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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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SECTION I. Supplement figures

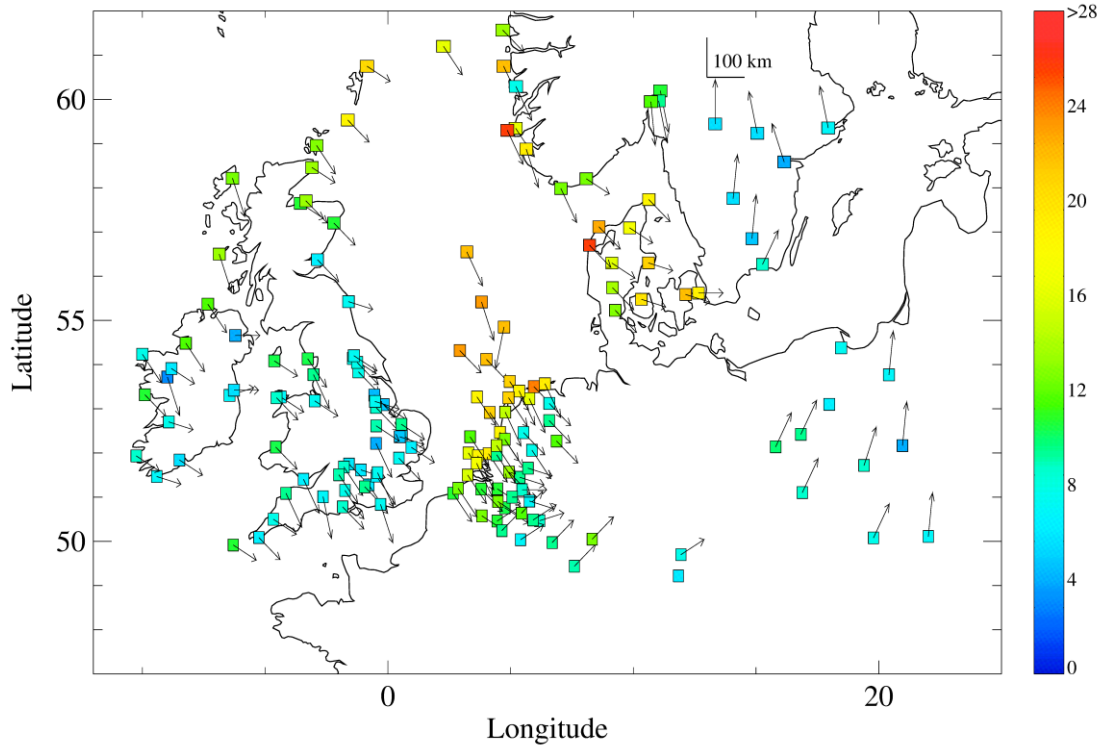

Figure S1. Wind speed (10 minute average, adjusted to 10 m height) and wind direction on 5 Dec. 2013 at 18:00 GMT for selected station records in the National Climate Data Center (NCDC) database.

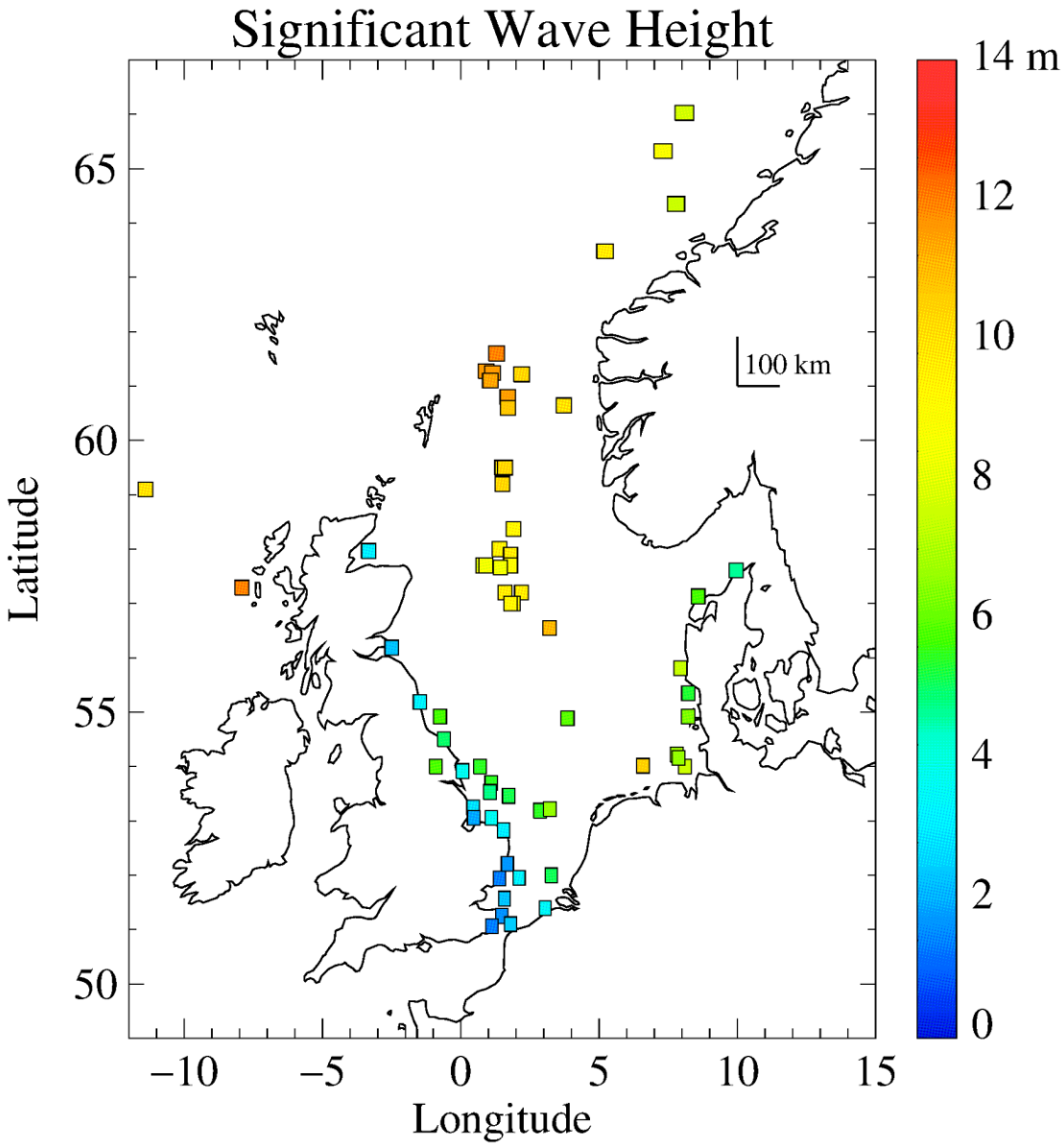

Figure S2. Maximum significant wave height for the 5–6 Dec. 2013. The data has been compiled from CEFAS-Wavenet (wavenet.cefas.co.uk) for the UK sector, from time series diagrams from the website of the Bundesamt für Seeschifffahrt und Hydrolographie (BSH) for German sites, from time series data from 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.

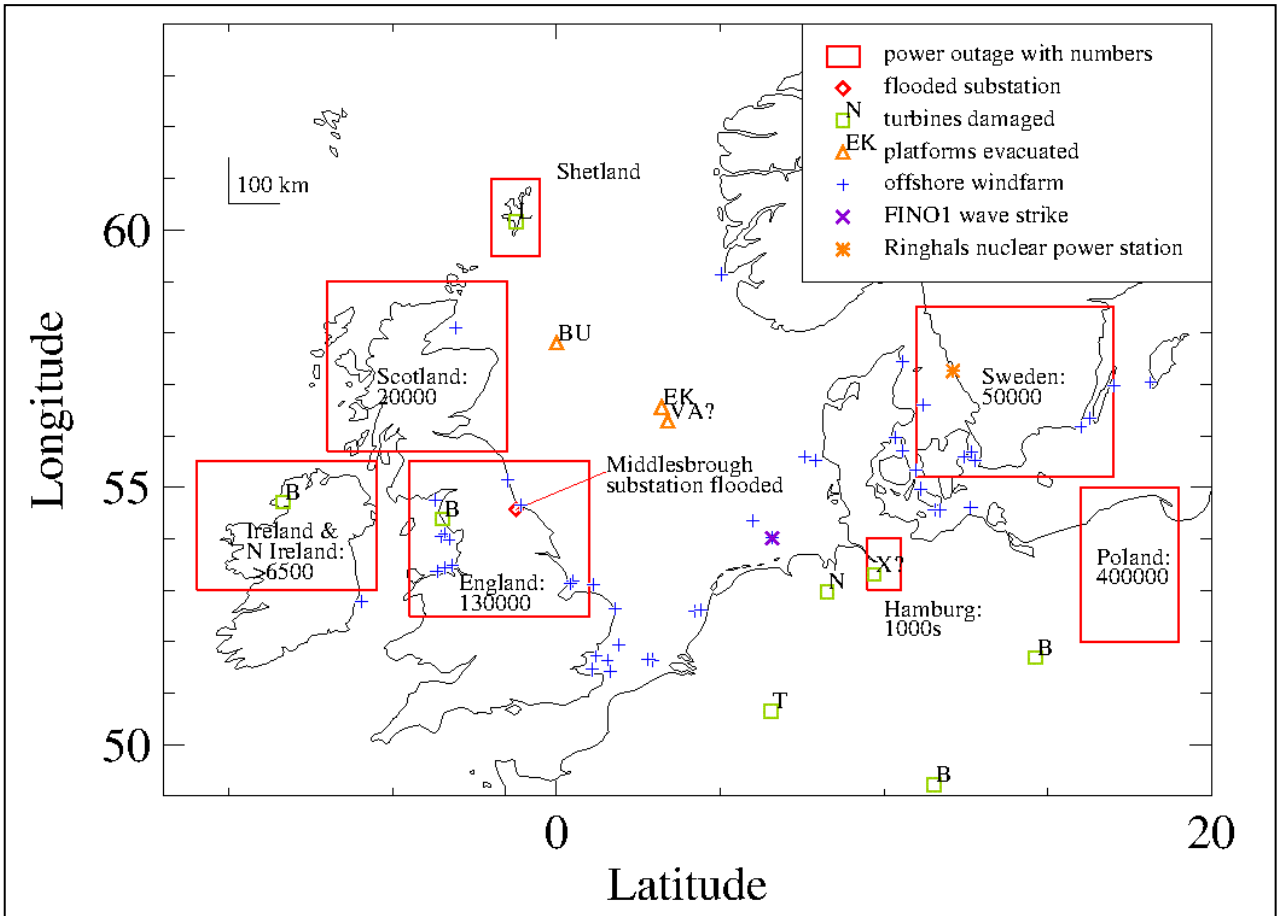

Figure S3. Thematic map of energy impacts by Storm Xaver on 5–6 Dec. 2013. The platform identifiers are: BU Buchan Alpha, EK Ekofisk, VA? Valhall, The wind turbine accident letter identifiers are: B blade damage, L lightning strike, T tower collapse, X? 'exploded'. The numbers are the number of customers (households and businesses) without power at some point during the storm.

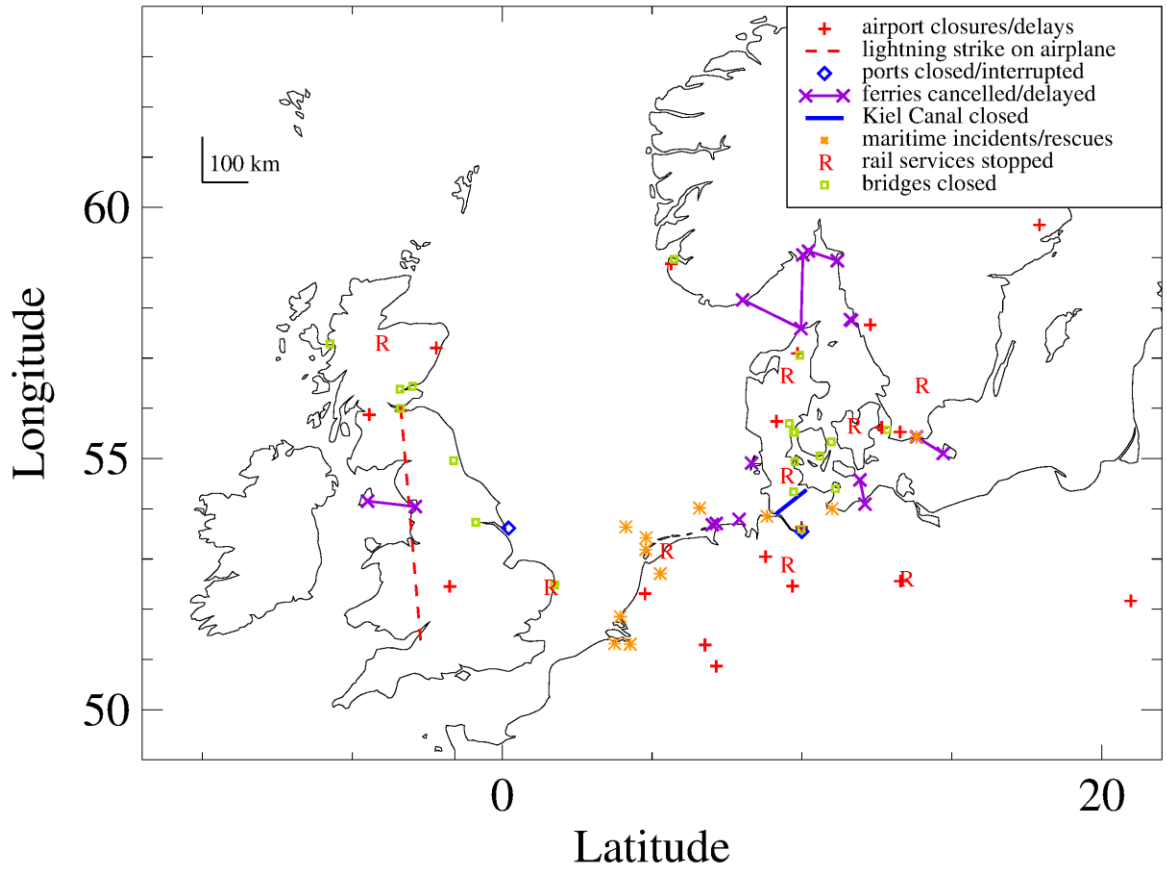

Figure S4. Thematic map of transportation impacts during Storm Xaver on 5–6 Dec. 2013.

