206) | IWR, Orkan Xaver bringen neuen Rekord - Deutsche Windkraftanlagen produzieren erstmals Strom mit ueber 26000 MW Leistung, 06Dec2013 09:31, https://www.iwr.de/news.php?id=25168 (accessed 07May2020) |
| Kanz et al (20131206) | Kanz M, B Muehr, K Schroeter, T Bessel, S Moehrle, T Muenzberg, S Brink, H-M Schmidt, Winterstorm Xaver - Report. 06Dec2013 - Report No.1, Situation Report - 19:00CET, CEDIM Forensic Disaster Analysis Group (FDA), Center for Disaster Management and Risk Reduction Technology. |
| National Wind Watch (20131210a) | National Wind Watch, 10Dec2013, Xaver zerstört ein Windrad bei Vlatten, original source: Aachener Zeitung, 60Dec2013 https://www.wind-watch.org/news/2013/12/10/xaver-zerstoert-ein-windrad-bi-vlatten/ |
| National Wind Watch (20131210b) | National Wind Watch, Sturm 'Xaver': Windrad stürzt auf Acker, 10Dec2013b, credit: von Manfred Reinnarth, Koelnhische Rundschau, 06/12/2013, https://www.wind-watch.org/news/2013/12/10/sturm-xaver-windrad-sturzt-auf-acker/ |
| National Wind Watch (20131212) | National Wind Watch, Xaver knickte Windrad um: fear of metal thieves, 12Dec2013 (Credit: 11/12/2013 - Iris Klingelhoefer and Alexander Kuffner, express.de) https://www.wind-watch.org/news/2013/12/12/xaver-knickte-windrad-um-angst-vor-metall-dieben/ |
| Nordbayern (20131207) | Nordbayern, Deming: 'Xaver' reiss Rotorblatt von Windrad ab. Windkraftanlage schleuderte Eissbrocken auf die Strasse, 07/12/2013, 12:27. https://www.nordbayern.de/region/neumann/deming-xaver-reiss-rotorblatt-von-windrad-ab-1-332692 |
| FINO1 (20140108) | FINO1, 15-m wave damaged FINO1, 08Jan2014. http://www.fino1.de/meldungen/alle-meldungen/137-15-meter-welle-beschaeidigt-fino1 |
| Leiding et al (2014) | Leiding T, B Tinz, G Rosenhagen, C Lefevre, S Haeseler, S Hagemann, I Bastigkiet, D Stein, P Schwenk, S Mueller, O Outzen, K Herklotz, F Kinder, T Neumann, Meteorological and Oceanographic Conditions at the FINO platforms during the severe storms Christian and Xaver, DEWI Magazin, No.44, p16-25, 2014, turbulence intensity exceeds category A turbines for several 10 minute intervals at FINO1, FINO2, FINO3 during Storm Xaver, wind speed jump from 23m/s to 37m/s with change of wind speed from 220-290deg (70deg) at FINO3, implications for Dantysk wind farm near FINO3, long interval when wind speed >25m/s turbine cutoff |
Table S38. Hydropower impacts (arranged by year and then alphabetically)

| Source | Full Reference and Notes |
|--------|---------------------------|
| Cheliotis et al (2016) | Cheliotis, I. G. Varlas, K. Christakos, The impact of cyclone Xaver on hydropower potential in Norway, conference paper, September 2016 In: T Karaostas, A Bais, PT Nastos (ed), Perspectives on Atmospheric Sciences, Springer Atmospheric Sciences, Springer, Cham, 2017 https://doi.org/10.1007/978-3-319-35095-0_25, first online 10Sep2016 [pdf document properties: author=Konstantinov Christakos; datestamp: 07/09/2016]  
-WRF model to quantify hydropower potential of rainfall |
| Cheliotis et al (2017) | Cheliotis, I. G. Varlas, K. Christakos, The impact of cyclone Xaver on hydropower potential in Norway, conference paper, September 2016 In: T Karaostas, A Bais, PT Nastos (ed), Perspectives on Atmospheric Sciences, Springer Atmospheric Sciences, Springer, Cham, 2017, https://doi.org/10.1007/978-3-319-35095-0_25  
-Norwegian hydropower system represents 50% of European reservoir capacity (Statkraft, 2009) |

Table S39. Structural damage to buildings, piers, and cultural monuments (arranged by year and then alphabetically)

| Source | Full Reference and Notes |
|--------|---------------------------|
| BT (20131208) | BT, Offer for Bodil: Koebe huset 15.august - nu er det vaek, 08Dec2013, 16:44, (contributor: Morten Eggert) https://www.bt.dk/danmark/offfer-for-bodil-koebe-huset-15-august-nu-er-det-vaek  
-summer house over cliff at Norlev Strand on Friday 06Dec2013 during Storm Bodil |
| Gccapitalideas (20131209) | gccapitalideas, Windstorm Xaver, 9Dec2013, https://www.gccapitalideas.com/2013/12/09/windstorm-xaver/  
some reports of roof damage |
| National Wind Watch (20131210a) | National Wind Watch, 10Dec2013a, Xaver zerstoert ein Windrad bei Vlatten, original source: Aachener Zeitung, 6Dec2013 https://www.wind-watch.org/news/2013/12/10/xaver-zerstoert-ein-windrad-bei-vlatten/  
-damage to houses by falling trees and branches |
| Spiegel International (20131206) | Spiegel International, Winter storm 'Xaver' batters northern Europe,6 Dec 2013, 12:56 https://www.spiegel.de/international/europe/idal-surge-winter-storm-xaver-batters-northern-europe-a-937576.html# FIG5. In Rostock fire fighters secure parts of a roof blown off by hurricane-force winds (DPA) |
| SyIter Rundschau (20131209) | SyIter Rundschau, Folgen des Orkans. Xaver knubberte 'Sylt massiv an, 09Dec2013 06:00 (from Friederike Reusser) https://www.shz.de/lokales/syiter-rundschau/xaver-knubberte-sylt-massiv-an-id5098481.html  
-most of beach access stairs at Hoernumer Odde not usable  
-ground floor damage to baeach restaurant Wonnemeyer the Wenningstedt |
| Unwetterzentrale (201312) | Unwetterzentrale, Orkantief XAVER - ein weiterer schwerer Wintersturm der letzten Jahrzehnte, Thomas Saxvert and Stefan Laps, Dec. 2013 http://www.unwetterzentrale.de/wwz/928.html  
some roof damage  
-Unterfeuer on southern part of Sylt destroyed |
| Axer et al (2015) | Axer, T Bistry, M Klaw, M Mueller, M Suesser, Deutsche Ruck Sturm dokumentation 2013 Deutschland, 2013, Deutsche Ruckversicherung Aktiengesellschaft, Hansaallee 177, 40549 Duesseldorf, www.deutscherueck.de [pdf document information: author=filiz; date stamp=07Aug2015]  
-cJurk, Landkreis Neumarkt, Oberpfalz: fallen wind blade from turbine  
-Deining Landkreis Neumarkt, Oberpfalz: fallen wind blade from turbine  
-numerous cases roof damage & toppled trees north Germany  
-Stralsund supermarket lost roof 200000 EUR  
-clock Marienkirche damaged |
Siblley et al. (2015) Siblley A, D Cox, H Titley, Coastal flooding in England and Wales from Atlantic and North Sea storms during the 2013/2014 winter, Weather, 70, 62-70, 2015. -lifeboat station at Hemsby destroyed as coastal cliffs undermined

Matelski (2016) Matelski, Birgit, Erfahrungen aus der Sturmflut Xaver von 5. und 6.12.2013 und dem Weihnachtschwohasser 2014 in Schleswig-Holstein, IWASA 2016 Tagungsbeitrag, (46. IWASA, 7-8 Januar 2016; Internationales Wasserbau-Symposium Aachen. [pdf document properties: autor=sonja; datestamp: 26Apr2016] -destroyed deckwork at Halligen

Sorensen (2016) Sorensen CS, Water NOT wanted - Coastal floods and flooding protection in Denmark, In RA Hermann & J Jensen (eds), Sicherung von Daemmen, Deichen und Staunlagen: Handbuch fuer Theorie und Praxis (Vol V pp3-21). Siegen: Universitaet Siegen, 2016 -inner Danish sea: Xaver flooding caused houses to be uninhabitable for a long time -inner Danish sea: medieval town centers Im above the highest floods experienced

Rucinska (2019) Rucinska D, Describing Storm Xaver in disaster terms, International Journal of Disaster Reduction, 34, 147-153, 2019 -Poland: Pomeranian Duke's Castle damaged

Wikipedia (20191002) Wikipedia, Stormen Bodil, https://da.wikipedia.org/wiki/Stormen_Bodil#cite_note-39 (accessed 02Oct2019) -damage to Glasgow train station causes evacuation

WIKI (20200124) WIKI, Cyclone Xaver, https://en.wikipedia.org/wiki/Cyclone_Xaver accessed 24Jan2020 -Happisburgh, Hemsby; holiday homes Norlev strand Denmark undermined -monument: 1634 stone Old Quay damaged at Whitehaven Cumbria -monument: Blackpool North Pier severely damaged. -monument: Cromer significant damage to pier

Wikipedia (20200329) Wikipedia, Stormen Sven, https://sv.wikipedia.org/wiki/Stormen_Sven#cite_note-15, accessed 29Apr2020 -Landskrona kallbadhus destroyed by the storm

Table S40. Forest damage and tree falls (arranged by year and then alphabetically)

| Source | Full Reference and Notes |
|--------|-------------------------|
| BBC (20131205) | BBC, In pictures: Winter storm hits UK, 5 December 2013, https://www.bbc.com/news/uk/scotland-25231224 -FI6G. [PHOTO] Many roads have been closed across Scotland due to fallen trees (AP) |
| Gccapitalideas | gccapitalideas, Windstorm Xaver, 9Dec2013, https://www.gccapitalideas.com/2013/12/09/windstorm-xaver/ -UK: fallen trees interrupt transport networks |
| GP (20131206) | GP, Fortsatt risk for halka, 6Dec2013 (correspondent: D Henriksson, K Vikingsson, P Sydvik, TA Akerblom) -http://www.gp.se/hyheten/goteborg/1.2201325-fortsatt-risk-for-halka (accessed 1May2020) -during night to Friday police received 90 reports of traffic blockages; mostly fallen trees |
| Kriststelt Dagblad (20131205) | Kriststelt Dagblad, Stormen blaeser Skotland omkuld: Doodsfald og nebrud, (contributor: Ritzaus), 05Dec2013 12:50 https://www.kriststelt-dagblad.dk/danland/stormen-bl%C3%A6ser-skotland-omkuld-d%C3%B8dsfald-og-nebrud -trees in Scotland cancelled by trees fallen on rails |
| Kunz et al (20131206) | Kunz M, B Muehr, K Schrtoet, B Bessel, S Moebrue, T Muenzberg, S Brink, H-M Schmidt, Winterstorm Xaver - Report, 06Dec2013 - Report No.1, Situation Report - 19:00CET, CEDIM Forensic Disaster Analysis Group (FDA), Center for Disaster Management and Risk Reduction Technology. -trees and branches on roads and rail tracksin Mecklenburg-Vorpommern & Schleswig-Holstein |
| National Wind Watch (20131210b) | National Wind Watch, Storm Xaver: Windrad stuerzt auf Acker, 10Dec2013, credit: von Manfred Reinmarth, Koeltnische Rundschau, 06/12/2013, https://www.wind-watch.org/news/2013/12/10/storm-xaver-windrad-sturzt-auf-acker/ -reference to a few toppled trees in Eise Kirkskær |
| Nordbayern (20131207) | Nordbayern, Deining: 'Xaver' reisst Rotorblatt von Windrad ab. Windkraftanlage schleuderte Eisbrocken auf die Strasse, 07/12/2013, 12.07. https://www.nordbayern.de/region/neumarkt/deining-xaver-riessst-rotorblatt-von-windrad-ab-1.3324692 -a few trees blown over in northern Bavaria |
| Spiegel International (20131206) | Spiegel International, Winter storm ‘Xaver’ batters northern Europe, 6 Dec 2013, 12:56 https://www.spiegel.de/international/europe/tidal-surge-winter-storm-xaver-batters-northern-europe-937576.html#FIG12:An uprooted tree in the village of Sankt Peter Ording on the North Sea coast on Thursday (Reuters) |
| The Local (20131205) | The Local, Sven’s strong winds sweep southern Sweden, 05Dec2013 15:57CET -trees and roots cut power lines for trains |
| Unwetterzentrale (201312) | Unwetterzentrale, Okrntief XAXER - ein weiterer schwerer Wintersturm der letzten Jahrzehnte, Thomas Savert and Stefan Laps, Dec, 2013 http://www.unwetterzentrale.de/uzw/928.html -vegetation damage; numerous trees down |
| SMHI (20140703) | SMHI, Simone, Hilde, Sven och Ivar okt-dec 2013, 3 Jul 2014, https://www.smhi.se/kunskapsbanken/meteorologi/simone-hilde-sven-och-ivar-okt-dec-2013-1.76183 -0.8 million m3 lost timber |
| Axer et al (2015) | Axer T, T Bistry, M Klaw, M Mueller, M Suess, Deutsche Ruck Sturm dokumentation 2013 Deutschland, 2013, Deutsche R disc fundierung Aktiengesellschaft, Hansalle 177, 40549 Duesseldorf, -Denmark: Bodil with Allan destroyed almost 2500 hectares of forest with over 2 million trees |
| Wikipedia (20191002) | Wikipedia, Stormen Bodil, https://da.wikipedia.org/wiki/Stormen_Bodil#cite_note-39 (accessed 02Oct2019) -Denmark: storm knocked down many trees in an area in Stenderup at Kolding |
| Wikipedia (20200502) | Wikipedia, Orkan Xaver, https://de.wikipedia.org/wiki/Orkan_Xaver (accessed 2 May 2020) -Denmark: Rotorblade with Allan destroyed almost 2500 hectares of forest with over 2 million trees |
Table S41. General ship/rig emergency reports/offshore incidents/platform evacuations (arranged by year and then alphabetically)