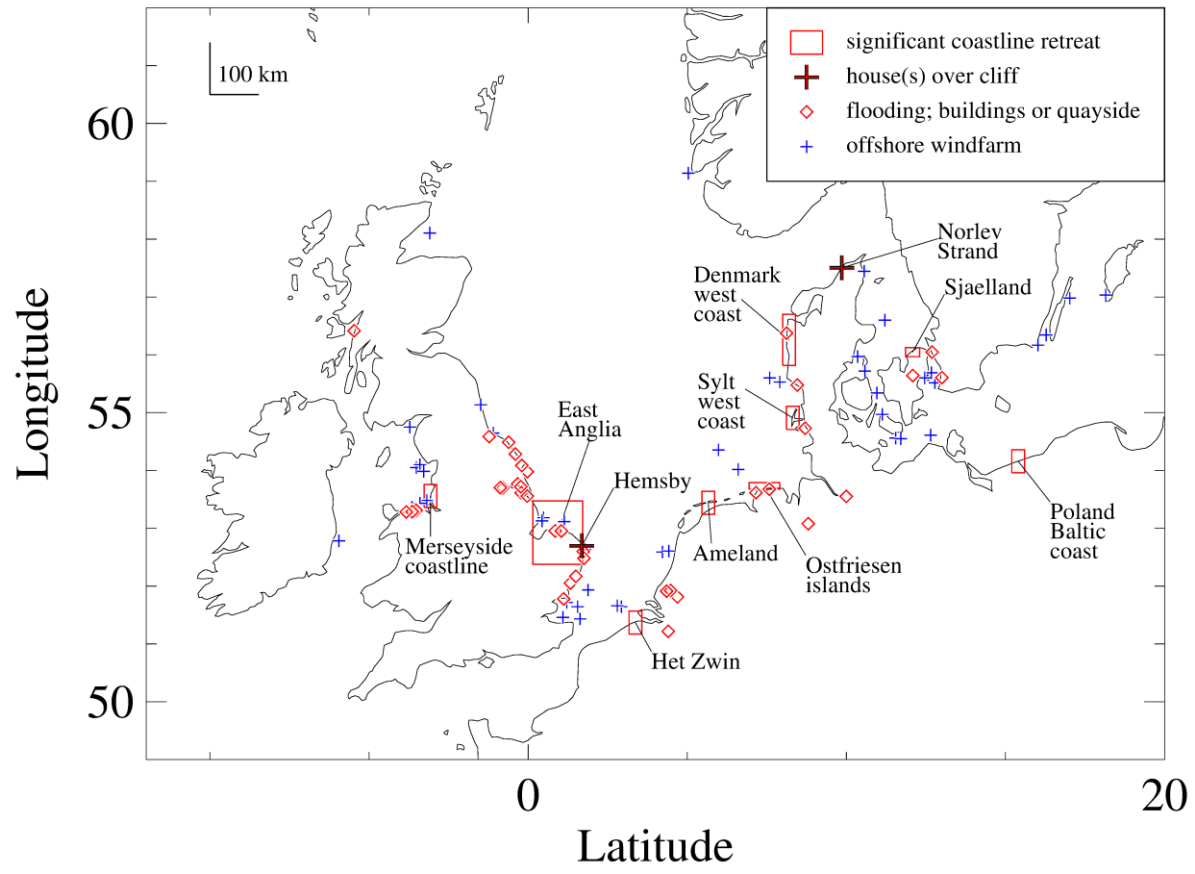

Figure S5. Thematic map of reported coastal damage and flooding during Storm Xaver on 5–6 Dec. 2013.

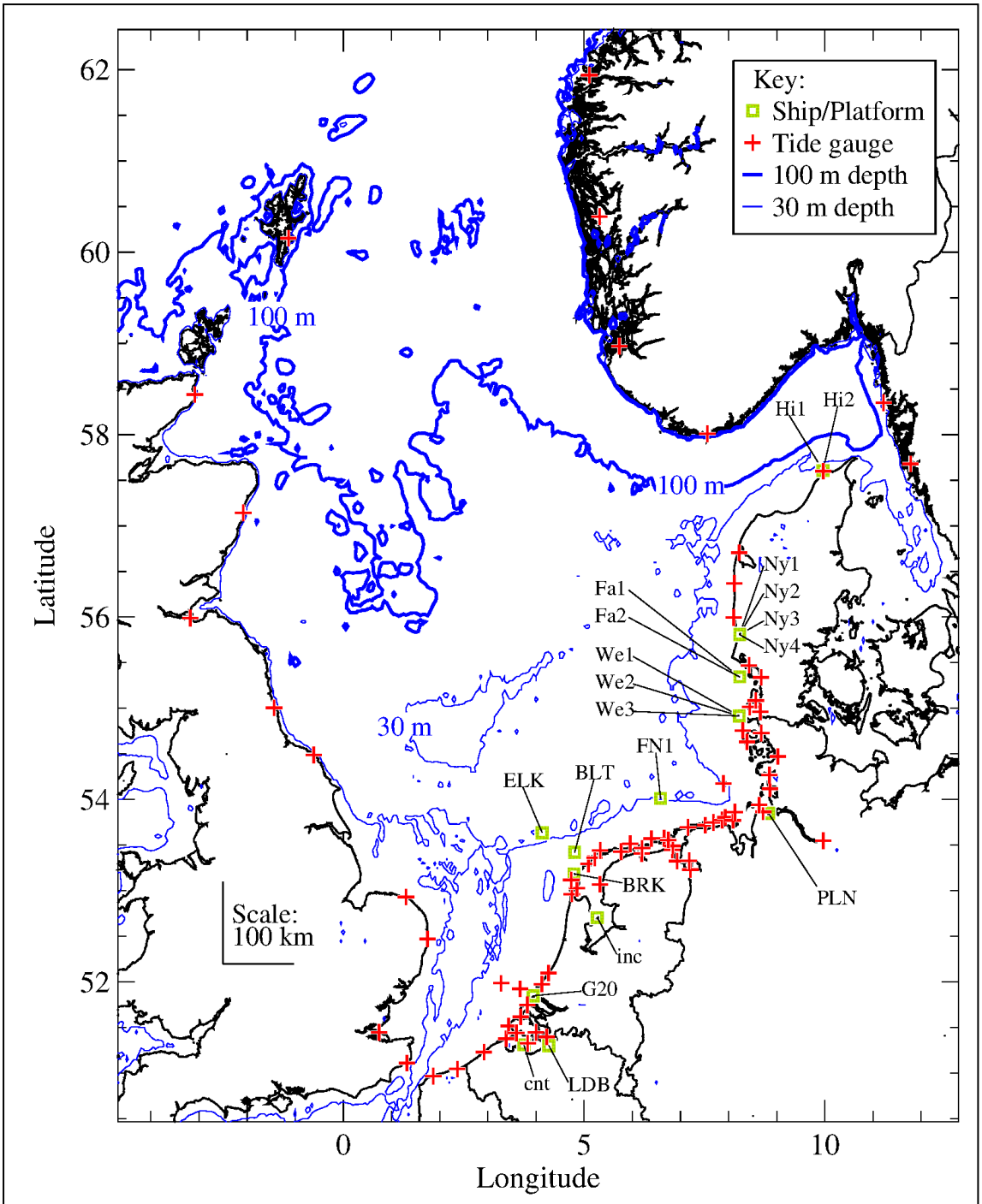

Figure S6. Map showing locations and identification of the North Sea offshore incidents during Storm Xaver of 5–6 Dec. 2013.

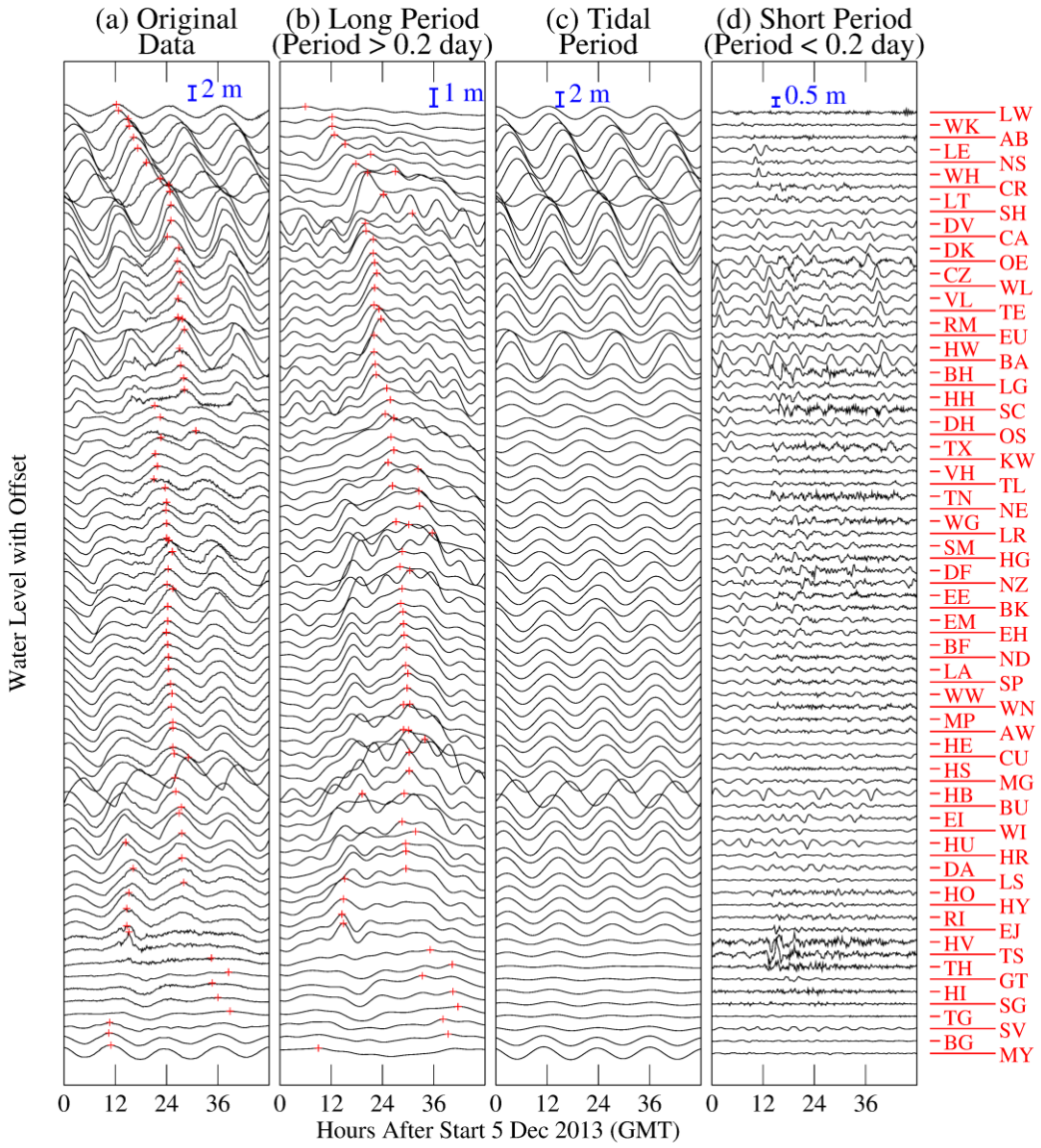

Figure S7. Time series of the (a) original water level data, and reconstructions of the (b) long period, (c) diurnal plus semi-diurnal tide, and (d) short period constructions of the original time series. The panels show all 77 water level stations that were analysed. The station identifications are given by two letter codes along right hand side of the panel, and the stations have been vertically offset according to counter-clockwise location around the North Sea starting from Lerwick in Scotland at the top and ending with Maløy on the Norwegian coast at the bottom. Red plus symbols in the first two panels indicate the maximum values during the two-day storm period.

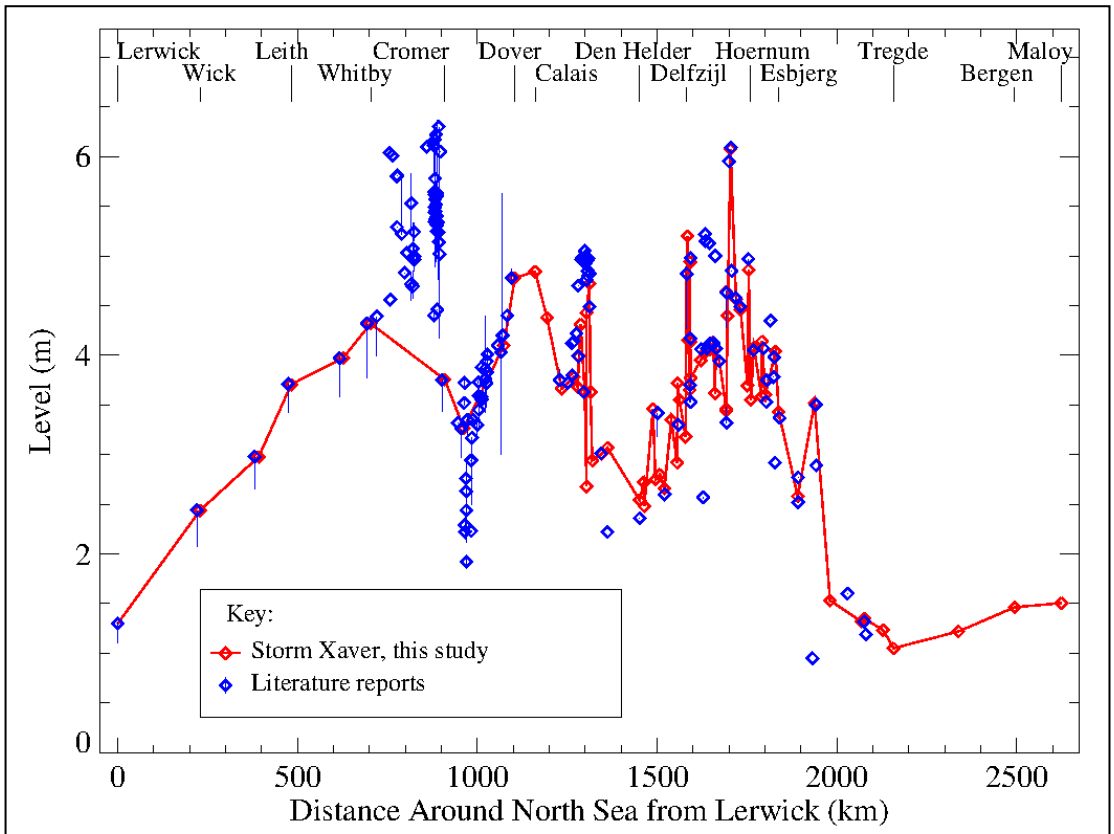

Figure S8. Maximum water levels above mean sea level during Storm Xaver on 5–6 Dec. 2013. The values are calculated from the tide gauge records and arranged by counter-clockwise distance around the North Sea starting from Lerwick. Literature reports are included for comparison.

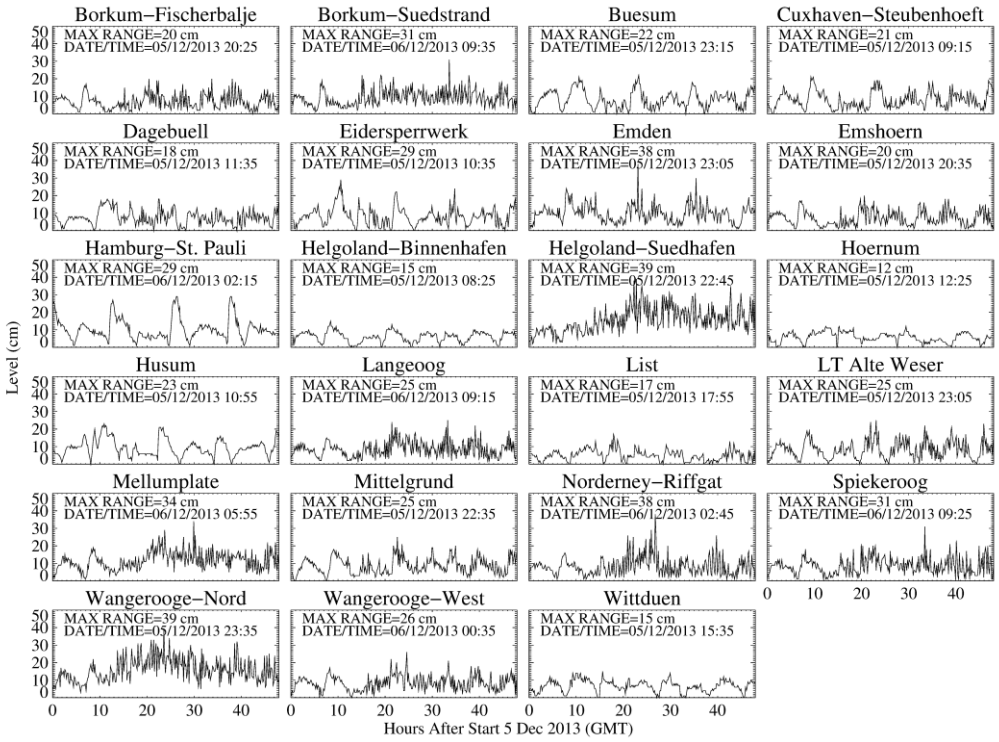

Figure S9. Time series of maximum minus minimum water level over 10 minute intervals for the 1-minute water level data of Germany. The range of water level variations across 10-minute time intervals approaches 40 cm during Storm Xaver on 5–6 Dec. 2013.

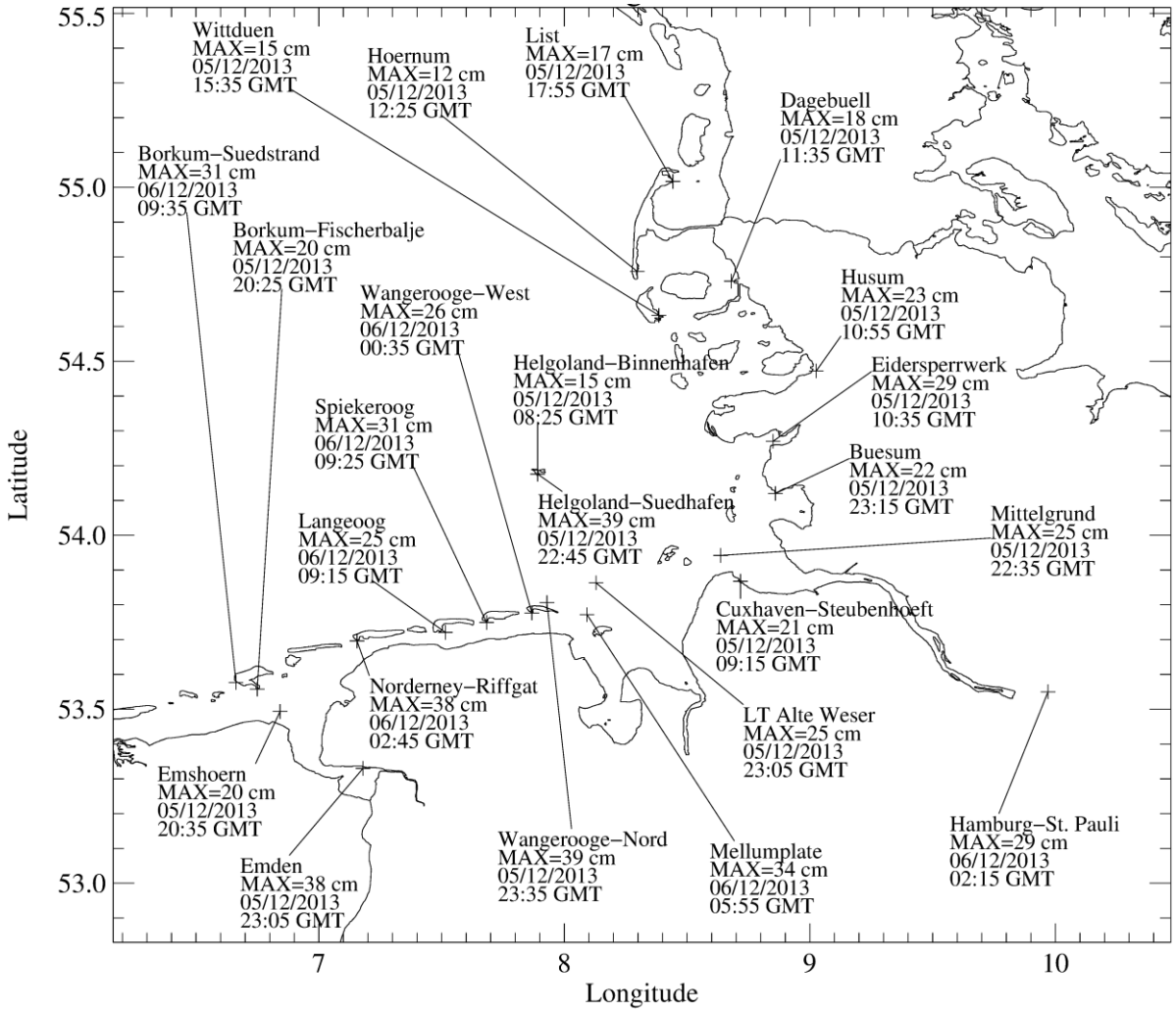

Figure S10. Map of the German tide gauge stations locations showing the maximum range of water level across 10 minute intervals from the original 1-minute time series data. The date and time of the maximum range is noted.

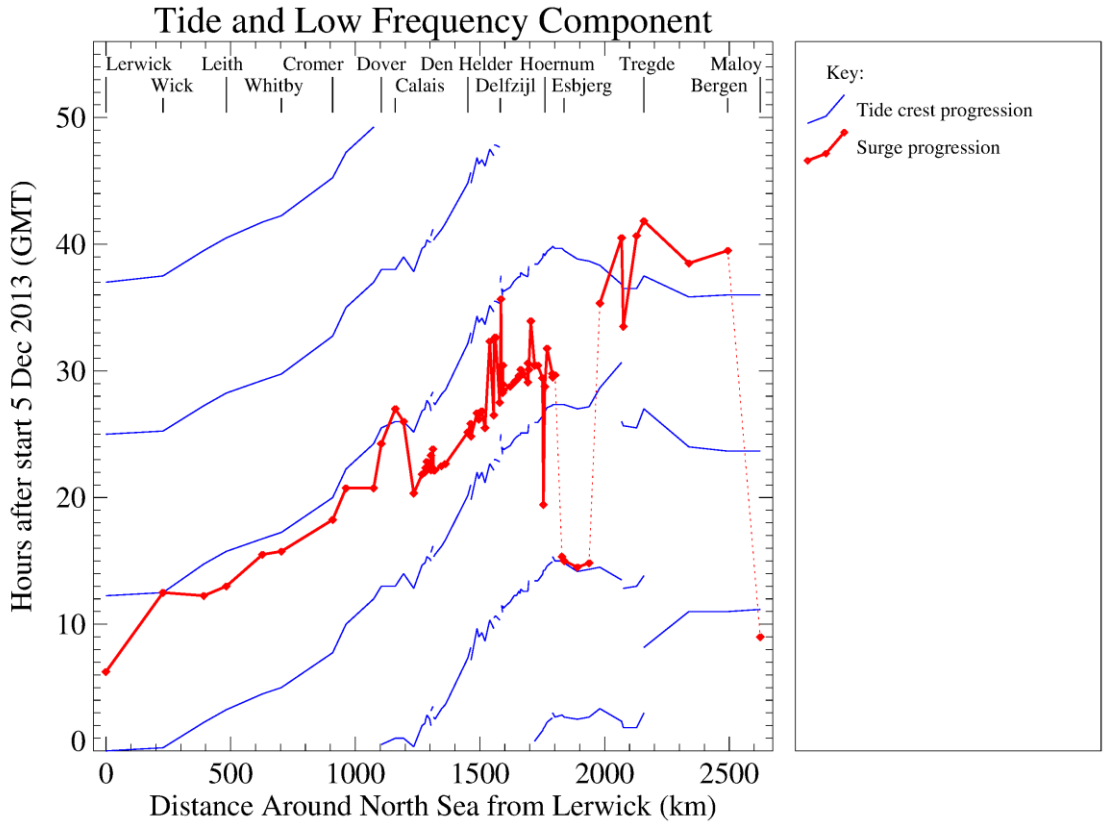

Figure S11. Progression of the tidal crests and storm surge peak around the North Sea on 5–6 Dec. 2013.

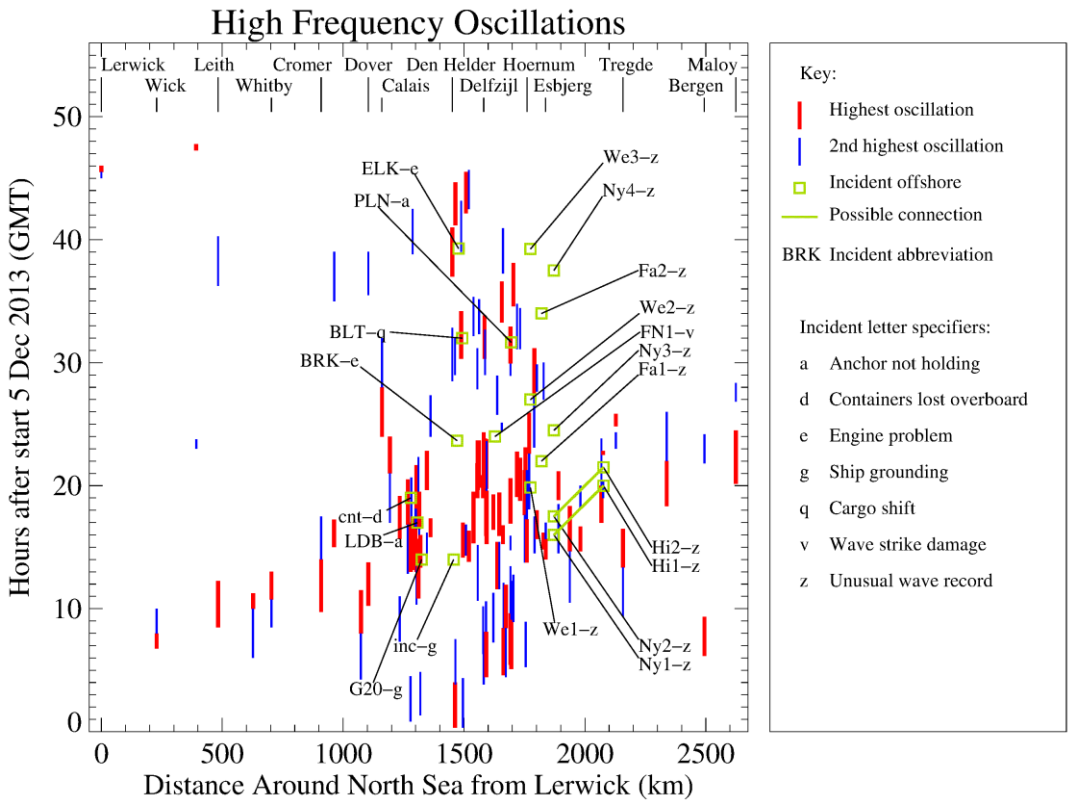

Figure S12. Arrangement of extreme short period water level fluctuations counter-clockwise around the coast of the North Sea during Storm Xaver with reported maritime incidents and accidents. The extreme short period water level fluctuations are the highest (red bar) and second highest (blue bar) range of up-crossing oscillations in the tide gauge records during the two-day period 5–6 Dec. 2013.