| Source | Full Reference and Notes |
|--------|-------------------------|
| 24liveblog (2013) | 24liveblog, Storm 5-6 december 2013, https://live.24liveblog.com/live/UYXaJ |
| - cutter GO-20 grounded; stowed to Stellendam arrival 0600M |
| - Burak Bayraktar engine problem 00:40AM |
| - Baltichborg cargo shift 09:10M |
| - Elka Athina motor problem 16:15M |
| BBC (20131204) | BBC, Workers off Talisman Sinopec oil platform Buchan Alpha over bad weather forecast, 04Dec2013 |
| - evacuation of Buchan Alpha ~100km NE of Aberdeen from 04 Dec 2013 |
| BBC (20131206) | BBC20131206, Deadly storm and tidal surge batter northern Europe, BBC 6 Dec2013 (report by Anna Holligan) |
| - 2 sailors swept off ship in south Sweden |
| Cargolaw (2013) | Cargolaw 2013 [Tim Schwabedissen, 12Dec2013] |
| - Finnish Ferry Finsky (20082 g) stranded |
| - ship anchored offshore to ride out storm after leaving Lubeck Dec6 |
| - became caught in on anchor chain & unable to proceed |
| DW (20131205) | DW, Storm Xaver pummels Europe, flood surge feared, 05/12/2013 |
| - production cut and staff evacuated from some platforms |
| - search for 2 sailors swept off ship out south coast of Sweden |
| Energy Voice (20131204) | Energy Voice, Oil staff withdrawn from North Sea ahead of storm conditions, 04/12/2013 10:30AM, https://www.energyvoice.com/other-news/healthandsafety/50140/oil-staff-withdrawn-north-sea-ahead-storm-conditions/ |
| - evacuation of Buchan Alpha FPSO (Talisman Sinopec), Ekofisk (Conocophillips), Valhall (BP) |
| - no effect on production during preparations. |
| Expressen (2013) | Expressen, Flera doda i Sverige efter stormen Sven, 06Dec2013, 17:34CET? |
| Fleetmon (20131207) | Fleetmon, Container ship Burak Bayraktar in trouble off Texel, Netherlands, (correspondent: Mikhail Voytenko, 7Dec2013 06:31) https://www.fleetmon.com/maritime-news/2013/2810/container-ship-burak-bayraktar-trouble-texel-nethe/ |
| - early morning 06Dec2013 container ship reported engine trouble to Dutch coast guard |
| - ship had to anchor to avoid grounding; anchor dragged |
| - latest reports: vessel is stable 4nm W of Texel |
| Fleetmon (20131208) | Fleetmon, Burak Bayraktar safe, Netherlands, (Mikhail Voytenko, Dec08, 2013 05:07) https://www.fleetmon.com/maritime-news/2013/2816/burak-bayraktar-safe-netherlands/ |
| - ship taken in tow by Tug Zeus away from coast; repaired by crew underway |
| Gandreassen (20131204) | Gandreassen, Oil workers moved from Ekofisk, 4Dec2013, https://gandreassen.com/oil-workers-moved-from-ekofisk/ |
| - ConocoPhillips transferred 157 workers from Ekofisk 1 day in advance of the storm; no evacuation |
| - BP is considering moving people from the field. |
| Gcapitalideas (20131209) | gcapitalideas, Windstorm Xaver, 9Dec2013, https://www.gcapitalideas.com/2013/12/09/windstorm-xaver/ |
| - ’North Sea oil and gas producers including ConocoPhillips, Maersk Oil and Statoil cut production and evacuated staff from some platforms’ |
| GVA (20131205) | GVA, Vifj containers even op drift op de Schelde, 05/12/2013 20:57. https://www.gva.be/cnt/aad1500792/vifj-containers-op-drift-op-de-schelde-2 |
| - 4 empty containers and 1 container with tapioca fallen from ship in Westerscheldt 2000MET |
| - Ladybug ship adrift & hit Deurganckdok at 1800MET; recovered by two tug boats |
| HBVL (20131205) | HBVL, Vifj containers even op drift op de Schelde, 05Dec2013 20:57, https://www.hbvl.be/cnt/aad1500792/vifj-containers-op-drift-op-de-schelde-2 |
| - ship traffic between Deurganckdok and Vlissingen stopped by 5 drifting containers than fell from ship 05Dec2013 20:00 |
| - C Ladybug adrift 05Dec2013 18:00; recovered by 2 tugboats |
| Reuters (20132015) | Reuters, Conocophillips cuts some output at Ekofisk field due to storm, 5Dec2013, https://finance.yahoo.com/news/conocophillips-cuts-output-ekofisk-field... |
| - ConocoPhillips relocated number of personnel onshore and to Ekofisk complex; production decreased |
| - PTLL earlier said it expected Ekofisk to produce 102000 barrels per day this year |
| The Local (20131205) | The Local, Sven's strong winds sweep southern Sweden, 05Dec2013 15:57CET, https://www.thelocal.se/20131205/storm-sven-sweeps-into-southern-sweden |
| - 2 sailors fall off Dutch ship off Ystad |
| Upstream (20131204) | Upstream, Talisman takes workers off Buchan Alpha, 4Dec2013 1710GMT (correspondent: Rob Watts) |
| - evacuation of Talisman Buchan Alpha pentagonal platform in northern North Sea in advance of storm. |
| Upstream (20131205) | Upstream, North Sea production curtailed over storm, 05Dec2013 (contributor: Bill Lehane and News Wires) |
| - production reduced at 2 North Sea oil platforms as explorers continue to de-man installations |
| - waves up to 10m expected before storm subsides late Thursday |
| Upstream (20131206) | Upstream, Buchan Alpha evacuated as North Sea storms loom, 6Dec2013 0000GMT (contributor Rob Watts) |
| - Talisman Sinopec Energy UK evac all workers off Buchan Alpha in UK Nsea ahead of severe storms |
| Upstream (20131209) | Upstream, Workers return to Buchan A, 09Dec2013 12:58GMT (contributor: Rob Watts) |
| - workers started returning to FPSO 08Dec2013 Sunday |
| Axer et al (2015) | Axer, T, Bistry, M Klawa, M Mueller, M Saesser, Deutsche Ruck Sturm dokumentation 2013 Deutschland, 2013, Deutsche Ruckversicherungs Aktiengesellschaft, Hansaallee 177, 40549 Duesseldorf, www.deutschereueck.de [pdf document information: author=filiz; date stamp=07Aug2015] |
| - Finnfjord's freighter (190m) headed from Warnemunde to Finland; had to anchor for several days; trucks in ship |
| Wadey et al (2015a) | Wadey MP, ID Haigh, RJ Nichols, JM Brown, K Horsburgh, B Carroll, SL Gallop, T Mason, E Bradshaw, A comparison of the 31 January-1 February 1953 and 5-6 December 2013 coastal flood events around the UK, UK |
Frontiers in Marine Science, 2, 84, 2015a.
-no maritime disasters for Storm Xaver as for 1953 storm

Wadey et al (2015b) Wadey MP, JM Brown, ID Haagh, T Dolphin, P Wisse, Assessment and comparison of extreme sea levels and waves during the 2013/2014 storm season in two UK coastal regions, Nat. Hazards Earth Syst. Sci. Discuss., 3, 2665-2708, 2015b.

-MC 1910022 Wikipedia, Stormen Bodøli, https://da.wikipedia.org/wiki/Stormen_Bodøli#/cite_note-39 (accessed 02Oct2019)

-British oil platform NE of Aberdeen evacuated 4Dec before storm

WIKI (20200124) WIKI, Cyclone Xaver, https://en.wikipedia.org/wiki/Cyclone_Xaver accessed 24Jan2020

-Buchan Alpha evacuated

Wikipedia (20200429) Wikipedia, Stormen Sven, https://sv.wikipedia.org/wiki/Stormen_Sven#cite_note-15, accessed 29Apr2020

-2 men fell overboard from a freighter off Ystad and died

Wikipedia (20200502) Wikipedia, Orkan Xaver, https://de.wikipedia.org/wiki/Orkan_Xaver (accessed 2 May 2020)

-2 sailors swept from ship off coast of Sweden; search unsuccessful

Table S42. Instrument failures during storm (arranged by year and then alphabetically)

Source | Full Reference and Notes
---|---
Deutschlander et al (2013) Deutschlander T, K Frieric, S Haeseler, C Lefebvre, Orkantief XAVER uer Nordeuropea von 5. bis 7. Dezember 2013, Deutscher Wetterdienst DWD, Stand 30. Dezember 2013, 1pp.

-Partial malfunction of weather station at Hamrug St. Pauli; 5Dec2013 09:45-12:00UTC

BSH (2013) BSH, Die Nordseesturmfluten von 5. und 6.12.2013, 3pp., prepared by Stockmann.K. (title: SturmFlut 2011_b1101; author stamp: b1101; document time stamp: 12/1023 12:52:30PM)

-Dagebübel tide gauge failed during evening high tide 6 Dec 2013

Deutschlander et al (2013) Deutschlander T, K Frieric, S Haeseler, C Lefebvre, Orkantief XAVER uer Nordeuropea von 5. bis 7. Dezember 2013, Deutscher Wetterdienst DWD, Stand 30. Dezember 2013, 1pp.

-Partial malfunction of weather station at Hamrug St. Pauli; 5Dec2013 09:45-12:00UTC

Mc Garricle et al (2013) McGarricle P (ed), UK coastal monitoring and forecasting: Annual report for 2013 for the UK National Tide Gauge Network, NERC 10017897, 2013 [pdf document properties: author=pamcg; created=16Apr2014]

-Aberdeen: no record surge max?

-Cromer: no record surge max or water level max?

-Harwich: no record surge max or water level max?

-Sheerness: primary instrument offline; secondary instrument functional but no data presented

-Wick: no surge max

Oceanografsch Meteorologisch Station (2013) Oceanografsch Meteorologischt Station, Stormverslag 05-06 december 2013, 26pp, 2013 [pdf document properties: author=Myriam Sys; datestamp=15Dec2013]

-large data gaps in Westhinder waverider series

-large data gaps in Bol van Heist wave period at 05Dec2013 1300UTC

SMHI (20131012) SMHI, Stormen Sven gav nya vattenstandsrekord i Oresund, https://www.smhi.se/miljostarkav/stormen-sven-gav-nya-vattenstandsrekord-i-oresund-1.34732, updated 20Mar2017; original datestamp 10Dec2013.

-tide gauge failure at Viken Sweden on 06Dec2013 14:00UTC

ABPmer (2014) ABPmer, Ensuring Flood Resilience. An overview of the 5/6 December 2013, Associated British Ports, Marine Environmental Research, July, 2014

-Immingham tide gauge non-operational on 06Dec2013.

Eriksen (2014) Eriksen J, Rekordvandstande i Isefjorden og Roskilde Fjord, Vejret, 138, 26Feb2014, 19pp. [pdf document properties: title=Lfd; Author=Thorsten Nommensen; datestamp=12Dec2018]

-25 of 32 wave recorders had no data during storm Xaver

Luecht and Peters (2014) Luecht, Fabian and Ove Peters, Bericht uber die Sturmflut vom 05.-06.12.2013 an der Westkueste Schleswig-Holsteins, Landesbetrieb fuer Kuestenschutz, Nationalpark und Meeresschutz Schleswig-Holstein, Husum 26Feb2014, 19pp. [pdf document properties: title=Lfd; Author=Thorsten Nommensen; datestamp=12Dec2018]

-no data for Dagebübel tide gauge during main storm tide

RWS (2014b) RWS, Stormvloedrapport van 5 t/m 7 december (SR91) Sint-Nicolaasvlied 2013, Watermanagementcentrum Nederland, Rijkswaterstaat, prepared by Ing. J. Kroos, 19 Mar 2014b, 48 pp

-Huijberts anemometer not functional

-no data from Scharmenmonkoog

Leiding et al (2014) Leiding T, B Tinz, G Rosenhagen, C Lefevre, S Haeseler, S Hagemann, I Bastigkeit, D Stein, P Schwenk, S Mueller, O Outez, K Herklotz, F Kinder, T Neumann, Meteorological and Oceanographic Conditions at the FINO platforms during the severe storms Christian and Xaver, DEWI Magazin, No.44, p16-25, 2014.

-data gaps in Hs and Hmax record for FINO1 FINO3 (6Dec2013 00:00-06:00 and 14:00-15:00) and FINO3 (6Dec2013 05:00-06:00); unknown instrument

MIROS ekolofik (2014) MIROS, Monthly report, Ekolofik, December 2013, Doc. No. ND1024/13/12, (prepared by SRS) 34pp, 9Jan2014

-[PDF document properties: author=Miros AS; datestamp=13Jan2014]

-low data capture rates especially for th wave recorders

MIROS heidrun (2014) MIROS, Manedrapport Heidrun, Desember 2013, Dok. Nr. ND1010/13/12, 21 pp, 07Jan2014, carried out by SRS, controlled by CNE, approved by OQ [pdf properties: author=Miros AS; date stamp: 08/01/2014]

-data gaps in water level data during Storm Xaver

MIROS heimdal (2014) MIROS, Manedrapport Heimdal, Desember 2013, Dok. Nr. ND1047/13/12 (carried out by SRS, controlled by CNE, approved by OQ) [PDF document properties: author=Miros AS; datestamp=06Jan2014]
- all wave data missing above Hs=5m; most information during Storm Xaver period

MIROS_norne (2014) MIROS, Maanedssportrap Norne, December 2013, Dok. Nr. ND/1087/11/12, 21pp, carried out by SRS, controlled by CNE, approved by OO [pdf properties: Author=Miros AS; datestamp: 06Jan2014] - no data from waverider buoy during Dec 2013

MIROS_sleepner (2014) MIROS, Maanedssportrap Sleipner A, December 2013, Dok. Nr. ND/1017/13/12, 06Jan2014, prepared by SRS, controlled by CNE, approved by OO. - gaps in water level and wave data during Storm Xaver

Gautier et al (2014) Gautier C, A Camarena, J van Nieuwkoop, SWAN hindcasts Wadden Sea, December 2013. Tidal inlet of Ameland and eastern Wadden Sea. Deltas, 2014, 197pp. Project 1209433-007, Reference 1209433-007-HYE-0005

Table S43. Model results and fields (arranged by year and then alphabetically)

Source
Cipollini et al (2014) Cipollini P, LJ West, HM Smaith, P Harwood, C Donlon, New altimetry products over shelf and coastal zone from the eSurge processor, poster presentation, 2014 [document time stamp: 2014/10/22] - DMI storm surge model to support Cryosat MIROS_sleipner - MIROS_norne (2014)
Deutschlander et al (2013) Deutschlander T, K Frerich, S Haeseler, C Lefebvre, Orkantief XAVER ueber Nordeuropa von 5. bis 7. Dezember 2013, Deutscher Wetterdienst DWD, Stand 30. Dezember 2013, 19pp.
Gccapitalideas (20131209) gccapitalideas, Windstorm Xaver, 9Dec2013, https://www.gccapitalideas.com/2013/12/09/windstorm-xaver/ - map of gusts during storm
KNMI (2013) KNMI, News report. De Zware storm van 5 december, 06 Dec 2013, https://www.knmi.nl/over-het-land/mediacentrum/nieuws/de-zware-storm-van-5-december
FIG1. [MAP] Surface pressure model field -06Dec2013. In 24h from 4-5Dec2013 the central pressure deepened by 41hPa. The criterion for rapid cyclogenesis is 24hPa in 24h
FIG2. [MAP] Precipitation warning for 5Dec2013 1700 along gust line front over De Bilt
FIG3. [MAP] showing large expanse of gust line
Kunz et al (2013) Kunz M, B Muehr, K Schroeter, T Bessel, S Moehrle, T Muenzenberg, S Brink, H-M Schmidt, Winterstorm Xaver - Report. 06Dec2013 - Report No.1, Situation Report - 19:00CET, CEDIM Forensic Disaster Analysis Group (FDA), Center for Disaster Management and Risk Reduction Technology.
-FIG1. Analysis of surface pressure and gust wind speed from Global Forecast System (GFS) on 5Dec2013 07:00CET, 19:00 and 06Dec2013 07:00CET
Unwetterzentrale (201312) Unwetterzentrale, Orkantief XAVER - ein weiterer schwerer Wintersturm der letzten Jahrzehnte, Thomas Savert and Stefan Laps, Dec. 2013 http://www.unwetterzentrale.de/uwz/928.html
-FIG4. [MAP] Animation of 10m model wspd together with surface pressure development from Wednesday 04Dec2013 1900MEZ to Saturday 07Dec2013 1900MEZ
FIG8. [MAP] Forecast of pressure on Friday 29Nov2013 for 06Dec2013, 1900MEZ (GFS model) FIG9. [MAP] Gust forecast of the European weather model at Mon 2Dec2013 for 5Dec 1900MEZ & 06Dec2013MEZ
FIG10. [MAP] Forecast of pressure division from 3Dec2013 for 5Dec2013 1900MEZ (ECMWF) FIG11. [MAP] Prediction of peak gusts from the ECMWF model from 4Dec2013 0100MEZ for 5Dec2013 1300-1900MEZ
FIG13. Animation of 850 hPa model average wspd (1500m) from 5Dec2013 0100MEZ to 7Dec2013 1900MEZ

Eriksen (2013) Eriksen J, Rekordvandstinde i Isfjorden og Roskilde Fjord, Vejret, 138, 2 40-48, 2014
-FIG14. [MAP] A GFS reanalysis for 6Dec2013 kl06UTC. The white line gives isobars. A high pressure center lies west of British isles & a power low P centre off Sweden's east coast.

Gautier et al (2014) Gautier C, A Camarena, J van Nieuwkoop, SWAN hindcasts Wadden Sea, December 2013. Tidal inlet of Ameland and eastern Wadden Sea. Deltas, 2014, 197pp. Project 1209433-007, Reference 1209433-007-HYE-0005
Hewson et al (2014)

Hewson T, L Magnusson, O Breivik, F Prates, I Tsonveisky, HW de Vries, Windstorms in northwest Europe in late 2013, ECMWF Newsletter, No 139, pp 22-28, Spring 2014.

-FIG5. Forecasts of 24h maximum wind between 00 and 24 UTC on 5Dec with mean sea level pressure for 12UTC on 5Dec from data times of (a) 00UTC on 3Dec and (b) 00UTC on 5Dec2013. Crosses denote the remnant of a meso-vortex discusses in the text.

Panel (c) shows verifying data from observations.

-FIG6. Maximum gust forecasts from ENS represented as the EFI and SOT for 00 to 24 UTC on 5Dec2013 from the data times (a) 00UTC on 30Nov, (b) 00UTC on 2Dec and (c) 00UTC on 4Dec. Panel (d) shows, for the same 24 period, maximum wind gust CDF's for Torsminde in NW Denmark from 14 ENS runs. M-CLim (black line) is the model climate.

Knaack and Heyken (2014)

Knaack H and H Heyken, Xaver hatte sehr schwere Sturmflut im Gepaeck, Jahresbericht 2013. Der Zukunft und Naturschutz, Niedersachsenscher Landesbetrieb fuer Wasserwirtschaft, Kuesten- en Naturschutz, pp.9-9, document date stamp 24Apr2014.

FIG. [MAP] Differences between Hurricane Christian and Hurricane Xaver in 2013. Christian came with strong winds from the southwest along the coast. Xaver had winds from northwest across the total length of the North Sea (modelled wind speeds over North Sea and northern Germany)

Nossent et al (2014)

Nossent J, M Deschamps, T Verwaet, F Vafidis, T Verwaet, Sinterklaastorm 6 december 2013. Beschrijving van de hydrometrische gebeurtenissen, Versie 4.0. WL Rapporten, 00-119, Waterbouwkundig Laboratorium, Antwerpen, Belgie. October 2014, WL2014R00_119_5 [document date stamp: 15Oct2014; author= Deschamps, Maarten]

* -FIG5. [TIMESERIES] Wind speed time series from Terneuzen; wspd max 2h later than expected

* -FIG6. [TIMESERIES] Wind speed time series from Hansweert; wspd max 2h later than expected

-FIG7. [TIMESERIES] Wind direction time series from Terneuzen

-FIG8. [TIMESERIES] Wind direction time series from Hansweert

-FIG9. [MAP] weather map 06Dec2015 0600UTC

-FIG10. [MAP] Model-derived wind fields at 06Dec2013 0100/0700/1300UTC

Pelt (2014)

Pelt AS, Bodils stormfods i de andre dansk farvande, Vejret, 138, 24-29, 2014

-FIG. Surface wind speed and direction for northwest Europe 06Dec2013 0400UTC

RWS (2014a)

RWS, Watermanagementcentrum Nederland, Stormvloedhjets 2013-07 van 5 t/m 7 december 2013, Rijkswaterstaat (document time stamp: 07Jan2014), 2014a

-FIG. Surface wind speed and direction for northwest Europe 06Dec2013 0400UTC

RWS (2014b)

RWS, Stormvloedrapport van 5 t/m 7 december (SR91) Sint-Nicolaasvloed 2013, Watermanagementcentrum Nederland, Rijkswaterstaat, prepared by Ing. J. Kroos, 19 Mar 2014b, 48 pp

FIG A4. [MAP] North Sea wind speed, direction, surface atmospheric pressure: 05Dec 0600UTC, 05Dec 1200UTC, 05Dec 1800UTC, 06Dec 0000UTC, 06Dec 0600UTC, 06Dec 1200UTC, 06Dec 1800UTC, 07Dec 0000UTC

SMHI (20140703)

SMHI, Simone, Hilde, Sven och Ivar okt-dec 2013, 3 Jul 2014, https://www.smhi.se/kunskapsbanken/meteorologi/simone-hilde-sven-och-ivar-okt-dec-2013-1.76183

-FIG. Map of wind speed return periods in southern Sweden

Stanev et al (2014)

Stanev E, J Staneva, S Grayek, J Schulz-Stellenfleth, S. Grashorn, A Behrens, Numerical modelling and data assimilation, COSYNA Progress Report 2013, pp 46-51, Helmholtz-Zentrum Geesthacht, June 2014.

-FIG5. Sea surface elevation (SLE) difference between coupled wave circulation model (WAM-GETM) and circulation model only (GETM) for the German Bight on 3Dec2013 (top) and during Storm Xaver on 6Dec2013 (bottom).

Staneva et al (2014)

Staneva J, K Wahle, E Stanev, Response of the German Bight Sediment Dynamics to Wave, Tide and Atmospheric Forcing, 3rd GODAE OceanView Coastal Oceans and Shelf Seas Task Team (COSS- TT) International Coordination Workshop, 21-24 January 2014, Roncon Beach Resort, Puerto Rico, 36pp

-FIG. [MAP] DWD weather map showing clouds and peak gusts

-FIG. [TIMESERIES] Time series of tide gauge data for 4 location German Bight 3-9Dec2013

-FIG. [TIMESERIES] modelled significant wave height German Bight 3-9Dec2013

Axer et al (2015)

Axer T, T Bistry, M Klawa, M Mueller, M Szesser, Deutsche Ruch Sturm dokumentation 2013 Deutschland, 2014, Deutsche Ruchversicherung Achtiggessellschaft, Hansaallee 177, 40549 Duesseldorf, https://www.deutscheunerck.de[pdf document information: author=feliz; date stamp=07Aug2015]

-FIG. Hurricane gust field Hurricane Xaver 05/12/2013

Cipollini et al (2015)

Cipollini P, J Benveniste, H Bonekamp, L Miller, M Picot, P Ted Strub, D Vandemark, S Vignudelli, Recovering more and better data from altimetry in the coastal zone: a community effort, Pilot ARCOM workshop Lisbon, 28, Spring 2014.

-FIG. [MAP] DMI model of storm Xaver sea level Friday 06Dec2013 23:05 (Madsen etal).

Fenoglio-Marc et al (2015)

Fenoglio-Marc L, R Scharroo, A Annuziato, L Mendoza, M Becker, J Lillbridge, Cyclone Xaver seen by geodetic observations, Geophys Research Letters, 42, 9925-9932, 2015

-FIG. [MAP] North Sea storm surge elevations for BSHnord and HyFlux2

NLWKN (20151210)

NLWKN 20151210, Stormfutwademansdel der Betriebstelle Norden-Norderney, NLWKN Niedersachsisscher Landesbetrieb fuer Wasserwirtschaft, Kuesten- und Naturschutz, Niedersachsen, document date stamp 10Dec2015.

-FIG. Modelled forecast wspd & wdir for 06Dec2013 010000MEZ (12h forecast).