SECTION II. Supplementary tables

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]	[2]	[3]	[4]	[5]	[6]	[7]	[8]	[9]
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	Huibertgat	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

Table S1 (continued)

N	Station Name	Abb	Country	Latitude (degree)	Longitude (degree)	Δt orig (min)	Δt use (min)	Source
[1]	[2]	[3]	[4]	[5]	[6]	[7]	[8]	[9]
41	Borkum−Fischerbalje	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	SP	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	Mellumplate	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	List	LS	DE	55.02	8.44	1	10	BAFG
62	Hojer	HO	DK	54.96	8.66	10	10	KDI
63	Havneby	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	Hirtshals	HI	DK	57.60	9.97	10	10	IOC
76	GoteborgTorshamnen	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 [1]	Ship/Platform Name or Incident [2]	Abb [3]	Lati–tude (deg) [4]	Longi–tude (deg) [5]	Date (GMT) dd/mm/yyyy [6]	Time GMT hh:mm [7]	Source [8]
1	Burak Bayraktar	BRK	53.19	4.79	05/12/2013	23:40	Fleet20131207,24Liveblog
2	cutter GO–20	G20	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	We2	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/maalinger-og-data/
- LSH: Digitized time series data of significant wave height from Luecht, Fabian and Ove Peters, Bericht über die Sturmflut vom 05.-0.6.12.2013 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	Huibertgat	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	Emshoern	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−Steubenhoeft	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	Vlieland 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	Maloy	5.6	8.92	2.50
77	Bergen	4.9	6.08	3.50

Table S4. Sorted list of return periods of water levels and references.

N [1]	Location [2]	Country [3]	Latitude (degree) [4]	Longitude (degree) [5]	Return Period (year) [6]	Source [7]
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 Staithe	UK	52.96	0.75	1736	WEA15
5	Scolt 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	Thorsminde Havet	DK	56.40	8.10	407	DEA19
21	Kobenhavns Havn	DK	55.70	12.60	285	DEA19
22	Thorsminde 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	Aldeburgh (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	Brons 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 [1]	Location [2]	Country [3]	Latitude (degree) [4]	Longitude (degree) [5]	Return Period (year) [6]	Source [7]
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	Grenaa 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	Hanstholm	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	Kalundborg 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	Vidaaslusen−Hojer I	DK	55.00	8.70	12	DEA19
65	Graadyb 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	Korsor 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 [1]	Location [2]	Country [3]	Latitude (degree) [4]	Longitude (degree) [5]	Return Period (year) [6]	Source [7]
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	Karrebaeksminde	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	Havneby 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:

- DEA19: Ditlevsen C, MM Ramos, C Sorensen, UR Ciocan, T Pionkowitz, Hojvandsstatistikker 2017, Miljo- og Foedevaremnisteriet, Kystdirektoratet, Lemvig, Februar, 2018

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- RWS14b: 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
- SW20: Surgewatch, Storm event 6th December 2013, https://www.surgewatch.org/events/1/ (last accessed 04Mar2020) TF20: www.tide-forecast.com
- WEA15: Wadey MP, ID Haigh, RJ Nichols et al, 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.
- WEA15b: 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, 2015.

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, piers, 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 informationwhere Strom 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)

Source	Type[1]	Full Reference and Notes
Horner (1979)	4	Horner RW, The Thames Barrier Project, The Geographical Journal, 145, 242-253, 1979.
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Stull (1988)	4	Stull, R.B.: An Introduction to Boundary Layer Meteorology, Kluwer Academic Publishers, Dordrecht, 1988.
Winther-Jensen and Jorgensen (1999)	4	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.
Goennert et al (2001)	4	Goennert G,, SK Dube, 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
Mueller-Navarra et al (2003)	4	Mueller-Navarra SH, W Lang, S Dick, KC Soetje, Ueber de Verfahren der Wasserstands- und Stormflutvorhersage. Hydrodynamisch-numerische Modelle der Nord- und Ostsee und ein empirisch-statistisches Verfahren fuer die Deutsche Bucht, promet. Jahrg. 29, Nr 1-4, 117-124, June 2003
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Ishihara et al (2005)	4	Ishihara T, Tamaguchi, A, Takahara K, Mekaru T, Matsuura S, An analysis of damaged wind turbines by Typhoon Maemi in 2003, The sixth Asia-Pacific Conference on Wind Engineering (APCWE-VI), Seoul, Korea, September 12-14, 2005
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Spiegel Online (2006c)	4	Spiegel Online, Storm bashes northern Europe, one dead as freighter sinks in Baltic Storm, 02/11/2006c, 13:00.
Eden (2007)	4	Eden, P., Weather log, November, 2006, Weather Magazine, 62, i-iv, 2007.
Cappelen (2007a)	4	Cappelen, J., Vejret I 2006 – I Denmark, I Nuuk pa Gronland og I Torshavn pa faeroerne, Vejret, 110, 13-17, 2007a.
Cappelen (2007b)	4	Cappelen, John, Teknisk rapport 07-01, Danmarks klima 2006 med Torshavn, Faeroerne og Nuuk, Groenland - with English translations, DMI, Transport- og Energiministeriet, www.dmi.dk/dmi/tr07-01, Kobenhavn, 2007b.
NCIC (2007)	4	NCIC, National Climate Information Centre, UK annual weather summary, Weather, 62, p.42, 2007.
Nielsen (2007)	4	Nielsen, Niels Woetmann, Om stormflod og eftersarsvejr I Danmark anno 2006, Vejret, 110, 24-33, 2007.
Rosenorn (2007)	4	Rosenorn, Stig, Efterarsvejret 2006 (SON autumn quarter summary), Vejret, 110, pp.20-23, 2007
Rosenthal and Lehner (2007)	4	Rosenthal, W. and S. Lehner, Individual wave height from SAR, Proc. 'Envisat Symposium 2007', Montreux, Switzerland, 23-27 April 2007 (ESA SF-636, July 2007) https://www.semanticscholar.org/paper/INDIVIDUAL-WAVE-HEIGHT-FROM-SAR-Rosenthal-Lehner/affabe337b05276112fca662375ec8a8b4bba4a6
Cruz and Krausmann (2008)	4	Cruz AM and E Krausmann, Damage to offshore oil and gas facilities following hurricanes Katrina and Rita: An overview, Journal of Loss Prevention in the Process Industries, 21, 620-626, 2008.
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Wihelmi and Barjenbruch (2008)	4	Wilhelmi J and U Barjenbruch, 2008, Application of radar gauges to measure the water level and the state of the sea Proceedings of 31st international conference on coastal engineering, Hamburg, Germany
Gonnert et al (2009)	4	Gonnert G, J Jensen, H von Storch, S Thumm, T Wahl, R Weisse, Der Meeresspiegelansteig. Ursachen, Tendezen, und Risikobwertung, Die Kueste, 76, FAK (2009), 225-256.
Paskal (2009)	4	Paskal, C., The vulnerability of energy infrastructure to environmental change, Energy, environment and resource governance, Apr. 2009, EERG BP 2009/11
Diamond (2012)	4	Diamond KE, Extreme weather impacts on offshore wind turbines: Lessons learned, Natural Resources and Environment, 27, fall, pp.1-5, 2012.
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BBC (20131204)	1	BBC, Workers off Talisman Sinopec oil platform Buchan Alpha over bad weather forecast, 04Dec2013
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		Eggert) https://www.bt.dk/danmark/offer-for-bodil-koebte-huset-15.-august-nu-er-det-vaek
Cargolaw (2013)	3	Cargolaw 2013 [Tim Schwabedissen, 12Dec2013]
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Andrews (2020)	2	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
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Notes:

[1] Type: 1=Xaver focus (or used as key example in general discussion); 2=1-4 case studies with Storm Xaver; 3=Storm Xaver is one of many case studies or mentioned only; 4=Xaver not mentioned; included for background information

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 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 but say 500 people could still be in need of help (Reuters). FIG3. [PHOTO] Storm hit Welsh coastline about lunchtime (AP) 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) FIG8. [PHOTO] Meanwhile residents in Great Yarmouth Norfolk have been filling sandbags in preparation for the stormy weather moving south (Getty Images) FIG9. [PHOTO] It's a scene repeated in Gorlesston-on-Sea on the east coast of England as residents prepare for the worst (Reuters). FIG10.[PHOTO] Elsewhere in England, high tides followed the storm's tidal surges, hitting 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 (Laura Steen) FIG14.[PHOTO] Further north the Cumbrian coastal village of Allonby has been battered by heavy seas (PA) FIG15.[PHOTO] Many homes in Northern Ireland have been left without power due to

	damage done by the storm (PA)
BBC (20131206)	BBC20131206, Deadly storm and tidal surge batter northern Europe, BBC 6 Dec2013 (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) https://www.bt.dk/danmark/offer-for-bodil-koebte-huset-15.-august-nu-er-det-vaek -FIG. house tipped over cliff onto beach; family of 3
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 FIG. [PHOTO] Firefighers stand at the site of a traffic accident between the villages of Wicko and Poraj in the Pomerania region. Three people killed and one injured when a tree fell on a car due to heavy storms. FIG. [PHOTO] Reception building of camping ground submerged in the midday high tide on the beach at Bensersiel this morning. FIG. [PHOTO] Hamburg's historic fish auction hall Fishmarkt is flooded by the water of teh Elbe river today after the storm Xaver reached the northern German city during the night FIG. [PHOTO] A boat lies on its side today in Thorsminde Harbour on the west coast of Jutland as Hurricane Xaver strikes
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/ FIG: map of ship positions FIG: ship Burak Bayraktar in distress
GP (20131206)	GP, Fortsatt risk for halka, 6Dec2013 (correspondent: D Henriksson, K Vikingsson, P Sydvik, TA Akerblom) http://www.gp.se/nyheter/goteborg/1.2201325-fortsatt-risk-for-halka (accessed 1May2020) FIG. [PHOTO] Trafikproblem. Traffic jam on Riksvag 40 at Tolkabro west of Ulricehamn (Adam Ihse)
Kristeligt Dagblad (20131205)	Kristeligt Dagblad, Stormen blaeser Skotland omkuld: Doodsfald og nebrud, (contributor: Ritzau), 05Dec2013 12:50 https://www.kristeligt-dagblad.dk/udland/stormen-bl%C3%A6ser-skotland-omkuld-d%C3%B8dsfald-og-nedbrud FIG. [PHOTO] Litter bins are washed along the promenade and waves bater the sea wall in Blackpool, NW England on 5Dec2013 as high winds hit north of England and Scotland. PHOTO: Paul Ellis
National Wind Watch (20131210a)	National Wind Watch, 10Dec2013, Xaver zerstoert ein Windrad bei Vlatten, original source: Aachener Zeitung, 6Dec2013 https://www.wind-watch.org/news/2013/12/10/xaver-zerstort-ein-windrad-bei-vlatten/ FIG. [PHOTO] near Vlatten storm Xaver destroyed a wind turbine. Foto: Vietoris
National Wind Watch (20131210b)	National Wind Watch, Sturm 'Xaver': Windrad stuerzt auf Acker, 10Dec2013b, credit: von Manfred Reinnarth, 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 (20131212)	National Wind Watch, Sturm 'Xaver': Windrad stuerzt auf Acker, 10Dec2013b, credit: von Manfred Reinnarth, 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' 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 FIG. wind blade sails 150m from turbine Thurday-Friday night from Anlage 7 of Deininger 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 (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# 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)