Patzer (2015)

Patzer, Marianne, Storm surge forecasting at DMI and perspectives on teh use of Earth Observations, ESA eSurge
Cheliotsis, I. G. Varlas, K. Christakos, The impact of cyclone Xaver on hydropower potential in Norway, conference paper, September 2016 In: T Karaoas, A Bais, PT Nastos (ed), Perspectives on Atmospheric Sciences, Springer Atmospheric Sciences, Springer, Cham, 2017 https://doi.org/10.1007/978-3-319-35055-0_25, first online 10Sep2016 [pdf document properties: author=Konstantinos Christakos; datestamp: 07/09/2016]
-WRF model assessment of Norway precipitation during Storm Xaver

Christakos K, I Cheliotis, G Varlas, G J Steenewelld, Offshore wind energy analysis of Cyclone Xaver over North Europe with Deep Sea Offshore Wind R&D Conference, EERA DeepWind2016, 20-22 January 2016, Trondheim, Norway, Energy Procedia, 94, 37-44, 2016.

ECMWF (20160316), WRF model assessment of Norway precipitation during Storm Xaver

Staneva J, H Guenther, E Stanev, Coastal flooding: impact of storm surge during extremes - a case study for the German Bight, Natural Hazards Earth Syst. Sci., 16, 2373-2389, 2016

Staneva J, E Stanev, Coastal flooding: impact of storm surge during extremes - a case study for the German Bight, Nat. Hazards Earth Syst. Sci., 16, 2373-2389, 2016
waves on the air-sea momentum fluxes for different wind and sea state conditions and oceanic responses, 1st International Workshop on waves, storm surges and coastal hazards, Liverpool, UK 10-15Sep2017 [pdf document properties: title=Anlass; author=Patrick Kalb-Anlass, datestamp=20/09/2017]

-FIG. [MAP] model field of significant wave height 04Dec2013 21:00

-FIG. [MAP] model field of 10m wind speed 03Dec2013 11:00

-FIG. [MAP] Maps comparing wave processes during Storm Xaver 5-6Dec2013 versus Oct-Dec2013 average

Wahle et al (2017) Wahle K, J Staneva, W Koch, L Fenoglio-Marc, HTM Ho-Hagemann, EV Stanev, An atmosphere-wave regional coupled model: improving prediction of wave heights in the southern North Sea, Ocean Sci., 13, 289-301, 2017.(doi:10.5194/os-13-289-2017).

-model can not capture small scale features in altimeter-derived significant wave height

-FIG9. [MAP] Significant wave height in the North Sea and German Bight at the peak of storm Xaver (6Dec2013)

-FIG10. [MAP] Average difference and rms difference of WAM modelled SWH and COSMO modelled wind speed when comparing one-way minus two way coupled modelling results. Differences are calculated as averages over the whole 3-month period.

-FIG11. [MAP] COSMO pressure (Pa) at mean sea level height in the North Sea during storm Xaver and (b) mean sea level pressure difference when comparing one-way minus two-way coupled modelling.

Fery et al (2018) Fery, Natascha, Birger Tinz, Lydia Gates, Reproduction of storms over the North Sea and the Baltic with the regional analysis COSMO-REA6 ISPR 2018, 17-19July2018, Bonn [pdf document properties: datestamp=16/07/2018]

-UK Coastal Monitoring and Forecast Service: frequency of severe and extreme events predicted to increase in future due to onset of global climate change

Niehuser et al (2018) Niehuser S, S Dangendorf, A Arns, J Jensen, A high resolution storm surge forecast for the German Bight, Conference: 9th Chinese-German Joint Symposium on Coastal and Ocean Engineering, Tainan, Taiwan, 2018 -Fig 12. [MAP] maps of vectors sowing wind speed ad direction at 12 h intervals 5-7 Dec 2013.

Table S44. Climatological background of storm; unusual preceding weather events (arranged by year and then alphabetically)

| Source | Full Reference and Notes |
|--------|--------------------------|
| BODC (201311205) | BODC, Storm surge and coastal flooding, News and Events, 5Dec2013. [url=https://www.bodc.ac.uk/about/news_and_events/storm_surge_and_coastal_flooding.html] |

| Met Eireann (2013) | Met Eireann, Monthly Weather Bulletin 2013 issues, Met Eireann, Glasnevin Hill, Dublin 9. |
|-------------------|------------------------------------------------------------------------------------------|
| * -warmest temperature measured in the northern hemisphere and world during April: 47.0 at Matam, Senegal on April 16. Seychelles International Airport had record 34.8C on April 10. |
| * -coldest temperature in the southern hemisphere and world -76.3C Dome Fuji, Antarctica April 3 |
| * -after 6days in early July with air>40C, Portugal officially entered a heatwave |
| * Rising temperatures led to heat health warnings for southern England & the Midlands for the UKs first prolonged heatwave since 2006 on 17July. The UK recorded its hottest day since July 2006 with 33.5C at Heathrow & Northolt west London on 22July |
| * -Powerful thunderstorms swept through parts of central & western Europe between 4-7Aug causing widespread damage & state of emergency in the Czech Republic. |
| * -Excessive rainfall led to major flooding across eastern Romania 11-15 killing at least 9 people. |
| * -Nov 8 one of strongest tropical cyclones ever recorded made landfall central Philippines: Super Typhoon Haiyan 8Nov2013. Category 5 with max sustained wind 315kph. Storm surge 6m. 8000 people killed or missing. |

| NLWKN (20131203) | NLWKN, Sturmflutgefahren an der Kueste und auf den Inseln, Zwei meter ueber dem normalen Hochwasser in der Nacht zum Freitag moeglich/pressinformation von 29 November 2013; (written by Herma Heyken, Pressesprecherin) , 03/12/2013 [url=https://www.nlwkn.niedersachsen.de/startseite/aktuelles/presse_und_offentlichkeitsarbeit/pressemitteilungen/sturmflutgefahren-an-der-kueste-und-auf-den-inseln-120187.html] |
|-----------------|---------------------------------------------------------------------------------------------|
| -NLWKN registered 17 storm surges in 2 month period from end Nov 2011 to end Jan 2012, then 12 month quiet period, then Hurricane Lennart Jan 2013, last great storm surge before Storm Xaver |
| -low storm surge activity 1950'-1960s; high activity 1970s-1980s and 2006—2008 |

| AON Bentfield (2014) | AON Bentfield, Impact forecasting. December 2013 Global Catastrophe Recap, 2014. [document properties: brand=abrandt; date stamp: 10Jan2014] |
|-------------------|----------------------------------------------------------------------------------|
| -patterns of severe weather across globe |
| -Storm Xaver: 15 dead, 800mill EUR insured loss; total loss higher |
| -hurricane-force wind, heavy rain, thunderstorms, highest recorded coastal tide |
| -damage heaviest Scotland, Germany, Netherlands, Belgium, Scandinavia, Poland |
| -Storm Dirk: 6 dead; insured loss 360 mill EUR |
| -main damage UK, France, Spain |
| -winter storm US early Dec; 18 dead; southern plains to New England; loss 100mill USD |
- another winter storm central & E US & E Canada killed 29 people
- one strongest winter storms in years Middle East; 10 deaths
- some of worst flooding 90 years affected SE Brazil killing 48 people; 14 billion USD
- heavy snow & rain China; no fatalities; 90,000 homeless from collapsed roofs; 410 million USD
- eastern Malaysia: seasonal monsoon rains caused floods
- floods Cuba, Leeward Islands, Indonesia
- Cyclone Christine made landfall W Australia

Eden (201402)  Eden, Phillip, Weather Log December 2013, Weather, Feb 2014, pp.1-iv
- in last 100 years there were 10 warmer winters

Goemert et al (2014)  Goemert G, O Mueller, M Schaper, K Sossudh, Die Sturmflut nach dem Tief Xaver von 5. bis 7. Dezember 2013. Berichte des Landesbetriebes Strassen, Bruecken und Gewaesser (LSBG), Freie und Hansestadt Hamburg, Nr. 16/2014, 26pp.
- mention of flooding on Eble and Danube in June 2013

Knaack and Heyken (2014)  Knaack H and H Heyken, Xaver hatte sehr schwere Sturmflut im Gepaeck, Jahresbericht 2013. Der Zukunft verpflichtet, NLWKN. Niedersachsischer Landesbetrieb fuer Wasewirtschaft, Kuesten- und Naturschatz, pp.8-9, document date stamp 24 Apr 2014.
- winter 2012-2013 was quiet with only one light storm surge at end of January 2013

RMS (2014)  RMS, 2013-2014 Winter Storms in Europe. An Insurance and Catastrophe Modeling Perspective. RMS White Paper. [PDF TIMESTAMP 11 Mar 2014]
- very cold polar air over Canada & warmer SST in subtropical west Atlantic caused stronger jet stream E seabd
- northerly deflection of North Pacific Jet
- jet stream strengthened by 30% greater than normal
- series of storms channelled across North Atlantic but most had nadir pressure west of UK and therefore gave lots of precipitation instead of strong winds. Storm Xaver was exception with pressure nadir east of UK

Slingo et al (2014)  Slingo J, S Belcher, A Scaife, M McCarthy, A Sautler, K McBeath, A Jenkins, C Huntingford, T Marsh, J Hannaford, S Parry, The Recent Storms and Floods in the UK, 29pp, Met Office, Fitzroy Road, Exeter, Devon, EX1 3PB, UK, February, 2014 [pdf document properties: author=huw.lewis; date stamp=11 Feb 2014]
- unusual winter UK storms from strengthened jet stream in fixed position over Pacific and North Atlantic
- unusual cold conditions over Canada and US
- moisture convergence area in southwest US
- storms over Indonesia and warm conditions in western Pacific
- El Nino not a contributor to UK storm pattern
- North Atlantic storm track deflected to more southern latitudes; storms carry more moisture and severe sea state to southwest Ireland and UK.

Axer et al (2015)  Axer T, T Bistry, M Klawa, M Mueller, M Suesser, Deutsche Ruck Sturm dokumentation 2013 Deutschland, 2013, document date stamp 24 Apr 2014.
-,in the last 100 years there were 10 warmer winters

Haigh and Bradshaw (2015)  Haigh J and E Bradshaw, A century of UK coastal flooding, Planet Earth, Winter 2015, (pdf document properties: [PDF TIMESTAMP 13 Jan 2016]), cluster of 7 severe surge events during winter 2013/2014 of 96 events in database
- Super typhoon Haiyan in Philippines Nov 2013

Kendon and McCarthy (2015)  Kendon M and M McCarthy, The UK's wet and stormy winter of 2013/2014, Weather, 70, 40-47, 2015
- UK wet & stormy conditions linked to low temperatures North America
- persistence & unusual strength of jet stream
- high SST and westward displacement of precipitation in tropical Pacific

Wikipedia (20200502)  Wikipedia, Orkan Xaver, https://de.wikipedia.org/wiki/Orkan_Xaver (accessed 2 May 2020)
- Storm Xaver followed more powerful Storm Christian on 28 Oct 2013
- large scale weather pattern that also caused low temperatures in North America
- pattern of unusual weather lasted until end of December

Table S45. Xaver surge soon after spring tide; phase of surge and tide (arranged by year and then alphabetically)

| Source | Full Reference and Notes |
|--------|--------------------------|
| GVA (20131205) | GVA, Voj containers even op drift op de Schelde, 05/12/2013 20:57. https://www.gva.be/cnt/aad1500792/vgj-containers-op-drift-op-de-schelde-2  |
| - coincidence of storm and spring tide causes problems at Antwerp |

| Unwetterzentrale (201312) | Unwetterzentrale, Orkantief XAVER - ein weiterer schwerer Wintersturm der letzten Jahrzehnte, Thomas Savert and Stefan Lap, Dec. 2013 http://www.unwetterzentrale.de/uwz/928.html  |
| - new moon on 3 Dec 2.5 days before storm |

| Hewson et al (2014) | Hewson T, L Magnusson, O Brevik, F Prates, T Tsonesvky, JW de Vries, Windstorms in northwest Europe in late 2013, ECMWF Newsletter, No 139, pp 22-28, Spring 2014. |
| - Evidently the peak of the storm surge coincided quite closely with the fortnightly spring tide which will occur two of three days after the moon is new or full |

| Nossent et al (2014) | Nossent J, L Bocckx, E Taverniers, M Deschamps, T Verwaest, F Mostaert, Sinterklaastorm 6 december 2013. Beschrijving van de hydrometrische gebeurtenissen, Versie 4.0, WL Rapporten, 00-119, Waterbouwkundig Laboratorium, Antwerpen, Belgium. October 2014, WL2014R0119_S [document date stamp=15 Oct 2014; authors=Descamps, Maarten] |
| - listing of high and low water levels at Antwerp showing spring tide during storm |
| - spring tides about 2.5 days after full and new moon; new moon on 2-3 Dec 2013 |

| Axer et al (2015) | Axer T, T Bistry, M Klawa, M Mueller, M Suesser, Deutsche Ruck Sturm dokumentation 2013 Deutschland, |
| - in the last 100 years there were 10 warmer winters |
Table S46. Tide analysis (arranged by year and then alphabetically)

**Source** | Full Reference and Notes
---|---
Gonnert et al (2004) | Gonnert G, K Iser, H Giese A Phuess, Charakterisierung der Tidekurve, Die Kueste, 68, 99-141, 2004
- includes M4 and M6 tides in partial tide analysis
- tide component amplitudes Helgoland: O1(8.9cm); K1 (10-11cm); M2 (dominant); M4 (7-10cm); M6(1-5cm)

Gonnert et al (2009) | Gonnert G, J Jensen, H von Storch, S Thamm, T Wahl, R Weisse, Der Meerespiegelanstieg. Ursachen, Tendenzen, und Risikobewertung, Die Kueste, 76, FAK (2009), 225-256.
- Normal Null reference level 0m appears about 1945
- MThw calculated over annual data segments
- FIG6. Time series of local avg MSL (annual average) for tide gauge Cuxhaven with smooth fitting function.
- Note sea level given in cmNN with zero-crossing at 1945.
- acceleration of curve since 1970s
- FIG7. Time series of avg high MThw for tide gauge Cuxhaven using annual avg (Gonnert et al 2007)

Goennert et al (2012) | Goennert G, Gerkensmeier, J-M Mueller, Ermittlung des Sturmflutbemessungswasserstandes fuer den oeffentlichen Hochwasserschutz in Hamburg, Berichte des Landesbetriebes Strassen, Bruecken und Gewaesser Nr 12/2012.
- explanation of surge residual difference calculated using average tidal cycle versus astronomical tide. (FIG23)

Deutschlander et al (2013) | Deutschlander T, K Friereich, S Haeseleer, C LeFebvre, Orkantief XAVER ueber Nordeuropaer von 5. bis 7. Dezember 2013, Deutscher Wetterdienst DWD, Stand 30. Dezember 2013, 19pp.
- MThw and MTaw indicated on diagrams for Husum, Norderney-Rifgat, Flensburg, Warnemunde, and Hamburg St. Pauli

Jensen et al. (2013) | Jensen J, S Nielhuser, A Amm, S Dangendorf, Sensor- und risikobasierter Fruehwarn-system fuer Seedeiche (EarlyDike), AP1 - Sturmflutmonitoring und Sturmflutsimulator - Fachbericht 2016, Siegen, April 2017
- tide components included in DTU10 model: M2, S2, N2 K2, K1, O1, P1, Q1, S1, M4 (shallow water tide)

McGarriche et al (2013) | McGarriche P (ed), UK coastal monitoring and forecasting: Annual report for 2013 for the UK National Tide Gauge Network, NERC 100017897, 2013 [pdf document properties: author=pmacg; created=16Apr2014]
- Doodson X0 filter used for sea level calculation
- check of temporal drift of tidal components: M2,S2,K1,O1 and Z0

Stanev et al (2014) | Stanev E, J Staneva, S Grayek, J Schulz-Stellenfleth, S Grashorn, A Behrens, Numerical modelliing and data assimilation, COSYNA Progress Report 2013, pp.46-51. Helmholtz-Zentrum Geesthacht, June 2014.
- tide components included in NEMO model: M2, S2, N2, K2, K1, O1, P1, Q1, M4
- unidivided coefficients from harmonic analysis provided by the OSU Tidal Inversion Software (OTIS)

Axer et al (2015) | Axer T, T Bistry, M Klawa, M Mueller, M Suess, Deutsche Ruck Sturm dokumentation 2013 Deutschland, 2013, Deutsche Rueckversicherung Aktiengesellschaft, Hansaallee 177, 40549 Duesseldorf, www.deutscherueck.de [pdf document information: author=filiz; date stamp=07Aug2015]
- absolute water levels not good because of river dredging and sea level rise; height over average high tide better

Fenoglio-Marc (2015) | Fenoglio-Marc L, R Scharroo, A Anzuatti, L Mendoza, M Becker, J Lilibrige, Cyclone Xaver seen by geodetic observations, Geophys Research Letters, 42, 9925-9932, 2015
- global ocean tide model GOT4.8 (Ray et al 2011)
- time series stations detides with Matlab software T_TIDE (Pawlowski et al 2002)

Gourgue et al (2015) | Gourgue O, BB Sishah, J Vanlede, H Komijani, M Chen, Modelling tides and storm surges on the European continental shelf, 22nd Telemac & Mascaret User Club, STFC Daresbury Laboratory, UK, 13-16 October 2015. [PDF document properties: datestamp: 05/10/2015]
- OSU Tidal Data Inversion Products
- OTIS Atlantic Ocean tidal solution; amplitude and phase of 11 harmonic constituents
- OSU Topex/Posidon Global Inversion Solution (TPXO): amplitude & phase of 13 harmonic constituents

Sibley et al. (2015) | Sibley A, D Cox, H Tiley, Coastal flooding in England and Wales from Atlantic and North Sea storms during the 2013/2014 winter, Weather, 70, 62-70, 2015
- FIG2. Met Office North Sea storm surge extended forecast model predictions for Lowestoft and North Shields from 01Dec2013 0600UTC and 05Dec2013 0000UTC. Forecast 01Dec2013 shows extreme surge possibility but 12h later than it actually occurred. Forecast 05Dec2013 gives quantitative flood levels 18h ahead.

Wadey et al. (2015) | Wadey MP, ID Haigh, RJ Nichols, JM Brown, K Horsburgh, B Carroll, SL Gallop, T Mason, E Bradshaw, A comparison of the 31 January-1 February 1953 and 5-6 December 2013 coastal flood events around the UK, UK Frontiers in Marine Science, 2, 84, 2015.
- 'Where high frequency time series longer than a month of data are available, sea levels were separated into the main component parts of tide, non-tidal residual (usually mostly surge) and MSL (Pugh , 1987).'
- 'For most of the 1953 HW recordings, there is not enough data available for a comparative tidal analysis. This is because the data is a single HW value, or in the case of Rossiter (1954), a 7-day time series'
Table S47. Data filtering and discretization issues (arranged by year and then alphabetically)

| Source                                                                 | Full Reference and Notes |
|----------------------------------------------------------------------|--------------------------|
| Oceanografisch Meteorologisch Station (2013)                        | Oceangrafisch Meteorologisch Station, Stormverslag 05-06 december 2013, 26pp, 2013 [pdf document properties: author=Miyriam Sys; datestamp=15Dec2013] -comment on differences between 5-min data, 1-min data and highest manual measurement |
| RWS (2014b)                                                          | RWS, Stormvloedrapport van 5 t/m 7 december (SR91) Sint-Nicolaasvloed 2013, Watermanagementcentrum Nederland, Rijkswaterstaat, prepared by Ing. J. Kroos, 19 Mar 2014b, 48 pp -global average of significant wave height and period: running average three 20 minute data segments |
| Spencer et al (2015)                                                 | Spencer T, SM Brooks, BR Evans, JF Tempest, I Moeller, Southern North Sea storm surge event of Dec.5, 2013: Water levels, waves, and coastal impacts, Earth Science Reviews, 146, 120-145, 2015 -UK water level data stored at 15min intervals to overcome seiche and wave effects |
| Wadef et al (2015b)                                                  | Wadef MP, JF Brown, ID Haigh, T Dolphin, P Wisse, Assessment and comparison of extreme sea levels and waves during the 2013/2014 storm season in two UK coastal regions, Nat. Hazards Earth Syst. Sci. Discuss., 3, 2665-2708, 2015b. -BODC 15min sampling interval chosen to remove seiches and waves |
| Thompson et al (2020)                                                | Thompson F, EN Renzel, A Sibley, DR Tappin, UK meteotsunamis: a revision and update on events and their frequency, Weather, 2000. -problems with characterizing meteotsunamis in UK data sets because of 15 min discretization interval -European data sets better to work with because they have 1 minute resolution |

Table S48. Difficulties in modelling Storm Xaver water levels and surge (arranged by year and then alphabetically)

| Source                                                                 | Full Reference and Notes |
|----------------------------------------------------------------------|--------------------------|
| Gautier et al (2014)                                                 | Gautier C, A Camarena, J van Nieuwkoop, SWAN hindcasts Wadden Sea, December 2013. Tidal inlet of Ameland and eastern Wadden Sea. Deltares, 2014, 197pp. Project 1209433-007, Reference 1209433-007-HYE-0005 -observation overshoot of model predictions mostly below 0.5m -Difflizijl had 1m observation overshoot at the height of the storm surge |
| Kristandl et al (2014)                                               | Kristandl, J., B. Brecht, H, Frank, H., Kaack, Optimization of empirical storm surge forecast-modeling of high resolution wind fields, Die Kuse, 81, 301-348, 2014 -new empirical surge level parameterizations give modelled water levels good to 20cm of observations. |
| Nosent et al (2014)                                                  | Nosent J, J, Boeckx, E Taverniers, M Deschamps, T Verwaet, F Mostaert, Sinterklaasstorm 6 december 2013. Beschrijving van de hydrometrische gebeurtenissen. Versie 4.0, WL Rapporten, 00-119, Waterbouwkundig Laboratorium, Antwerpen, Belgje. October 2014, WL2014R00_119_5 [document date stamp: 15Oct2014; author= Deschamps, Maarten] -2 hour difference between measured and modelled wind speeds at Hansweert and Terneuzen |
| Zijl et al (2015)                                                    | F Zijl, J Sumihar, M Verhaan, Application of data assimilation for improved operational water level forecasting on the northwest European shelf and North Sea, Ocean Dynamics, 65, 1699-1716, 2015 -model predicted surge level 35cm under true level for Hoek of Holland |
| Staneva et al (2016a)                                                | Staneva J, K Wahle, H Guenther, E Stanen, Coupling of wave and circulation models in coastal-ocean predicting systems: a case study for the German Bight, Ocean Sci., 12, 797-806, 2016a. -difference in water levels between coupled wave-circulation model and wave only model 30cm along German Bight coast and >50cm for Waddensee. |
| Staneva et al (2016b)                                                | Staneva J, K Wahle, W Koch, A Behrens, L Fenoglio-Marc, EV Stanen, Coastal flooding: impact of waves on storm surge during extremes - a case study for the German Bight, Nat. Hazards Earth Syst. Sci., 16, 2373-2389, 2016 -smallest RMSE error 0.15m between best model run and set of BODC tide gauge stations -smallest bias of -0.10m between best model run and set of BODC tide gauge stations |
| Staneva et al (2017b)                                                | Staneva J, C Schrum, A Behrens, S Grayek, H Ho-Hagemann, V Alan, O Breivik, J-R. Bullot, A North Sea-Baltic Sea Regional Coupled Models: Atmosphere, wind waves and ocean, in Proceedings of the Eighth EuroGOOS International Conference (Operational Oceanography. Serving Sustainable Marine Development), 3-5 October 2017, Bergen, Norway, 2017b. -ordinary surge model underpredicts actual surge -0.48m difference between surge model with and without waves |
| Wahle et al (2017)                                                   | Wahle K, J Staneva, W Koch, L Fenoglio-Marc, HTM Ho-Hagemann, EV Stanen, An atmosphere-wave regional coupled model: improving prediction of wave heights in the southern North Sea, Ocean Sci, 13, 289-301, 2017.(doi:10.5194/os-13-289-2017). -model can not capture small scale features in altimeter-derived significant wave height |
| Niehuser et al (2018)                                               | Niehuser S, S Dangendorf, A Arns, J Jensen, A high resolution storm surge forecast for the German Bight, Conference: 9th Chinese-German Joint Symposium on Coastal and Ocean Engineering, Tannan, Taiwan, Taiwan, 2018 -RMSE at stations range from 0.13m (for Helgoland) to 0.20m (for Husum) -maximum surge model prediction differences: 78cm for Wyk, 90cm for Husum & Emden, 27cm for Norderey |
| Wikipedia (20191002)                                                | Wikipedia, Stormen Bodil, https://da.wikipedia.org/wiki/Stormen_Bodil#cite_note-39 [accessed 02Oct2019] -Calais & Boulogne-sur-Mer large differences between expected and meas water levels |

Table S49. Future sea level rise and flooding effects (arranged by year and then alphabetically)
Goennert et al (2012) Goennert G, B Gerkensmeyer, J-M Mueller, Ermittlung des Sturmnflutbemessungswasserstandes fuer den offentlichen Hochwasserschutz in Hamburg, Berichte des Landesbetriebes Strassen, Bruecken und Gewaesser Nr 12/2012.

The Lowestoft Journal (20131214) The Lowestoft Journal, Suffolk MP hits out at environment secretary in statement about the floods, 14Dec2013, correspondent: Annabelle Dickson.