	FIG4. Floodwaters in Hamburg early on Friday morning. City officials closed off flooded areas and some people reportedly had trouble reaching work in the morning (DPA) FIG5. In Rostock fire fighters secure parts of a roof blown off by hurricane-force winds (DPA) FIG6. Streets also flooded in the northwestern 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 Dagebuell on Thursday night (DPA) FIG9. The pier at the Bensersiel port of lower Saxony was also flooded by the storm surge (DPA) FIG10.Strong gusts of wind up to 155km/h reported across Germany, damaging roofs, uprooting trees and causing traffic problems. That did not this man from getting right in the thick of it on Thursday (DPA) FIG11.The UK, Germany, Netherlands, Scandinavia most heavily affected by the severe storm, but cancelled flights and tranins 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) FIG12.An uptrooted tree in the village of Sankt Peter Ording on the North Sea coast on Thursday (Reuters) FIG13.A rescue vessel patrols the North Sea island of Norderney on Thursday (DPA) FIG14.Scotland also say high winds on Thursday. Here, rescue workers at the scene a truck accident near Bathgate (AP) FIG15.Snow from Xaver gnarled traffic near Olpe in the state of Nord Rhine Westphalia on Friday morning (DPA) FIG16.Here waves batter th 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)
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 FIG: [PHOTO] part of a viewing platform and or stairs lying on the beach of Hoernum on a damaged dune
Sylter Rundschau (20131209)	Sylter Rundschau, Folgen des Orkans. Xaver 'knabberte' Sylt massiv an, 09Dec2013 06:00 (from Friederike Reussner) https://www.shz.de/lokales/sylter-rundschau/xaver-knabberte-sylt-massiv-an-id5098481.html FIG. [PHOTO] First floor of Wenningstedter Restaurant Wonnemayer damaged during Storm Xaver
TheJournal (20131205)	TheJournal, Homes remain without electricity after high winds batter power lines, 05Dec2013 08:20PM, https://www.thejournal.ie/storm-ireland-1207783-Dec2013/ PHOTO: coastal area Ireland [Sasko Lazarov, Photocall Ireland]
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 -FIG. [PHOTO] Storm Sven sweeps into Malmo [Joham Nilsson, TT]
Upstream (20131205)	Upstream, North Sea production curtailed over storm, 05Dec2013 (contributor: Bill Lehane and News Wires) FIG. [PHOTO] Weather impact. Platformscut output over storm, seen here causing flooding in Wales. (Photo: Reuters, Scanpix)
ABPmer (2014)	ABP mer, Ensuring Flood Resilience. An overview of the 5/6 December 2013, Associated British Ports, Marine Environmental Research, July, 2014 -FIG_p3. [PHOTO] Weiring over Grimsby flood gate -FIG_p3. [PHOTO] Coastal erosion at Hemsby [Albanpix] -FIG_p3. [PHOTO] Wave damage to Cromer frontage [David Tipling]
BBC (20141205)	BBC, East coast surge: what happened next? (report by Richard Haugh), 5Dec2014 -PHOTO: seven cliff top houses collapsed in Hemsby on the night of the worst storm surge for 60 years (beach view of 2 collapsed bungalows) -PHOTO: residents formed a human chain to help salvage items from homes in Hemsby (aerial view of 4 houses over cliff edge) -PHOTO: hundreds of homes in Lincolnshire were also evacuated during the tidal surge (ambulance crew evacuating resident by boast) -PHOTO: flats in Boston were flooded (woman on stairs of flat with 50cm water) -PHOTO: some families had to be rescued by boat on Boston High street (ambulance crew evacuating people in zodiac) -PHOTO: Hugh Drake lost 25 acres of his land and can not grow crops on a large section (picture of farmer in front of coastal salt marsh) -PHOTO: ironically, the Bizzaro restaurant in Boston was hosting a Venice themed night on 5 December 2013. The image on the right shows how the street outside the restaurant looks now (before and after photos of Boston high street) -PHOTO: Ray Mooney was still in his house in Hemsby when it started to be washed away (picture of Hemsby house overhanging sand cliff) -PHOTO: remains of the houses can still be seen on Hemsby Beach (steel trusses protruding from sand cliff) -PHOTO: several pilot sea defence schemes have been placed along the beach with the help of residents (square rock baskets on Hemsby beach) -PHOTO: the Netherlands improved flood defences after 1836 people died in 1953. (archive photo of Dutch house

	in 2m of seawater from 1953 surge with ground floor washed away)
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_p15. Scarborough beach front sustained significant storm damage, including damage to sea wall -FIG_p16. Flooded building being dried out at a location in Lowestoft -FIG_p17. Visible water line from the surge event at a location with protection installed. -FIG_p20. 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, Rekordvandstande i Isefjorden og Roskilde Fjord, Vejret, 138, 2 40-48, 2014 -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-beschaedigt-fino1 FIG. [PHOTO] ripped 15m deck grating on 15m side of the FINO1 platform FIG. [PHOTO] photo smashed small wooden deck at 17m
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] Qualmwasseraustritt on 6Dec2013 (ground water erupting out of ground) -FIG11.[PHOTO] St. Pauli Fischmarkt on 6Dec2013 at 06:30 -FIG12.[PHOTO] Am Sandtorkal (morning of 6Dec) -FIG13.[PHOTO] Dalmannkai on evening of 6Dec2013 -FIG14.[PHOTO] Dalmannkai on evening of 6Dec2013 -FIG17. [PHOTO] Fischmarkt on monring 6Dec2013
Knaack and Heyken (2014)	Knaack H and H Heyken, Xaver hatte sehr schwere Stumflut im Gepaeck, Jahresbericht 2013. Der Zukunft verplichtet, NLWKN, Niedersaechsischer Landesbetrieb fuer Waserwirtschaft, Kuesten- und Naturschutz, pp.8-9, document date stamp 24Apr2014. FIG. [PHOTO] 60000 cubic meters sand will be brought to Juist to strengthen the dunes
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. WL Rapporten, 00-119, Waterbouwkundig Laboratorium, Antwerpen, Belgie. October 2014, WL2014R00_119_5 [document date stamp: 15Oct2014; author= Deschamps, Maarten] FIG19. [PHOTO] Aerial oblique photo from 06/12/2013 of the height of Bergenmeersen and Paardeweide (viewing direction from upstream to downstream)
Pelt (2014)	Pelt AS, BODIL's stormflod i de indre dansk farvande, Vejret, 138, 24-29, 2014 -FIG4. [PHOTO] During the storm surge Nordsjaellands Kattegatkyst experienced large erosion and damage. Photo of Rageleje Strandvej, which was closed to through traffic because waves swept over the road. -FIG. [PHOTO]. Backside photo of flooding in Lynaes Havn at Hundested in connection with Bodil's record water level (photo Mikael Scharling)
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 FIG8. [PHOTO] closed flood gate at Delfzijl 06Dec2013 FIG11.[PHOTO] Seaweed flood line on dike at Emmapolder; west of Eemshaven
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 -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: titl=Regional advisering: Ameland NW; author=Arnold van Rooijen; keywords: 1209381-008-ZKS-0008; date stamp: 18/12/2014] FIG2.4. [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 Suesser, 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] -FIG_p39. [PHOTO] toppled Christmas tree in front of the Schloss Bellevue, residence of Bundespraesident Joachim Gauck
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. -FIG2.10.[PHOTO] General view of the Dutch dunes at Het Zwin and records of

	large portion of dunes scarped by Sinterklaasstorm -FIG2.11.[PHOTO] Record of the overwash event
Fischer et al. (2015)	Fischer, JG, C Senet, A Schneehorst, O Outzen, 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, Sturmflutwarndienst der Betriebstelle Norden-Norderney, NLWKN Niedersachsischer 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, 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. -FIG2. [PHOTO] Impacts of storm surge of 5-6Dec2013: (a) Fresh cliff falls overlying near basal notching, Covehythe Cliffs Suffolk (b) sand dune cliffing and retreat, Donna Nook North Lincolnshire (c) large reactivated washover fan, central Scolt Head North Norfolk cost (d) breaching of the Cley-Weybourne barrier with flooding of freshwater marshes and development of new washover fans over back barrier saline lagoons. (e) breach in the Walberswick-Dunwich gravel barrier, Dingle Marshes Suffolk (f) multiple breaches in the NW section earthen flood defene bank, Blakeney Freshes, North Norfold -FIG8. [PHOTO] Local variations in surge water levels, North Norfolk coast (a) Massive debris bank reaching 5.95m ODN, Privet Hill, Scolt Head Island (b) typical back barrier driftline at 5.52m ODN Great Aster Marsh, Scolt 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, Holkham Gap 4.46m ODN -FIG9. [AERIAL PHOTO] Net shoreline movement (NSM, m) dynamics (a) Covehithe, Suffolk Coast (Aug 2013-08Dec2013), (b) Holkham Gap, North Norfolk (Aug 2013-16Jan2014), (c) Scolt Head Island (Aug 2013-14Feb and 03Mar2014) Aerial photography basemaps coutesy of the Shoreline Management Group, UK EA -FIG10. [PHOTO] Open coast and barrier island surge impacts, North Norfolk Coast (a) Cliffing of high dunes, looking east from The Hut dunes, Scolt Head Island (b) vertical cliffing of high dunes, outer duneline, Holkham gap (c) roll up of sand dune rootmat layer, seaward margin of Wire Hills, Scolt Head Island (d) beach sands piled up against new low erosional dune front, Smuggler's Gap, Scolt Head Island (e) new washover deposits at western end of reactivated washover, previously formed 1978, looking towards The Hut, Scolt Head Island, (f) new washover deposits between the 2007 washover at Spartina Marsh and the seaward margin of wire hills dune field, looking west towards far point -FIG11. [PHOTO] Dynamics of the Cley-Weybourne barrier. a) breach opposite village of Salthouse, 09Dec2013, (b) closure of breach 24Jan2014
Vanmassenhove (2015)	Vanmassenhove, Niels, Storm surge measures ports Flemish coast, Blankenberge, Tuesday February 3rd, Maritieme Sientverlening en Kust, Coastal Division, Flanders Hydraulic Research.[document properties: title=Geintegreerd Kustveiligheidsplan; author=Maarten; datestamp=27/02/2015] -FIG_S9: [PHOTO] view of one of the critical points in the harbour of Ostend during the December 2013 storm -FIG_S10: [PHOTO] emergency workers placing sandbags Ostend during Dec2013 flood -FIG_S11: [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 Weihnachshochwasser 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 dike damage Nordstrand Alter Koog FIG9. [PHOTO] Loose grass being gathered from inland dike
Nederhoff et al (2016)	Nederhoff K, E Elias, T Vermaas, Erosie op Ameland Noordwest. Modelstudie: simulaties met Delft3D en XBeach, Deltares, 117pp, July, 2016 -FIG2.4. [PHOTO] Impact on the westkop of Ameland after the Sinterklaasstorm 5-6Dec2013
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: Universitaet 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 Frederikssund (left) and Helsinore (Sealand). 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. -FIG2.[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) (c) 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 setting of Scolt Head Island showing the barrier and back barrier marshes following the 5Dec storm with Brancaster Bay in the far distance (photo M. Page 09/12/2013)
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/bostonbarriertwao/results/appendix-1---history-of-flooding-sources.pdf -FIG. [PHOTO] two night photographs showing flooding in streets of Boston 5Dec2013
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 -FIG6. [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 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. [PHOTO] Photo wave impact at unknown coastal location in German Bight -FIG. [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 surge during Hurrican Bodil
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] -Photo of Hamburg Fishmarket flooded in early morning, probably during Storm Xaver (Birger Tinz)
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 -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 -FIG1. (a) [MAP] schematic of the study area of the Storm Surge in the North Norfolk coast. The Dec 2013 storm surge destroyed the coastal defence. spreading the sediments and flooding with seawater the inland freshwater marshland ecosystem. UAV survey (b) before and (c) after the storm surge -FIG2. [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 -FIG1. [PHOTO] damaged promenade Sheringham -FIG2. [PHOTO] damaged promenade and earth bank Sheringham -FIG3. [PHOTO] damaged sea wall and earth bank Sheringham -FIG4. [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) -FIG1. [PHOTO] Flooding in Hamburg -FIG3. [PHOTO] Tree fall in Denmark; Hadsund, north of Randers -FIG4. [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 *-FIG8. Flooded 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) tken 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 (20200124)	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, Baltasound, Unst, 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] Breached sea dike at Burnham Norton, Norfolk, Seaward to left; flooding to right FIG [PHOTO] December 2013 storm surge on Sheringham seafront
Wikipedia (20200429)	Wikipedia, Stormen Sven, 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
Wikipedia (20200502)	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 (20131205)	Aftenposten, Varsler full storm I Sor-Norge, 5Dec2013 15:03 (correspondent Per Annar Holm) https://www.aftenposten.no/norge/i/bKEjl/varsler-full-storm-i-soer-norge -last serious Norway storm Hilde, affecting Trondelag & Helgeland
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 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 (20131206)	BBC20131206, Deadly storm and tidal surge batter northern Europe, BBC 6 Dec2013 (report by Anna Holligan) -worst storm surge in eastern England in 60 years -Hamburg experienced biggest storm surge since the 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 (2013)	BSH, Die Nordseesturmfluten 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) -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 (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 -this is the only storm surge press release among the collection of press releases spanning 2004-2018
Deutschlander et al (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. -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 ueber 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 Britta 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.aweablog.org/ireland-u-k-germany-set-new-wind-generation-records/, 11Dec2013 -record wind energy production Germany 06Dec2013
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. -three largest comparable events in Germany: Kyrill (18-19Jan2007); Lothar (26Dec1999); Daria/Vivian/Wiebke -new extreme water levels Dagebuell, Husum, Buesum, Eidersperrwerk, Cuxhaven -top 10 absolute high water levels Hamburg: 03Jan1976>06Dec2013>18Jan1994>10Jan1995>03Dec1999>24Nov1981>23Jan1993>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.
Mills et al (20131206)	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/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 early2013; SWH and wind speeds highest of previous 9 months
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/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, Waserstaende zwischen Zweieinhale und Knapp vier metern registriert // presseinformation 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://nos.nl/artikel/583218-hoogste-waterstand-sinds-1953.html -highest water level in Vlissingen (3.99m NAP) since 1953 surge (4.55m NAP)
Oceanografisch 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 Vaderoarna 10.7m; less than recordd 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
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 -record sea state level of 6m; highest since record start in 1987
Sylter Rundschau (20131209)	Sylter Rundschau, Folgen des Orkans. Xaver 'knabberte' Sylt massiv an, 09Dec2013 06:00 (from Friederike Reussner) https://www.shz.de/lokales/sylter-rundschau/xaver-knabberte-sylt-massiv-an-id5098481.html -Arfst Hinrichsen, Landesamt fuer Kuestenschutz on Sylt beach damage: 'Das war schon heftig, solhe Schaeden habe ich selten gesehen'
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 -rank 2 storm surge; Storm Xaver storm surge lower than 03Jan1976 -squall lines observed for Storm Xaver (2013), Kyrill (2007) & Emma (2008) -Xaver was among the most powerfu storm of recent decades in Germany
AON Benfield (2014)	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 -other events are Storm Dirk 23-25Dec2013; winter storms US and Canada; floods SE Brazil worst in decades
ABPmer (2014)	ABPmer, 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, Lowestoft -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; 04/04/2014] -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 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] -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\ -1953 surge event highest for at least 250y -Southend water level 4.1m or 0.06 m higher than previous record in 2007

Eden (201402)	Eden, Phillip, Weather Log December 2013, Weather, Feb 2014, pp.i-iv -'a rapidly deepening depression tracked from just northwest of Scotland to the southern Baltic between the 5th and 7th, bringing the greatest storm surge to the east coast since 1953'
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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, Spit 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 12Feb1938, storm surge 1Jan1995, storm surge 1953
JBA Risk Management (2020)	JBA Risk Management, Storm Xaver 2013. Event Commentary, 2020. [PDF document properties: author=Cameron Whitwham] -COBRA meeting on 05Dec2013 beccause 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 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 843y -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/i/bKEjl/varsler-full-storm-i-soer-norge -met.no has been monitoring Bodil for a week
BBC (20131204)	BBC, Workers off Talisman Sinopec 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 winds, large wave and storm surge Thu to Sat morning -this is the only storm surge warning among the press releases 2004-2018
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/ -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 Friday storm
GVA (20131205)	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 -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/sturmflutgefahr-an-der-kueste-und-auf-den-inseln-120187.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, Stormverslag 05-06 december 2013, 26pp, 2013 [pdf document properties: author=Myriam Sys; datestamp=15Dec2013] -wind forecasts available from 30Nov2013; storm conditions d=forecase starting from 01Dec2013 -detailed wind and sea state forecasts from 04Dec2013 -water level forecasts from different model from 01Dec2013
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 -US GFS model made predictions from 29Nov of storm on Dec6. -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
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] -4Dec2013: EA sent warning 'prepare for worst E coast tidal surge in 30y'
Hewson et al (2014)	Hewson T, L Magnusson, O Breivik, F Prates, I Tsonevsky, 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)	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] -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, 48 pp -advance forecast from 27Nov2013 -detailed 12h forecasts before surge maximum at each reference station
Van Dorland	van Dorland, R, Zware storm op 5 december, Zenit, p43, Januari 2014 -KNMI issued code orange severe weather warning for gusts in NW part of country on 04Dec2013 -Upgraded to code red severe weather warning on 05Dec2013
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=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, 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 -pre-storm beach surveys were made on 3Dec2014
NLWKN (20151210)	NLWKN20151210, Sturmflutwarndienst der Betriebstelle Norden-Norderney, NLWKN Niedersachsischer 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 squaly 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 7 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 (20160316), 201312 - Windstorm - 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 observationsin the previous section. The first forecast is from 05Dec 00UTC and following is 04 dec and so on (1day 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 wrnings of strong winds 4-7Dec2013 -FIG5. [MAP] Forecasts of expected significant weather threats issued on (a) 4Dec 2249UTC, (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 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. -'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 explos overnight -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 kh/m -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
Gccaptialideas (20131209)	gccapitalideas, 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, Stormverslag 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 (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 -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.
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] -'The storm surge that damaged many defences and received significant media attention on 5th and 6th Decembr 2013 does not appear to have had exceptional wave conditions at the Tyne Tees 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 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] -EA aerial photo of London area flooed in absence of London Barrier -cost of 1953 flood 500mill GBP; 1983 construction cost 535mill GBP -EA: flood defenses 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.-0.6.12.2013 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] -in spite of extreme wind 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 compares with UK 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 fom 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 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=filiz; date stamp=07Aug2015] -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 ueber die potenzielle Katastrophe an der Nordsee berichtet, die sich glucklicherweise nicht realisierte' (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 100y 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 Weihnachshochwasser 2014 in Shleswig-Holstein, IWASA 2016 Tagungsbeitrag, (46. IWASA, 7-8 Januar 2016; Internationales Wasserbau-Symposium Aachen. [pdf document properties: autor=sonja; datestamp: 26Apr2016] -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.northnorfolk.org/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.northnorfolk.org/coastal, photo of plaque on wall taken 30Dec2019 -no drowning fataliies for 2013 storm in comparison to 2013 storm because of effective sea defences, 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 milder than expected on France's north coast near Denmark

JBA Risk Managment (2020)	JBA Risk Management, Storm Xaver 2013. Event Commentary, 2020. [PDF document properties: author=Cameron Whitwham] -UK flood defences avoided estimated 32 billion GBP in damage costs
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 de Schaeden weniger verheerend als zuvor befuerchtet.'

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

Source	Full Reference and Notes
Sueddeautsche 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 -emergency sandbags placed at Keitum on east side of Sylt to prevent a water inbreak
Sylter Rundschau (20131209)	Sylter Rundschau, Folgen des Orkans. Xaver 'knabberte' Sylt massiv an, 09Dec2013 06:00 (from Friederike Reussner) https://www.shz.de/lokales/sylter-rundschau/xaver-knabberte-sylt-massiv-an-id5098481.html -storm damages Sylt boundary dunes and dikes
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 -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 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] -2013 flood: 100 properties flooded & flood protection structures damaged
Knaack and Heyken (2014)	Knaack H and H Heyken, Xaver hatte sehr schwere Stumflut im Gepaeck, Jahresbericht 2013. Der Zukunft verplichtet, NLWKN, Niedersaechsischer Landesbetrieb fuer Waserwirtschaft, 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 -Delfzijl water level 52cm higher than forecast -Roompot 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: 13Jan2016) -COBRA crisis committee briefings for several storms
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, Wilhelshaven, Norderney
Vanmassenhove (2015)	Vanmassenhove, Niels, Storm surge measures ports Flemish coast, Blankenberge, Tuesday February 3rd, Maritieme Sientverlening en Kust, Coastal Division, Flanders Hydraulic Research.[document properties: title=Geintegreerd Kustveiligheidsplan; author=Maarten; datestamp=27/02/2015] -emergency workers placed sandbags in Ostend Harbour
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. -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'
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. -breaching of water level defences in Suffolk
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/bostonbarriertwao/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 onThursday 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 Dec2013 (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 2011_bm1101; author stamp: bm1101; document time stamp: 12/102013 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 ueber Nordeuropea 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 winterlich mit Schnee bis in tiefere Lagen.'
KNMI (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 -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/nyhetsarkiv/stormen-sven-gav-nya-vattenstandsrekord-i-oresund-1.34732, updated 20Mar2017; original datestamp 10Dec2013. -short duration flood on west coast Sweden
Sylter Rundschau (20131209)	Sylter Rundschau, Folgen des Orkans. Xaver 'knabberte' Sylt massiv an, 09Dec2013 06:00 (from Friederike Reussner) https://www.shz.de/lokales/sylter-rundschau/xaver-knabberte-sylt-massiv-an-id5098481.html -storm damages Sylt dunes and coast over 2-day period
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 -Xaver had exceptionally long duration -Station Hiddensee-Dornbusch on Baltic Island had 41h of storm winds -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; datestamp; 04/04/2014] -Newbiggin Ness wave buoy storm duration: 20h -Tyne Tees Wavenet buoy storm duration: 38.5h -Whitby waverider storm duration: 26h
Eden (201402)	Eden, Phillip, Weather Log December 2013, Weather, Feb 2014, pp.i-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. -wind speed over the North Sea over 20m/s for 19h in the direction 270-300 deg as measured at Scharhoern
Knaack and Heyken (2014)	Knaack H and H Heyken, Xaver hatte sehr schwere Stumflut im Gepaeck, Jahresbericht 2013. Der Zukunft verplichtet, NLWKN, Niedersaechsischer 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 at. (2014)	Kristandt, J., B. Brecht, H. Frank, H. Knaack, Optimization of empirical storm surge forecast-modeling of high resolution wind fields, Die Küste, 81, 301-348, 2014 -surge flooding continued over 4 tide tide cycles
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 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. -Storm Xaver raged in German Bight for 2.5 days; several storm tides. -FINO2: wind speed >20m/s for 35h -FINO3: wind speed >25m/s for >24h
Luecht and Peters (2014)	Luecht, Fabian and Ove Peters, Bericht ueber die Sturmflut vom 05.-0.6.12.2013 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] -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 11h -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, I. Moller, B.R. Evans, Where local matters: Impacts of a major North Sea storm surge, EOS, 95, 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 damge
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=filiz; 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
Kendon and McCarthy (2015)	Kendon M and M McCarthy, The UK's wet and stormy winter of 2013/2014, Weather, 70, 40-47, 2015 -wet & stormy conditions persisted through Dec 2013 to Feb 2014
Matelski (2016)	Matelski, Birgit, Erfahrungen aus der Sturmflut Xaver von 5. und 6.12.2013 und dem Weihnachshochwasser 2014 in Shleswig-Holstein, IWASA 2016 Tagungsbeitrag, (46. IWASA, 7-8 Januar 2016; Internationales Wasserbau-Symposium Aachen. [pdf document properties: autor=sonja; datestamp: 26Apr2016] -three storm surge peaks -long duration flood conditions: water on sand fo 9h; dunes subjected to wave attack -on List auf Sylt water level >700cm PN for 532min
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. -Storm Xaver propagation across the North Sea very fast in comparison with 31Jan1953 storm
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. -surge continued over 2 high tides
Brooks et al (2016)	Brooks SM, T Spencer, A McIvor, I Moller, Reconstructing and understanding the impacts of storms and surges, southern North Sea, Earth Surface Processes and Landforms, 41, 855-864, 2016. -14h period when surge residual >1m; exceeded only by Storm Britta 01Nov2006 with 18.75h time interval
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 McCarroll -Hornbaek water level exceeded 1.5m for over 18h; tidal range 0.2-0.4m with annual exceedance 1.08m DVR90
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)	Peter Frohle & Norman Dreier, EarlyDike - Sensor - und risiko basiertes Fruhwarnsystem fuer Seedeiche, 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
Environment Agency (2018)	Environment Agency, Thames Barrier Project Pack 2018, January, 2018 -record number of Thames Barrier closures in Jan & Feb 2014
Kystdirektoratet (2018)	Kystdirektoratet, Shoreface nourishment effects. An analysis of the 2011 nourishment performed at Skodbjerge. Kystdirektoratet, Hojbovej 1, 7620 Lemvig, Dec 2018 [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
Schenk and Mueller-Navarra (2019)	Schenk, L and S Mueller-Navarra. 3.4.4. Windstaustatistiken und Haufigkeit von Sturmfluten 2012-2015 https://www.bsh.de/DE/PUBLIKATIONEN/Nordseezustand_Aktuell/_Anlagen/Downloads/3_4_4_Windstatistiken.pdf?__blob=publicationFile&v=2 [pdf document properties: author=Ludwig Schenk; datestamp=14Feb2019] -3 consecutive storm surges at Hamburg
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 Dirk, 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)	Aftenposten, Varsler full storm I Sor-Norge, 5Dec2013 15:03 (correspondent Per Annar Holm) https://www.aftenposten.no/norge/i/bKEjl/varsler-full-storm-i-soer-norge 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. Cipollini P, LJ West, HM Snaith, 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] Hewson T, L Magnusson, O Breivik, F Prates, I Tsonevsky, HJW de Vries, Windstorms in northwest Europe in