ABPmer (2014) ABPmer, Ensuring Flood Resilience. An overview of the 5/6 December 2013, Associated British Ports, Marine Environmental Research, July, 2014

Dunbar et al (2014) Dunbar I, N Phipps, M Szonyi, Risk Nexus. After the storm: how the UK's flood defences performed during the surge following Xaver, Flood resilience review 09.14, Zurich Insurance Company Ltd., Mythenquai 2, 8002, Zurich, Switzerland [document properties: date 28Aug2014; author= Zurich]

Slingo et al (2014) Slingo J, S Belcher, A Saffe, M McCarthy, A Saulnier, K McBeath, A Jenkins, C Huntingford, T Marsh, J Hannaford, S Parry, The Recent Storms and Floods in the UK, 29pp, Met Office, Fitzroy Road, Exeter, Devon, EX1 3BP, UK, February, 2014 [pdf document properties: author=hwu;lewis; date stamp=11Feb2014]

Sibley et al. (2015) Sibley A, D Cox, H Tittley, Coastal flooding in England and Wales from Atlantic and North Sea storms during the 2013/2014 winter, 2013-2014, Weather, 70, 62-70, 2015

Haigh and Bradshaw (2015) Haigh I and E Bradshaw, A century of UK coastal flooding, Planet Earth, Winter 2015, (pdf document properties: 13Jan2016)

Spencer et al (2015) Spencer T, SM Brooks, BR Evans, JA Tempest, I Moeller, Southern North Sea storm surge event of Dec,5, 2013: Water levels, waves, and coastal impacts, Earth Science Reviews, 146, 120-145, 2015

Wadey et al (2015b) Wadey MP, IM Brown, ID Haigh, T Dolphin, P Wisse, Assessment and comparison of extreme sea levels and waves during the 2013/2014 storm season in two UK coastal regions, Nat. Hazards Earth Syst. Sci. Discuss., 3, 2665-2708, 2015b.

Brooks et al (2016) Brooks SM, T Spencer, A McIvor, I Moeller, Reconstructing and understanding the impacts of storms and surges, southern North Sea, Earth Surface Processes and Landforms, 41, 855-864, 2016.

Dangendorf et al (2016) Dangendorf S, A Arns JG Pinto, P Ludwig, J Jensen, The exceptional influence of storm 'Xaver' on design water levels in the German Bight, Environmental Research Letters, 11, 2016, 054001

Gerber et al (2016) Gerber M, A Ganske, S Mueller-Navarra, G Rosenhagen, Categorization of meteorological conditions for storm tide episodes in the German Bight, Meteorologische Zeitschrift, 25, 447-462, 2016.

Sorensen et al (2016b) Sorensen C, NH Broge, MR Molgaard, CS Schow, PThomsen, K Vognsen, P Knudsen, Assessing future flood hazards for adaptation planning in a northern European Coastal Community, Frontiers in Marine Science, 3,69, doi:10.3389/fmars.2016.00069, 2016b

Niehuser et al (2018) Niehuser S, S Dangendorf, A Arns, J Jensen, A high resolution storm surge forecast for the German Bight, Conference: 9th Chinese-German Joint Symposium on Coastal and Ocean Engineering, Tainan, Taiwan, 2018

WIKI (20200124) WIKI: Cyclone Xaver, https://en.wikipedia.org/wiki/Cyclone_Xaver accessed 24Jan2020

Table S50. Storm event as manifestation of climate change (arranged by year and then alphabetically)
- Report. 06Dec2013 - Report No.1. Situation Report - 19/00CET. CEDIM Forensic Disaster Analysis Group (FDA), Center for Disaster Management and Risk Reduction Technology.
- single events such as Xaver cannot be attributed to any changes in the local or regional climate'
- 'according to statistical analysis from regional climate models, extreme wind speeds increase in the future over several European regions such as Northern Germany’ southern Germany with decrease in storm speeds
- intensity of recent storms unusual but not necessarily unprecedented
- continued run of deep depressions Dec-Jan-Feb is not common
- ‘it raises the possibility that disruption of our usual weather patterns may be how climate change may manifest itself’
- heavy rain events becoming more freq. 125d rain event fro 1960s becomes 85d rain event now
- ‘it is not possible yet to give a definitive answer on whether climate change has been a contributor or not’

Thorne (2014)
Thorne, Colin, Geographies of UK flooding in 2013/4, The Geographical Journal, 180, 297-309, 2014.
- ‘A causal link to climate change cannot be proved for any of the floods of 2013/13, but they (and the jet stream pattern and position that generated them) do look like those predicted in a warming world’
- ‘As yet, there is no definitive answer on the possible contribution of climate change to the recent storminess, rainfall amounts and the consequent flooding.
- ‘This is partly due to the highly variable nature of UK weather and climate
- ‘couple of decades needed to clarify whether floods 2013/14 from extreme whether or start of climate change pattern
- ‘Although no individual storm can be regards as exceptional, the clustering and persistence of storms is highly unusual’

Kendon and McCarthy (2015)
Kendon M and M McCarthy, The UK's wet and stormy winter of 2013/2014, Weather, 70, 40-47, 2015
- question if UK experiencing more record breaking weather than in the past;
- highly variable nature of UK's climate

Sibley et al (2015)
Sibley A, D Cox, H Tittley, Coastal flooding in England and Wales from Atlantic and North Sea storms during the 2013/2014 winter, Weather, 70, 62-70, 2015
- 'Julia Slingo: ’it is uncertain whether these coastal flood events can be attributed directly to climate change’ (Slingo, 2014)

Sorensen (2016)
Sorensen CS, Water NOT wanted - Coastal floods and flooding protection in Denmark, In RA Herrmann & J Jensen (eds), Sicherung von Dammen, Deichen und Stauanlagen: Handbuch fuer Theorie und Praxis (Vol V pp.3-21). Siegen: Universistaet Siegen, 2016
- ‘different to the 2006 event the floods were perceived more as a consequence of climate change than being due to an extreme event’

WIKI (20200124)
WIKI, Cyclone Xaver, https://en.wikipedia.org/wiki/Cyclone_Xaver accessed 24Jan2020
- Peter Aldous (MP Waveney) house of Commons debate: ‘It is wrong to dismiss these floods as a one in 500-year occurrence. There were floods six years ago. I think with rising sea levels these are to be a thing of the future and we do need to be looking at protecting the most vulnerable areas.’

Wikipedia (20200502)
Wikipedia, Orkan Xaver, https://de.wikipedia.org/wiki/Orkan_Xaver (accessed 2 May 2020)
- 'much media attention on Storm Xaver because of public awareness of climate change and weather extremes
- repeated extreme storm reports helped avert damage in Cuxhaven.

Table S51. Baltic Sea events (arranged by year and then alphabetically)

| Source                          | Full Reference and Notes                                                                                                                                                                                                                                                                                                                                 |
|--------------------------------|----------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| BBC (20131206)                 | BBC20131206, Deadly storm and tidal surge batter northern Europe, BBC 6 Dec2013 (report by Anna Holligan)
- 2 sailors swept off ship on south coast Sweden
- Poland: 400000 homes without power; 3 fatalities due to tree falling on car.                                                                                                                                                                                                                       |
| Daily Mail (20131206)         | Daily Mail, Huge storm strikes Europe causing death and destruction and leading to cancellation of hundreds of flights, 6Dec2013. (correspondent: Nick Enoch), https://www.dailymail.co.uk/news/article-2519517/Huge-storm-strikes-Europe-causing-death-destruction-leading-cancellation-hundreds-flights.html
- gusts cause fatal traffic accident in N Poland; Poland LOT airline cancels flights.                                                                                                                                                                                                                                                                         |
| Deutschlandet al (2013)        | Deutschlander T, K Friereich, S HaeCELER, C Lelefbvre, Orkantief XAVER uebcr Nordeuropa von 5. bis 7. Dezember 2013, Deutscher Wetterdienst DWD, Stand 30. Dezember 2013, 19pp.
- water level time series for Flensburg and Warnemuende
- model field of significant wave height for Baltic Sea
- summary of met-ocean data for Poland                                                                                                                                                                                                                                                                                                                          |
| Kunz (20131206)               | Kunz M, B Muehr, K Schroeter, T Bessel, S Moehrlt, T Muenzberg, S Brink, H-M Schmidt, Winterstorm Xaver - Report. 06Dec2013 - Report No.1, Situation Report - 19/00CET. CEDIM Forensic Disaster Analysis Group (FDA), Center for Disaster Management and Risk Reduction Technology.
- event description on German Baltic Sea coast                                                                                                                                                                                                                                                                                                                   |
| SMHI (20131210)               | SMHI Stormen Sven gav nya vattenstandsrekord i Oresund, https://www.smhi.se/nyhetsarkiv/stormen-sven-gav-nya-vattenstandsrekord-i-oresund-1.34732, updated 20Mar2017; original datestamp 10Dec2013.
- water level extremes around coast of Sweden from Stockholm to Norway
- extreme minimum water levels on Baltic Sea coast                                                                                                                                                                                                                                                                                                               |
| Unwetterzentrale (201312)     | Unwetterzentrale, Orkantief XAVER - ein weiterer schwerer Wintersturm der letzten Jahrzehnte, Thomas Saverett and Stefan Laps, Dec. 2013 http://www.unwetterzentrale.de/uvz/928.html
- vegetation damage; numerous trees down
- gusts and snowfall accumulations for the German Baltic Sea region.                                                                                                                                                                                                                                                                                           |
| Leiding et al (2014)           | Leiding T, B Timz, G Rosenhagen, C Lefevre, S HaeCELER, S Hagemann, I Bastigkeit, D Stein, P Schwenk, S Mueller, O Outzen, K Herkelot, F Kinder, T Neumann, Meteorological and Oceanographic Conditions at the
FINO platforms during the severe storms Christian and Xaver, DBW1 Magazin, No.44, p16-25, 2014.
• meteorological conditions at FINO1.

Pelt (2014) Pelt AS, BODIL’S stormfodde i de indre dansk farvande, Vejret, 138, 24-29, 2014
• unusually low water levels south of Danish Belt during Storm Bodil; opposite of Storm Britta

SMHI (201407/03) SMHI, Simone, Hilde, Sven och Ivar okt-dec 2013, 2 Jul 2014, https://www.smhi.se/kunskapsbanken/meteorologi/simone-hilde-sven-och-ivar-okt-dec-2013-1.76183
• minimum water levels at Skanor
• map of wind speed return periods also for Baltic region

Axer et al (2015) Axer T, T Bistry, M Klawa, M Mueller, M Saessler, Deutsche Ruck Sturm documentation 2013-2014, Deutsche Ruckversicherung Aktiengesellschaft, Hansealle 177, 40549 Duesseldorf, www.deutscheueck.de [pdf document information: author=filiz; date stamp=07Aug2015]
• high sea state along Baltic coast
• cargo ferry to Finnland disabled offshore
• alot of fallen trees from wind gusts in Mecklenburg-Vorpommern
• alot of emergency call-outs Berlin

Gierleussen et al (2015) Gierleussen T, H Lauridsen, F Langhans, J Bejdic, Met-ocean and wind resource related studies for nearshore windfarms in Denmark, seminar at the Danish Energy Agency, 27 February 2015.
• Bornholm airport wind speed
• Archona wind speed and direction

Christakos et al (2016) Christakos K, I Cheliotis, G Varlas, GJ Steeneveld, Offshore wind energy analysis of Cyclone Xaver over North Europe, 13th Deep Sea Offshore Wind R&D Conference, EERA DeepWind2016, 20-22 January 2016, Trondheim, Norway, Energy Procedia, 94, 37-44, 2016.
• WRF model study shows wind speed over Baltic in optimal range 11-25m/s for 70h during 84h integration.

Sorensen (2016) Sorensen CS, Water NOT wanted - Coastal floods and flooding protection in Denmark, In RA Herrmann & J Jensen (eds), Sichterung von Daemmen, Deichen und Stauanlagen: Handbuch fuer Theorie und Praxis (Vol V pp3-21), Siegen: Universiatsaeg Siegen, 2016
• inner Danish sea; flooding of houses; highest ever water levels at Hornbaek & Copenhagen (series 1890-2015)

Ribeiro et al (2017) Ribeiro R, R Rudge, D Racinska, Analysis of physical factors of the windstorm Xaver in Poland: post-hazard review, Weather, 72, 2017, pp.378-382
• Impacts of storm Xaver in Poland

Ditlevssen et al. (2018) Ditlevssen C, MM Ramos, C Sorensen, UR Ciocan, T Pionkowitz, Hojvandsstatistikker 2017, Miljø- og Foedevareministeriet, Kystdirektoratet, Lemvig, Februar, 2018
• ranked tide gauge storm levels for both the North and Baltic

Racinska (2019) Racinska D, Describing Storm Xaver in disaster terms, International Journal of Disaster Reduction, 34, 147-153, 2019
• Poland: 4 fatalities, blackout in 400,000 homes affecting 1.11 million people

WIKI (202002124) WIKI, Cyclone Xaver, https://en.wikipedia.org/wiki/Cyclone_Xaver accessed 24Jan2020
• power outage Poland

Wikipedia (20200502) Wikipedia, Orkan Xaver, https://de.wikipedia.org/wiki/Orkan_Xaver (accessed 2 May 2020)
• fatal traffic accident associated with tree fall in Poraj, Poland
• offshore winds cause low water levels in Flensburgfoerde and Schleiemuendung
• Badawanneeflet caused water levels to increase to +140cm on evening 6Dec2013
• PHOTO of extreme low water levels in Ekernfoerde