	late 2013, ECMWF Newsletter, No 139, pp 22-28, Spring 2014. Pelt AS, BODIL's stormflod i de indre dansk farvande, Vejret, 138, 24-29, 2014 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 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 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=filiz; date stamp=07Aug2015] Gierlevsen 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. Patzer, Marianne, Storm surge forecasting at DMI and perspectives on teh use of Earth Observations, ESA eSurge Sympositum, Deltares, the Netherlands, (powerpoint presentation) January 21, 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. ECMWF (20160316), 201312 - Windstorm - Xaver/Bodil/Sven, North-western Europe https://confluence.ecmwf.int/pages/viewpage.action?pageId=28315390 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: Universitaet Siegen, 2016 Danish Emergency Management Agency DEMA, National Risk Profile for Denmark, April 2018 Wikipedia, Stormen Bodil, https://da.wikipedia.org/wiki/Stormen_Bodil#cite_note-39 (accessed 02Oct2019) WIKI, Cyclone Xaver, https://en.wikipedia.org/wiki/Cyclone_Xaver accessed 24Jan2020 Wikipedia, Stormen Sven, https://sv.wikipedia.org/wiki/Stormen_Sven#cite_note-15, accessed 29Apr2020 Wikipedia, Orkan Xaver, https://de.wikipedia.org/wiki/Orkan_Xaver (accessed 2 May 2020)
Cameron	WIKI, Cyclone Xaver, https://en.wikipedia.org/wiki/Cyclone_Xaver accessed 24Jan2020
Ksavery (Poland)	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. Wikipedia, Stormen Bodil, https://da.wikipedia.org/wiki/Stormen_Bodil#cite_note-39 (accessed 02Oct2019) Wikipedia, Orkan Xaver, https://de.wikipedia.org/wiki/Orkan_Xaver (accessed 2 May 2020)
Nikolausflut	NLWKN20151210, Sturmflutwarndienst der Betriebstelle Norden-Norderney, NLWKN WIKI, Cyclone Xaver, https://en.wikipedia.org/wiki/Cyclone_Xaver accessed 24Jan2020 Niedersachsischer Landesbetrieb fuer Wasserwirtschaft, Kuesten- und Naturschutz, Niedersachsen, document date stamp 10Dec2015.
Nikolaus-Orkan	Wikipedia, Orkan Xaver, https://de.wikipedia.org/wiki/Orkan_Xaver (accessed 2 May 2020)
Nordseesturmfluten von 5. und 6.12.2013	BSH, Die Nordseesturmfluten von 5. und 6.12.2013, 3pp, prepared by Stockmann,K. (title: Sturmflut 2011_bm1101; author stamp: bm1101; document time stamp: 12/102013 12:5136PM)
St Nicholas	Hewson T, L Magnusson, O Breivik, F Prates, I Tsonevsky, HJW de Vries, Windstorms in northwest Europe in late 2013, ECMWF Newsletter, No 139, pp 22-28, Spring 2014.
Sint-Nicolaasvloed	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
Sinterklaasstorm	Oceanografisch Meteorologisch Station, Stormverslag 05-06 december 2013, 26pp, 2013 [pdf document properties: author=Myriam Sys; datestamp=15Dec2013] RWS, Watermanagementcentrum Nederland, Stormvloedflits 2013-07 van 5 t/m 7 december 2013, Rijkswaterstaat (document time stamp: 07Jan2014), 2014a 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] van Rooijen A, A Oost, Memo: Regionale advisering Ameland Noordwest, Deltares, 1209381-008-ZKS-0008, 43pp, 18Dec2014 [PDF document properties: titl=Regional advisering: Ameland NW; author=Arnold van Rooijen; keywords: 1209381-008-ZKS-0008; date stamp: 18/12/2014] 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=filiz; date stamp=07Aug2015] 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. 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 Nederhoff K, E Elias, T Vermaas, Erosie op Ameland Noordwest. Modelstudie: simulaties met Delft3D en XBeach, Deltares, 117pp, July, 2016 Li, H., The Ameland Inlet during the Sinterklaas Storm: the role of flooding of watersheds, 2DH model study in Delft3D-FLOW, M.Sc. Thesis, Utrecht University, 01May2018 Wikipedia, Stormen Bodil, https://da.wikipedia.org/wiki/Stormen_Bodil#cite_note-39 (accessed 02Oct2019) WIKI, Cyclone Xaver, https://en.wikipedia.org/wiki/Cyclone_Xaver accessed 24Jan2020 Wikipedia, Orkan Xaver, https://de.wikipedia.org/wiki/Orkan_Xaver (accessed 2 May 2020)
Storm surge of 5 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
Sven (Sweden)	Aftenposten, Varsler full storm I Sor-Norge, 5Dec2013 15:03 (correspondent Per Annar Holm) https://www.aftenposten.no/norge/i/bKEjl/varsler-full-storm-i-soer-norge 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. Expressen, Flera doda i Sverige efter stormen Sven, 06Dec2013, 17:34CET?

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Xaver (Germany)	Aftenposten, Varsler full storm I Sor-Norge, 5Dec2013 15:03 (correspondent Per Annar Holm) https://www.aftenposten.no/norge/i/bKEjl/varsler-full-storm-i-soer-norge 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. 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. 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 Unwetterzentrale, Orkantief XAVER - ein weiterer schwerer Wintersturm der letzten Jahrzehnte, Thomas Savert and Stefan Laps, Dec. 2013 http://www.unwetterzentrale.de/uwz/928.html AON Benfield, Impact forecasting. December 2013 Global Catastrophe Recap, 2014. [document properties: abrandt; date stamp: 10Jan2014] 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 Cipollini P, LJ West, HM Snaith, 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] 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] Hewson T, L Magnusson, O Breivik, F Prates, I Tsonevsky, HJW de Vries, Windstorms in northwest Europe in late 2013, ECMWF Newsletter, No 139, pp 22-28, Spring 2014. (from Berlin's Free University) Knaack H and H Heyken, Xaver hatte sehr schwere Stumflut im Gepaeck, Jahresbericht 2013. Der Zukunft verplichtet, NLWKN, Niedersaechsischer Landesbetrieb fuer Waserwirtschaft, Kuesten- und Naturschutz, pp.8-9, document date stamp 24Apr2014. Kristandt, J., B. Brecht, H. Frank, H. Knaack, Optimization of empirical storm surge forecast-modeling of high resolution wind fields, Die Küste, 81, 301-348, 2014 Leiding T, B Tinz, G Rosenhagen, C Lefevre, S Haeseler, S Hagemann, I Bastigkeit, 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. Mai, S., Sea state at the research platform FINO1 during the winter storm 'Xaver', BFG, Bundesamt fuer Gewasserkunde, document properties: author=Mai, date=16May2014 RMS, 2013-2014 Winter Storms in Europe. An Insurance and Catastrophe Modeling Perspective. RMS White Paper. [PDF TIMESTAMP 11Mar2014] 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 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=filiz; date stamp=07Aug2015] 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 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 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. NLWKN20151210, Sturmflutwarndienst der Betriebstelle Norden-Norderney, NLWKN Niedersachsischer Landesbetrieb fuer Wasserwirtschaft, Kuesten- und Naturschutz, Niedersachsen, document date stamp 10Dec2015. Patzer, Marianne, Storm surge forecasting at DMI and perspectives on teh use of Earth Observations, ESA eSurge

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

Source	Full Reference and Notes
Deutschlander et al (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. -ABB2a.[MAP] Bodenanalyse Nordatlantik/Europa von 5.Dezember 2013, 00UTC -ABB2b.[MAP] Bodenanalyse Nordatlantik/Europa von 5.Dezember 2013, 18UTC -ABB2c.[MAP] Bodenanalyse Nordatlantik/Europa von 6.Dezember 2013, 00UTC -ABB3. [MAP] Satellitenbild mit Luftdruck (in hPa) und Wind (Richtung und Geschwindigkeit) am 6.Dezember 2013 00UTC, ueber dem nordlichen Europea (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
Mills (20131206)	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/website/home/News/DAT_2087062.html (last accessed: 19Nov2019, 28Jun2020) -FIG1. Met-10 and Jason, 05Dec2013 1800UTC; channel IR 10.8um; source EUMETrain -FIG2. Met-10, 05Dec2013, 1800UTC; Airmass with the MSLP (pressure lines)
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 -FIG1. [MAP] UKMO weather maps E Atlantic & Europe 04Dec2013 0600UTC to 07Dec2013 1200UTC -FIG2. [MAP] IR? cloud image Europe 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 N North Sea -FIG15. [MAP] visible satellite image with lightning band in front of the Netherlands coast
Eden (201402)	Eden, Phillip, Weather Log December 2013, Weather, Feb 2014, pp.i-iv -series of daily weather maps of surface pressure for Europe
Eriksen (2014)	Eriksen J, Rekordvandstande i Isefjorden og Roskilde Fjord, Vejret, 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 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. -FIG3. [MAP] Satellite cloud image with air pressure and wind direction on 6Dec2013 0000UTC
Matelski et al. (2014)	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. -FIG3. Satellite image with air pressure (hPa) and wind (direction and speed) on 6Dec2013 00UTC (source: DWD)
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. WL Rapporten, 00-119, Waterbouwkundig Laboratorium, Antwerpen, Belgie. October 2014, WL2014R00_119_5 [document date stamp: 15Oct2014; author= Deschamps, Maarten] -FIG2. [MAP] weather map 05Dec2015 0000UTC, 0600UTC, 1200UTC (KNMI2013b, Kroos 2013) -FIG3. [MAP] Model-derived wind fields at 05Dec2013 0700/1300/1900CET -FIG4. [MAP] Model-derived wind field at 05Dec2013 1900CET; max in German Bight
RWS (2014a)	RWS, Watermanagementcentrum Nederland, Stormvloedflits 2013-07 van 5 t/m 7 december 2013, Rijkswaterstaat (document time stamp: 07Jan2014), 2014a -FIG. Surface pressure weather map of Europe and eastern North Atlantic 05Dec2013 1300MET with warm and cold fronts marked -FIG. Visible satellite image 06Dec2013 1200??? From EUMETSAT
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_p0: Visible satellite image of storm over Europe -FIG2. [MAP] Weather map from 05Dec2013 0100MEZ -FIG3. [MAP] Weather map from 05Dec2013 0700MEZ -FIG4. [MAP] Weather map from 05Dec2013 1300MEZ -FIG5. [MAP] Thunderstorm radar picture 05Dec2013 1510MEZ
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=filiz; date stamp=07Aug2015] -FIG_p48. [MAP] Hurricane Xaver 05Dec2013 0100MEZ -FIG_p48. [MAP] Hurricane Xaver 06Dec2013 0100MEZ
Kendon and McCarthy (2015)	Kendon M and M McCarthy, The UK's wet and stormy winter of 2013/2014, Weather, 70, 40-47, 2015 FIG1a. UK Met Office analysis map for 1200UTC 05Dec2019 showing surface pressure and fronts
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 -FIG1. Surface pressure with fronts marked: 04Dec2013 1200UTC, 05Dec2013 0000UTC; 05Dec2013 1200UTC
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 -FIG4.(map) Met analysis chart at 1200UTC 5 Dec 2013
Christakos et al (2016)	Christakos K, I Cheliotis, G Varlas, G-J Steeneveld, Offshore wind energy analysis of Cyclone Xaver over North Europe, 13th Deep Sea Offshore Wind R&D Conference, EERA DeepWind'2016, 20-22 January 2016, Trondheim, Norway, Energy Procedia, 94, 37-44, 2016. FIG1. (a) Surface pressure analysis map on 5Dec2013 1200UTC from UKMO, Xaver P=967hPa (b) Regional SatRep over North Sea 5Dec2013 0900UTC showing fronts & thorms
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. German weather maps for 05Dec2013 1200GMT and 06Dec2013 1200UTC
ECMWF (20160316)	ECMWF (20160316), 201312 - Windstorm - Xaver/Bodil/Sven, North-western Europe https://confluence.ecmwf.int/pages/viewpage.action?pageId=28315390 -FIG2. [MAP] Satellite images (Meteosat from yr.no) from 5Dec 0000-2100UTC every 3h.
Cheliotis et al. (2017)	Cheliotis, I, G. Varlas, K. Christakos, The impact of cylone 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 FIG1. [MAP] Surface pressure analysis map hPa on 5Dec2013 at 12:00UTC from UK Met office sfc analysis archive
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 -FIG1. [MAP] Pressure lines in Poland on 5Dec2013 1800UTC (adapted from Eumetsat 2013) -FIG2. [MAP] Clouds of storm Xaver in Europe on 5Dec2013 at 2330UTC
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] -satellite cloud image of Storm Xaver
Wikipedia (20191002)	Wikipedia, Stormen Bodil, https://da.wikipedia.org/wiki/Stormen_Bodil#cite_note-39 (accessed 02Oct2019) -FIG2. [MAP] Meteorological development of storm
WIKI (20200124)	WIKI, Cyclone Xaver, https://en.wikipedia.org/wiki/Cyclone_Xaver accessed 24Jan2020 FIG [SATELLITE] Xaver making landfall over Norway and Denmark on 05Dec2013 FIG [MAP] weather map loop eastern Atlantic & Europe FIG [MAP] surface pressure chart 12:00 UTC 05Dec2013
Wikipedia (20200502)	Wikipedia, Orkan Xaver, https://de.wikipedia.org/wiki/Orkan_Xaver (accessed 2 May 2020) FIG1. [MAP] Surface pressure chart of NOAA on 5Dec2013 12:00UTC FIG2. [MAP] Weather map of Orkan Xaver 5Dec2013 00:00UTC-9Dec 12:00UTC

	FIG3. [MAP] Trajectory of hurricane front anhand der Blitzentladungen in the area of the Netherlands

Table S10. Satellite altimeter strip maps (arranged by year and then alphabetically)