Table S52. Aftermath: new defenses; new design criteria; assessment of sea level rise (arranged by year and then alphabetically)

| Source | Full Reference and Notes |
|--------|--------------------------|
| The Lowestoft Journal (20131214) | The Lowestoft Journal, Suffolk MP hits out at environment secretary in statement about the floods, 14Dec2013, correspondent: Annabelle Dickson. UK MP Peter Aldous and the return period definition |
| Sueddeutsche Zeitung (20131215) | Sueddeutsche Zeitung, Xaver holte sich Land; Sturmschaden auf Sylt, 15Dec201315:36 https://www.sueddeutsche.de/panorama/sturmschaeden-auf-sylt-xaver-holte-sich-land-1.1844100
• budget for reconstructing coast defenses at Sylt not settled |
| Sylter Rundschau (20131209) | Sylter Rundschau, Folgen des Orkans. Xaver ‘knabberte’ Sylt massiv an, 09Dec2013 06:00 (from Friederike Reusser) https://www.shz.de/lokales/sylter-rundschau/xaver-knabberte-sylt-massiv-an-ad5098481.html
• Sylt west coast dune loss during Xaver will be partially replaced by natural wind action
• Badawanneeflet caused water levels to increase to +140cm on evening 6Dec2013
• PHOTO of extreme low water levels in Ekernfoerde |
| CH2MHill Halcrow (2014) | CH2MHill Halcrow, Cell 1 Regional Coastal Monitoring Programme, Wave Data Analysis Report 2: 2013-2014, Final Report, March 2014 [document properties: author=Andy Parson@ch2m.com; datestamp; 04/04/2014]
• it is recommended that extreme water level statistics are now revised to take the event into account for future predictions’ |
| Knaack and Heyken (2014) | Knaack H and H Heyken, Xaver hatte sehr schwere Sturmhfit im Gepaeck, Jahresbericht 2013. Der Zukunft verpflichtet, NLWKN, Niedersachsicherer Landesbetrieb fuer Weserwirtschaft, Kuesten- und Naturschutz, pp.8-9, document date stamp 24/April/2014. |
| NOZ (20140129) | NOZ Nach Xaver, 9.4 Millonen Euro fuer Juist, Spiekeroog und Wangerooge, 29Jan2014 https://www.noz.de/deutschland-welt/niedersachsen/artikel/446888/nach-xaver-9-4-millonen-euro-fuer-juist-spiekeroog-und-wangerooge1
• Ostfriesland island dunes to be strengthened by additional sand summer 2014
• exact sand amounts for Juist, Wangerooge, Spiekeroog
• sand-catchin fence to be rebuilt |
| Thorne (2014) | Thorne, Colin, Geographies of UK flooding in 2013/4, The Geographical Journal, 180, 297-309, 2014. map of damaged of REngland coastal defences that had to be repaired rapidly or after winter 2013/2014 |
Table S53. Worst case storm surge situation (arranged by year and then alphabetically)

| Source | Full Reference and Notes |
|--------|--------------------------|
| Cruz and Kraussmann (2008) | Cruz AM and E Kraussmann, Damage to offshore oil and gas facilities following hurricanes Katrina and Rita: A overview, Journal of Loss Prevention in the Process Industries, 21, 620-626, 2008. *Katrina and Rita worst hurricanes for offshore platform damage in US history* |
| Diamond (2012) | Diamond KE, Extreme weather impacts on offshore wind turbines: Lessons learned, Natural Resources and Environment, 27, fall, pp.1-5, 2012 | *climate change and black swan event* |
| Oceanografisch Meteorologisch Station (2013) | Oceanografisch Meteorologisch Station, Stormverslag 05-06 december 2013, 26pp, 2013 [pdf document properties: author=Myriam Sys; datestamp=15Dec2013] | *worst case storm; Xaver pressure could have been higher with wind speeds more northerly* |
| van Rooijen and Oost (2014) | van Rooijen J, J Oost, Memo: Regionale advisering Ameland Noordwest, Deltares, 1209381-008-ZKS-0008, 43pp, 18Dec2014 [PDF document properties: title=Regional advising: Ameland NW; author=Arnold van Rooijen; keywords: 1209381-008-ZKS-0008; date stamp: 18/12/2014] | *Xbeach model study of how Ameland protection dunes would be completely eroded for a 50y storm or worse* |
| Fery et al (2018) | Fery, Natasha, Birger Tinz, Lydia Gates, Reproduction of storms over the North Sea and the Baltic with the regional analysis: COSMO-REA6 ISP 2018, 17-19July2018, Bonn [pdf document properties: datestamp=16/07/2018] | *comparison of the reanalysis model fields for the 5 North Sea storms as part of the Extremeness Project* |
| Ulm et al. (2018) | Ulm, Marius, Arne Arns, Juergen Jensen, Assessing consequences of extreme events for the German Bight, 36th International Conference on Coastal Engineering 2018 - Coastal Protection and Risk - ID 1527 | *Project Extremeness* |

Table S54. Damage costs; insurance losses (arranged by year and then alphabetically)

| Source | Full Reference and Notes |
|--------|--------------------------|
| Air Worldwide | Air Worldwide, Press Release, Boston, 12Dec2013, https://www.air-worldwide.com/In-the-News/AIR- |
**Table S55. Online data sets (arranged by year and then alphabetically)**

| Source | Full Reference and Notes |
|--------|--------------------------|
| Wahle et al (2017) | Wahle K, J Staneva, W Koch, I Fenogljo-Marc, HTM Ho-Hagemann, EV Staney, An atmosphere-wave regional coupled model: improving prediction of wave heights in the southern North Sea, Ocean Sc., 13, 289-301, 2017. (doi:10.5194/os-13-289-2017). |
| ARAL/AltiKa data | http://aviso.altimetry.fr, |
| RADS data | http://rads.tudelft.nl, GPOD data: https://gpod.esa.int |
| WAM | http://mywave.github.io/WAM |
| COSMO | http://www2.cosmo-model.org/ |
| Bathymetry | http://www.EMODnet-Hydrography.eu/ |
| In-situ data used for validation | MARNET data http://www.bsh.de/Meeresdaten/Beobachtungen/MARNET-Messnetz/index.jsp |

| (20201212) | Estimates-Losses-from-European-Windstorm-Xaver-at-Between-EUR-700-Million-and-EUR-1.4-Billion/ (accessed 02Jan2020) |
| -Air worldwide est insured lossed from Storm Xaver 0.7-1.4 billion EUR | -most losses Denmark, Germany, UK |
| -some losses Netherlands, Belgium, Sweden, Norway | -flood and coastal storm surge losses will like be significant |
| -AIR's insured losses include: | -wind damage to onshore property; residential & commercial |
| -losses to insured forestry in Norway & Sweden | -AIR's insured losses do not include: |
| -losses from coastal surge & inland flooding | -business interruption expenses |
| -UK impacted worst by Xaver | |

| Luecht and Peters (2014) | Luecht, Fabian and Ove Peters, Bericht ueber die Sturmflut vom 05.-06.12.2013 an der Westkueste Schleswig-Holsteins, Landesbetrieb fuer Kuestenschutz, Nationalpark und Meeresschutz Schleswig-Holstein, Husum 26Feb2014, 19pp. [pdf document properties: title=Lfd; Authors:Thorsten Nommensen; datestamp: 11Dec2018] |
| -Strom Xaver: 15 dead, 800mill EUR insured loss; total loss higher | -itemized cost of repairs and cleanup for Schleswig-Holstein |

| AON Benfield (2014) | AON Benfield, Impact forecasting. December 2013 Global Catastrophe Recap, 2014. [document properties: abrandt; date stamp: 10Jan2014] |
| -Storm Xaver: 15 dead, 800mill EUR insured loss; total loss higher | |

| Thorne (2014) | Thorne, Colin, Geographies of UK flooding in 2013/4, The Geographical Journal, 180, 297-309, 2014. |
| | -cost of all UK flooding winter 2013/2014 290 million GBP |

| Axer et al (2015) | Axer T, T Bistry, M Klawa, M Mueller, M Saesser, Deutsche Ruck Sturm dokumentation 2013 Deutschland, 2013, Deutsche Rueckversicherung Aktiengesellschaft, Hansaallee 177, 40549 Duesseldorf, www.deutschereueck.de [pdf document information: author=filiz; date stamp=07Aug2015] |
| -insured storm damage in Germany less than Hurricane Christian; estimated at 100-200 million EUR | -insured damage across Europe 759 million EUR |

| Matelski (2016) | Matelski, Birgit, Erfahrungen aus der Sturmflut Xaver von 5. und 6.12.2013 und dem Weihnachtschwockes | 2014 in Schleswig-Holstein, IWASA 2016 Tagungsbeitrag, (46. IWASA, 7-8 Januar 2016; Internationales Wasserbau-Symposium Aachen. [pdf document properties: autoresponsible; datestamp: 26Apr2016] |
| -3.4 million EUR damage cost for Schleswig-Holstein: clearing Treibsel, fising broken deckwork, wave break lengthenung | |

| DEMA (2018) | Danish Emergency Management Agency DEMA, National Risk Profile for Denmark, April 2018 |
| | -Denmark: 900 million DKK costs |

| Wikipedia (20191002) | Wikipedia, Stormen Bodil, https://da.wikipedia.org/wiki/Stormen_Bodil#cite_note-39 (accessed 02Oct2019) |
| | -Denmark damage evaluated at 11 million Kr |

| JBA Risk Management (2020) | JBA 'Risk Management,' Storm Xaver 2013. Event Commentary, 2020. [PDF document properties: author=Cameron Whitwham] |
| -Europe total loss | 1.22-1.65 bill EUR (Zurich 2014) |
| -Europe total insured loss | =0.662 billion EUR (PERILS 2017) |
| -UK total loss | =0.250 billion GBP |
| -UK insured loss | =0.1 billion GBP |
| -1000 business flooded in UK |
| -flood defences avoided an estimated 32 billion in cost (Zurich 2014) |
| -Social, Housing, Other |
| -1400 houses flooded in UK; 4200 people affected (Zurich 2014) |
| -130000 homes/businesses without power (GC Capital Ideas 2013) |
| -fatalities: 15 in Europe; 2 in UK |
| -up 800,000 homes protected from flood defence systems in place |
| -several houses collapsed into the sea at Hemsby because of excessive cliff erosion |
| -6.8km2 agricultural land flooded |

| Surgewatch (20200304) | Surgewatch, Storm event 6th December 2013, https://www.surgewatch.org/events/1/ (last accessed 04Mar2020) |
| -insured losses 1.4-1.9 billion EUR, including wind & surge flooding |

| Wikipedia (20200502) | Wikipedia, Orkan Xaver, https://de.wikipedia.org/wiki/Orkan_Xaver (accessed 2 May 2020) |
| -insured damage 0.7-1.4 billion EUR (Air Worldwide) | -100-200 million EUR insured damage Germany (Aon Benfield) |
Extreme weather impacts on offshore wind turbines: Lessons learned

Table S56. Context and background information where Storm Xaver not mentioned (arranged by year and then alphabetically)

| Source | Full Reference and Notes |
|--------|-------------------------|
| Hornern (1979) | Horner RW, The Thames Barrier Project, The Geographical Journal, 145, 242-253, 1979. |
| Sanders and Gyakum (1980) | Sanders F and JR Gyakum, Synoptic-dynamic climatology of the 'Bomb', MWR, 108, 1589-1606, 1980 |
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4Coffshore (20151215) 4Coffshore, Samsø turbine collapse due to welding crack, Dec.15, 2015
-offshore wind turbine accident due to welding crack

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-Model output of the pre-operational models: http://codm.hzg.de/codm/
Table S57. Climatological background for Storm Britta in Nov 2006; Storm Xaver not mentioned (arranged alphabetically)

Source | Full Reference and Notes
---|---
Cappelen (2007a) | Cappelen, J., Vejret I 2006 – I Denmark, I Nuuk på Grønland og I Torshavn på Færøerne, Vejret, 110, 13-17, 2007a. -description of record warm autumn for Denmark, Torshavn & Greenland -global & northern hemisphere climate very warm 2006
Cappelen (2007b) | Cappelen, John, Teknisk rapport 07-01, Danmarks klima 2006 med Torshavn, Færøerne og Nuuk, Grønland - with English translations, DMI, Transport- og Energeministeriet, www.dmi.dk/dmu07-01, Kobenhavn, 2007b. -record breaking warm year Denmark avg=9.4C, 0.1C higher than previous record 1990 -record monthly temperatures Denmark July-September -annual temperature 0.42C above normal; 5 th warmest on record -Torshavn warmest September on record from advection warm air from south -Torshavn 3rd warmest year on record after 2003, 1993
Eden (2006) | Eden, P., Weather log. Consistently warm especially by night. Some heavy falls of rain. Weather Magazine, 61, i-iv, 2006 -3rd warmest Oct on record after 2001 & 2005 -Scotland with 2-3 times more rain than avg
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NCIC (2007) | NCIC, National Climate Information Centre, UK annual weather summary, Weather, 62, p.42, 2007. -temperature record in UK: warmest year of series since record start 1914 -Scotland had 6th wettest year; Cornwall had 8th driest
Nielsen (2007) | Nielsen, Niels Woetmann, Om stormflod og eftersarsvejr I Danmark anno 2006, Vejret, 110, 24-33, 2007. -warmest September-November on record
Paskal (2009) | Paskal, C., The vulnerability of energy infrastructure to environmental change, Energy, environment and resource governance, Apr. 2009, EERG BP 2009/11 -The vulnerability of energy infrastructure to environmental change -hot European summer 2006; France, Spain, Germany had to shut down nuclear plants because of heat & water problems -clarification that 2006 summer not as hot at 2003
Rosenorn (2007) | Rosenorn, Stig, Eftersarsvejr I Danmark anno 2006, Vejret, 110, pp.20-23, 2007 -Sept 2006 same as previous warm record 1999; temperature higher than normal July & Aug temperature -Oct 2006 highest temperature 12.2C on record; no frost; previous record Oct 2001 with 12.0C -Nov 2006 0.4C higher than previous 1938 record 7.7C -storm on Nov 1-2 only two cold days; wind blast at Gällivare described by Leif Rasmussen 26m/s 20min avg
Spiegel Online (Nov.2, 2006c) | Spiegel Online, Storm bashes northern Europe; one dead as freighter sinks in Baltic Storm, 02/11/2006c, 13:00. -Storm bashes northern Europe, one dead as freighter sinks in storm -comparison Britta to Katrina hurricane -global warming leads to extreme weather -Britta came directly after second warmest October in Germany records (since 1901) -Erich Roeckner, MPI-Meteorology, world climate will change more rapidly than ever before in next 100y

Table S58. Errors/typos in source reports for Storm Xaver (arranged by year and then alphabetically)

Source | Full Reference and Notes
---|---
Air Worldwide (20201212) | Air Worldwide, Press Release, Boston, 12Dec2013, https://www.air-worldwide.com/In-the-News/AIR-Estimates-Losses-from-European-Windstorm-Xaver-at-Between-EUR-700-Million-and-EUR-1-4-Billion/ (accessed 02Jan2020) -maximum water level Hamburg Germany reported to be 4m above sea level when it should be 4m MTHW -streets along Elbe in Hamburg reported to be under 6m of water; the maximum water level was about 6m above sea level with about 1m of water on the streets
Luecht and Peters | Luecht, Fabian and Ove Peters, Bericht ueber die Sturmflut vom 05.-06.12.2013 an der Westkueste Schleswig-
Table S59. Abbreviations used in manuscript (arranged by year and then alphabetically)

| Abbreviation | Full name |
|--------------|-----------|
| BAFG         | Bundesanstalt für Gewässerkunde |
| CEFAS        | Centre for Environment, Fisheries and Aquaculture Science |
| GESLA        | Global Extreme Sea Level Analysis |
| IEC          | International Electrotechnical Commission |
| IOC          | Intergovernmental Oceanographic Commission |
| KNRM         | Koninklijke Nederlandse Rotschapsmaatschappij |
| NCDC         | National Climate Data Center |
| RMS          | Risk Management Solutions |
| RWS          | Rijkswaterstaat |
| UK           | United Kingdom |

Table S60. People contacted for information about Storm Xaver (arranged by year and then alphabetically)

| Name              | Affiliation                                                       |
|-------------------|-------------------------------------------------------------------|
| Beswick, Mark     | Met Office National Meteorological Archive                        |
| Blumel, Maria     | Landesbetrieb für Küstenschutz, Nationalpark und Meereschutz Schleswig-Holstein (LKN-SH) |
| Dhoop, Thomas     | Channel Coast Observatory (CCO)                                    |
| Eecen, Peter J.   | ECN                                                               |
| Egest, Cathrine Netland | MIROS                                                            |
| Fijnaut, Charlotte| Koninklijke Nederlands Meteorologisch Instituut (KNMI)            |
| Frederiksen, Bjørn| Kustdirektoratet (KDI)                                             |
| Gates, Lydia      | Deutscher Wetterdienst (DWD)                                      |
| Granneman, Edwin  | Kustwacht, Netherlands Coastguard                                 |
| Haigh, Ivan       | National Oceanography Centre, University of Southampton           |
| Horsburgh, Kevin J.| National Oceanography Centre, Liverpool                           |
| Huers, Vibeke     | Danish Meteorological Institute (DMI)                              |
| McKenny, Collette | JBA Risk Management Limited                                       |
| Murphy, Aidan     | Met Eireann                                                       |
| Pearce, Chris     | Associated British Ports Marine Environmental Research (APB MER)  |
| Schaap, Wendy     | Noordzeewind                                                      |
| Skaland, Reidun Gangstø | Met.no                                                                   |
| Snath, Helen      | British Oceanographic Data Centre (BODC)                         |
| Spencer, Tom      | University of Cambridge                                           |
| Stoker, Eric      | Datawell BV                                                       |
| Van Hoorne, Bart  | Intergovernmental Oceanographic Commission (IOC)                  |
| Van Vliet, Gerda  | Koninklijke Nederlandse Rotschapsmaatschappij (KNRM)              |
| Wilhelmi, Jens    | Bundesanstalt für Gewässerkunde (BAFG)                            |
| Zijderveld, Annette| Rijkswaterstaat                                                   |

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Air Worldwide, Press Release, Boston, 12Dec2013, https://www.air-worldwide.com/In-the-News/AIR-Estimates-Losses-from-European-Windstorm-Xaver-at-Between-EUR-700-Million-and-EUR-1-4-Billion/ (accessed 02Jan2020)  
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SECTION IV. Selected referee comments and author responses

Anthony James Kettle, Storm Xaver over Europe in December 2013: Overview of energy impacts and North Sea events

REFEREE 1:

Referee 1 comment

The study portraits the Xaver storm in December 2013 on its impact on a series of societal and energy infrastructure. This paper collects very interesting information on the damage of this severe storm, which will help raising attention to both scientific and political panels.

Author response:

Thanks for the positive overview

Referee 1 comment:

1. Line 58, 'rapid rotation of extreme winds' - extreme wind in offshore wind application means something special. I think what you mean here are tropical strong winds.

Author response:

The accident reports from south and east Asia comment that the wind turbines collapsed during the tropical hurricane force winds but also clarified that the rapid rotation of the wind field was an important factor in turbine tower collapse. When the turbine is misaligned with the wind, the blades present a greater cross-sectional area with greater wind loading on the structure. In the North Sea area, Argyriadis et al. (2005) analyze storm data from FINO1 and also note the importance of rapid wind direction changes during storm conditions.

Referee 1 comment:

2. Line 64: what happened exactly to those wind farms?

Author response:

For the Samsø wind farm, one of turbines lost its nacelle and blade assembly, which fell from the top of the tower into the sea. For the Alpha Ventus case, one turbine lost its nacelle cover. Media reports were making a big deal of this as it was long after the period when start up problems would have been addressed. The fault should not have happened so long into its operating lifetime. There was media speculation that the environmental forces were misjudged at the offshore site (turbulence or corrosion). I have not found a technical report of either accident to give more information.

Referee 1 comment:

4. Line 78: Difficult to see what content the reference is for from this sentence - need a rephrase

Author response:

The sentence makes reference to the fact that Storm Xaver belonged to the class of "super-bomb" storms of explosive cyclogenesis that was characterized in an earlier meteorological study by Sanders and Gyakum (1980). The concept would help to frame an intercomparison of severe North Sea winter storms for meteorologists. However, it does not help to understand energy and societal infrastructure damage during Storm Xaver, and the sentence has been removed.

Referee 1 comment

5. Line 86: What's special about the surge event of 1953? You explained at the end of the paper, maybe it should be here
Author response:

I have expanded to sentence to explain why the 1953 event was important.

REFEREE 2

Referee 2 comment

It is a good paper on storm Xaver in 2013. In a first step, you describe impacts on societal and energy infrastructure. Then, you use tide gauge records to reconstruct the progression of the storm and calculate the skew surge for every of your 77 stations. In a next step you analyse the spectra of the water level data by separating them into three different frequency components.

Author response:

Thanks for the positive comments.

Referee 2 comment

(1) The abstract is clearly written, but the added value of the paper is not obvious. Please elaborate on the research question of the paper more clearly and state the most important results of the research conducted.

Author response:

Similar to other review papers, the contribution brings together and compares information from different sources to identify the important meteorological impacts on infrastructure. The synthesis of information from the different sources allows the storm events to be related in time and space, and it also highlights knowledge gaps.

The impact of large waves offshore is an important knowledge gap. A lot of energy infrastructure is located offshore, so that met-ocean conditions during the storm are important. Some of the offshore incidents and measurements indicate the presence of large infragravity waves.

Referee 2 comment

(2) Lines 70-73: Please elaborate on the description in the research question of this study. Are there no prior investigations on this storm?

Author response:

The scientific objective of the contribution is to present a literature review thatcatalogues storm infrastructure impacts, and gives information to relate the storm events in time and location. The study is partly motivated by the occurrence of a large wave at the FINO1 platform during Storm Britta on 31 Oct.–1 Nov. 2006. The platform was damaged four times by large waves in 2006, 2007, 2009, and 2013.

There are previous investigations on this storm, and these are presented in the literature survey. However, they tend to focus on particular subject areas (e.g., coastal erosion in eastern England or water levels along the coast of the Netherlands) or geographic areas (e.g., meteorological conditions over Germany). The value of this review is that it assembles the information from different types of reports.

Referee 2 comment

(3) Line 150: To compare the data in spectral analysis, they must have the same time resolution

Author response:

To compare the data in spectral analysis, the importance of the time resolution depends on the characteristic periods being compared. For example, if one were comparing the diurnal or semi-diurnal tidal reconstructions among the group of tide gauge stations, then it makes little difference if the data are presented with a one hour
or one minute time discretization. The same is also true comparing the long period time series reconstructions created using the spectral cutoff threshold of 0.2 days.

However, if one is looking for harbour seiches or meteotsunamis in the short period time series reconstructions, then it does make difference whether the data are presented with the discretization of 1 minute, 10 minutes, or 1 hour. The characteristic period of harbour seiches is on the order of minutes. This would appear as noise in records of 10 or 15 minute discretization, possibly with aliasing effects. The impact of different time discretizations is not so important in the present analysis as most of the records going into the spectral analysis have time steps of 10 or 15 minutes.

Before computer analysis, the old discretization standard was 1 hour to give manageable amount of data to remove diurnal and semidiurnal tide and assess the nontidal residual (surge). With the advent of computer analysis, it became possible work with data sets of shorter time discretizations, and the UK (for example) switched to a 15 minute standard. With further computer developments and recent interest in meteo-tsunamis, there has been a trend to using 1 minute data discretizations. Thompson et al. (2020) have highlighted the deficiency of the UK tide gauge data discretization in light of European norms and user requirements.

Referee 2 comment

(4) In the conclusions you do not refer satisfactorily to your own results. Please elaborate on this rather than giving an overview of other studies.

Author response:

I have rearranged the information in the conclusion and included a passage that summarizes the results from the tide gauge analysis. There is some evidence for an important role of large waves in causing offshore accidents and possibly some harbour flooding. The issue has been highlighted by Pleskachevsky et al. (2012).

Other important issues that came out of the literature survey were that the statistics of the return period of extreme surge levels was changing, and that there was a fear that an atmospheric circulation tipping point had been passed.

Referee 2 comment

Line 66: Please give reference to the case studies

Author response:

The only information about these North Sea wind turbine incidents were descriptions in the media reports, which are already cited in the manuscript. There was speculation in the media reports about the possible causes of the accidents, but no follow-on case study reports have been located. I emailed the wind farm operators for more information on the accidents, but I have received no response.

Referee 2 comment

Lines 190-197: I am not sure I got the statement right. Can the magnitude of the oscillation not also be due to the fact that the 14-day period is considered, which takes into account both storm conditions and normal water levels?

Author response:

The referee's question relates to whether the features of the short period oscillations shown in Fig. 4d would change significantly if another time interval instead of 14 days were chosen for the discrete Fourier transform analysis. The characteristics or magnitudes of the short period oscillations over the two day period of the storm would not change significantly whether the analysis period chosen was 28 days or 7 days. The discrete Fourier transform does a very good job of isolating the short period component of the original time series from long period component and the diurnal/semidiurnal tides.
Lines 207-209: You mention that “there are large differences in the skew surge values around the North Sea, with stations in the German Bight and northern Netherlands approaching 4 m in some instances.” Do you have an explanation for this?

Author response:

There are two main factors influencing the height of the surge around the North Sea. The first is the action of the strong northwest wind pushing water from north to south so that water levels along the coast of the Netherlands and Germany would be expected to have much higher surge levels than Scotland. The second the factor is that the external surge travels as a Kelvin wave similar to the semidiurnal tidal wave and would be expected to have similar amplitude characteristics as the tides around the North Sea. The tidal range in the German Bight is larger than in Scotland.

Referee 2 comment

Figure 3: Please elaborate on the calculation of the noise level in the methods

Author response:

The noise level labelling was removed from the spectral graph. Following Stull (1988), the spectrum is calculated without uncertainties and is treated as a mathematical tool to move between the time series and spectral domains without loss of information.

References for the referee comments section

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