Source	Full Reference and Notes
Mills et al (20131206)	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/website/home/News/DAT_2087062.html (last accessed: 19Nov2019, 28Jun2020) -Jason strip map -FIG3. SARAL/AltiKa compared with tidal gauges: wind speed, wave height, sea level anomaly. 06Dec2013 0447UTC Helgoland Suedhaven, Luchtturm Alte Weser, Norderney Riffgat, Borkum Fischerbalje (a) time series water level Helgoland Suedhaven, Leuchtturm Alte Weser (b) time series wind speed Norderney Riffgat and Borkum Fischerbalje
Cipollini et al (2015)	Cipollini P, LJ West, HM Snaith, 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] -Cryosat-2 sea level strip map along axis of Kattegat and Danish Belt -surge increases from 0.1m at Swedish coast to 1.2 m at Danish islands -additional 0.9-1.0 m increase within 10 km of coast
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, 1/2 Sept 2015 -FIG. [MAP] 3 panels of E North Sea at different times during Storm Xaver surge -FIG. [PROFILE] latitude profiles from SARAL of U10, SWH, SLA during storm Xaver -FIG. [MAP] DMI model of storm Xaver sea level Friday 06Dec2013 23:05 (Madsen etal) -FIG. [PROFILE] Cryosat-2 profile of relative total water level along Kattegat 23:05GMT 06Dec2013 -FIG. [MAP] map of Cryosat-2 total water level along Kattegat.
Fenoglio-Marc et al (2015)	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 -ascending pass 629 of SARAL mission crosses North Sea at 04:47UTC 6Dec2013 -FIG1. Study area: (right) German Bight and (left) enlarged to North Sea with SARAL/ALtika altimeter ground track and in situ stations with GPS (circle), sea level (triangle), wave height (inverted triangle) & wind speed (square) data -FIG3. (left) Surge at the time of the overflight predicted by BSHmod and HyFlux2 simulations with various wind forcing and derived from in situ data. Profiles at the SARAL/Altika overflight of wind speed, significant wave height, and surge height derived from altimeter observations and from models. Gray lines correspond to observations before and after Cyclone Xaver.
Patzer (2015)	Patzer, Marianne, Storm surge forecasting at DMI and perspectives on teh use of Earth Observations, ESA eSurge Sympositum, Deltares, the Netherlands, (powerpoint presentation) January 21, 2015 -FIG. [MAP] map of storm surge water level, altimeter strip water level & 3 Zeeland tide gauges 07Dec2013 00:00
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 -RADS Radar Altimeter Database System: Jason-2, Cryosat-2, SARAL/AltikKa -FIG6. Along track observed and modelled significant wave height (m): (a) SARAL/ALtiKa ground track for overflight in calm conditions 03Dec2013 1800UTC; (b) during storm XAVER 06Dec2013 0400UTC; (c) observed & modelled significant wave height on 03Dec2013 1800UTC, (d) during storm XAVER 06Dec2013 -FIG8. (a) Surge at the time of SARAL over in calm conditions on 03Dec2013 1800UTC (b) Surge at the time of storm Xaver 06Dec2013 0400UTC (c) profiles of SARAL/Altika overflight of surge height derived from the altimeter observations and GETM mdoel on 03Dec2013 1800UTC (d) profiles of SARAL/Altika overflight of surge height derived from altimeter observations and GETM model 06Dec2013 at 0400UTC.
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). -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

Table S11. List meteorological data (arranged by year and then alphabetically)

Data type	Location	Time Interval	Full Reference and Notes
[MAP] ABB5. map with data listed for maximum 3 second wind gusts over 6 hour time intervals	Northern Germany, southern North Sea, western Baltic Sea and neighboring countries	5 Dec 2013 12-18UTC & 6 Dec 2013 00-06UTC	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.
[MAP] ABB6. Map with the	Northern Germany, southern	5Dec2913	Deutschlander T, K Frierich, S Haeseler, C Lefebvre,

data listed for 10-min average wind	North Sea, western Baltic Sea and neighboring countries	19:00UTC	Orkantief XAVER ueber Nordeuropea 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 Nordeuropea 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/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] ABB8. Time series of 1-min average wind speed, peak gust and air pressure	Hamburg St. Pauli	5 Dec2013	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] ABB9. Time series of wind direction	List/Sylt, Norderney, Rostock/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.
[MAP] ABB15. Daily precipitation in mm; initial values, unverified	Germany	5 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.
[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 Nordeuropea von 5. bis 7. Dezember 2013, Deutscher Wetterdienst DWD, Stand 30. Dezember 2013, 19pp.
[FIG] ABB8. 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 Nordeuropea 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); Eieroya (Norway); Nidingen, Vaaderooarna (Sweden); Snieszka/Schneekoppe, Ustka (Poland)	Point measurements	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 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 Fischerbalje	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/website/home/News/DAT_2087062.html (last accessed: 19Nov2019, 28Jun2020)
[FIG] Time series of wind speed and direction and gust	Zeebrugge Meteopark, Zeebrugge Daminstrumentatie (Westelijke Dam)	5-6 Dec 2013	Oceanografisch Meteorologisch Station, 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	Ireland, 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	Unwetterzentrale, Orkantief XAVER - ein weiterer schwerer Wintersturm der letzten Jahrzehnte, Thomas Savert and

		6 Dec 2013 0700 MEZ	Stefan Laps, Dec. 2013 http://www.unwetterzentrale.de/uwz/928.html
[MAP] 24 h snowfall accumulations	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
[TEXT] mention of met-ocean measurements available through COSYNA project	Station Watt (Pile at Spiekeroog)	?	Badewien T., Long-term observatory @ Pile Spiekeroog ICBM,COSYNA Progress Report 2013, p24. Helmholtz-Zentrum Geesthacht, June 2014
[TABLE] Wind speed and gust.	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
[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-iv
[FIG] Time series of wind gust, wind speed, wind direction, air temperature, atmospheric pressure	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 wind speed and wind direction	AWG platfrom	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 Scharhoern	Scharhoern	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 Gewaesser (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 Breivik, F Prates, I Tsonevsky, 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, NLWKN, Niedersaechsischer Landesbetrieb fuer Waserwirtschaft, Kuesten- und Naturschutz, pp.8-9, document date stamp 24Apr2014.
[MAP] maximum gusts at 10m; FINO1 max gust at 100m 49.0 m/s; FINO2 max gust at 100m 38.6m/s; FINO3 max gust at 100m43.2m/s	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 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.
[FIG] Time series graph of 10min wind speed and 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 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.
[FIG] Time series graph of wind speed, wind gust, wind direction	Messpfahl Westerland	1-9Dec2013	Luecht, Fabian and Ove Peters, Bericht ueber die Sturmflut vom 05.-0.6.12.2013 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]
[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, 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.
[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,

3second gust reduced to 10m, air temperature, relative humidity, air pressure, cloud height, visibility, precipitation			approved 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, Manedsrapport 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, 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]
[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, Manedsrapport Heimdal, Desember 2013, Dok. Nr. ND/1047/13/12 (carried out be SRS, controlled by CNE, approved by OO) [PDF document 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	Norne	1-31 Dec 2013	MIROS, Maanedsrapport Norne, 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, Manedsrapport Sleipner A, Desember 2013, Dok. Nr. ND/1017/13/12, 06Jan2014, prepared by SRS, controlled by CNE, approved by OO.
[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, 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 serie s wind speed and direction	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 average wind and gust	Torsminde	5Dec2013	Pelt AS, BODIL's stormflod i de indre dansk farvande, Vejret, 138, 24-29, 2014
[FIG] Time series graphs of wind speed and direction	Europlatform, 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 2014b, 48 pp
[TEXT] Highest wind and highest gust	Vaderoarna	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] Highest hourly average wind speed	Vlieland	5-6Dec2013	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

[TEXT] Highest gusts	Edinburgh, Drumalbin, Scotland mountains, List auf Sylt (Ellenbogen), Glucksburg-Meierwik, Borkum, Wangerooge, Rostock-Warnemuende, Dresden/Klotzsche, Chieming in Bayern	5Dec2013	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=filiz; date stamp=07Aug2015]
[FIG] Time series average 10m wind speed	Cadzand, Vlakte van de Raan	5-7 Dec 2013	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.
[FIG] Time series of wind speed and wind direction	Wirral Peninsula	1 Dec 2013 - 31 Jan 2014	Dissanayake 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] SARAL-AltiKa satellite altimetry wind speed	Strip profile through North Sea	6 Dec 2013 0447UTC	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 wind speed	FINO1	3-7Dec2013	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 wind speed and wind direction; 10m; maximum value 22m/s	Bornholm Airport	1–13 Dec 2013	Gierlevsen 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] Time series of wind speed and wind direction; 10m; maximum value 27m/s	Arkona offshore site	1–13 Dec 2013	Gierlevsen 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] Maximum gusts in UK	Altnaharra Sutherland, Edinburgh Blackfor Hill, Aonach Mor 1130m	5–6 Dec 2013	Kendon M and M McCarthy, The UK's wet and stormy winter of 2013/2014, Weather, 70, 40-47, 2015
[TEXT] Maximum gusts in UK	Aonanach Mor near Fort William, Cairnwell Cairngormsm Edinburgh, Boulmer Northumberland, Weybourne Norfolk	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
[TABLE] Maximum wind gust	Skillinge, Malmo, Horby, Hano, Helsingborg, Olands sodra udde, Hallands Vadero, Vaxjo, Ljungby, Nidingen, Olands norra udde,Tomtebacken, Goteborg, Farosund-Ar, Malexander, Masekar, Visingso, Harstena, Hallum, Gotska Sandon, Vaderoarna, Nordkoster, Naven, Palgrunden, Landsort	5-6 Dec 2013	SMHI, Egon - saesongens foersta ordentliga storm, 12Jan2015. https://www.smhi.se/nyhetsarkiv/egon-sasongens-forsta-ordentliga-storm-1.83408
[TEXT] Maximum gust 110km/h	Wattisham	5 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 hourly-average wind speed and wind direction at 100m height	FINO1, FINO2, FINO3	4-7 Dec 2013	Christakos K, I Cheliotis, G Varlas, G-J Steeneveld, Offshore wind energy analysis of Cyclone Xaver over North Europe, 13th Deep Sea Offshore Wind R&D Conference, EERA DeepWind'2016, 20-22 January 2016, Trondheim, Norway, Energy Procedia, 94, 37-44, 2016.
[FIG] Time series of wind speed, wind direction, surface atmospheric pressure	Norderney	5–6 Dec 2013	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
[FIG] Map of maximum obserbed wind gusts and mean wind during 24 h period	Northwest Europe	5 Dec 2013	ECMWF (20160316), 201312 - Windstorm - Xaver/Bodil/Sven, North-western Europe https://confluence.ecmwf.int/pages/viewpage.action?pageId=28315390
[FIG] Time series of 10 meter wind speed for Ekofisk and Thorsminde	Northwest Europe	4-6 Dec 2013	ECMWF (20160316), 201312 - Windstorm - Xaver/Bodil/Sven, North-western Europe https://confluence.ecmwf.int/pages/viewpage.action?pageId=28315390
[FIG] Time series of wind	Messstation	4-7 Dec 2013	Matelski, Birgit, Erfahrungen aus der Sturmflut Xaver von 5.

speed and direction	Strucklahnungshoern (Nordstrand)		und 6.12.2013 und dem Weihnachshochwasser 2014 in Shleswig-Holstein, IWASA 2016 Tagungsbeitrag, (46. IWASA, 7-8 Januar 2016; Internationales Wasserbau-Symposium Aachen. [pdf document properties: autor=sonja; datestamp: 26Apr2016]
[TEXT] maximum gusts	Strucklahnungshoern, Hallig Hooge, Buesum	5-6 Dec 2013	Matelski, Birgit, Erfahrungen aus der Sturmflut Xaver von 5. und 6.12.2013 und dem Weihnachshochwasser 2014 in Shleswig-Holstein, IWASA 2016 Tagungsbeitrag, (46. IWASA, 7-8 Januar 2016; Internationales Wasserbau-Symposium Aachen. [pdf document properties: autor=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 speed; maximum 25m/s 05Dec2013 12:00	FINO1 at 60m	2-9 Dec 2013	Peter Frohle & Norman Dreier, EarlyDike - Sensor - und risiko basiertes Fruhwarnsystem fuer Seedeiche, Teilprojekt: Wellenmonitoring und Wellenbelastungssimulator (AP2), Hamburg, April 2017
[FIG] Time series graph wind speed; maximum 21m/s 05Dec2013 12:00	Helgoland at 14m	2-9Dec 2013	Frohle P & N Dreier, EarlyDike - Sensor - und risiko basiertes Fruhwarnsystem fuer Seedeiche, Teilprojekt: Wellenmonitoring und Wellenbelastungssimulator (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 magnitude and wind direction	FINO1	1 Oct 2013-31 Dec 2013, 1-8 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 wind speed	Helgoland	3-8 Dec 2013	Staneva J, C Schrum, A Behrens, S Grayek, 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 Eigth 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	3-7Dec2013	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 04:46:55UTC	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 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
[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, 17-19July2018, Bonn [pdf document properties: datestamp=16/07/2018]

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 Frierich, S Haeseler, C Lefebvre, Orkantief XAVER ueber Nordeuropea 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 Frierich, S Haeseler, C Lefebvre, Orkantief XAVER ueber Nordeuropea von 5. bis 7. Dezember 2013, Deutscher Wetterdienst DWD, Stand 30. Dezember 2013, 19pp.
[FIG] Saral-AltiKa strip map of signficant wave height	North-south transect of North Sea	06Dec2013 04:47UTC	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/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 Vaderoarna	5Dec2013	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.
[TEXT] record sea state of 6 m	North Sea area of Sylt	5-6 Dec 2013	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
[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 wave height at peak	Newbiggin Ness, Tyne Tees, Whitby waverider	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 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.

Hmax=13.5m			
[FIG] Time series of signficant wave height	wave measurement buoy Westerland	2-9 Dec 2013	Luecht, Fabian and Ove Peters, Bericht ueber die Sturmflut vom 05.-0.6.12.2013 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]
[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 Dec2013	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	Mai S, J Wilhelmi, T Zenz, U Barjenbruch, Orkan 'Xaver' - Seegangsstatistik an den Stationen FINO1 und Borkum-Suedstrand, 19. KFKI-Seminar, Bremerhaven 11.11.2014 (presentation slides)
[FIG] Time series of significant wave height	Westerland	4-8 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.
[FIG] Time series of signficant 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, 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]
FIG] Time series of significant wave height and maximum wave height	Norne	1-31 Dec 2013	MIROS, Maanedsrapport Norne, 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, Manedsrapport 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, IJ muiden	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 2014b, 48 pp
[FIG] Time series of maximum wave height	Scheur West Wandelaar, Europlatform, Platform K13a, IJ muiden	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 2014b, 48 pp
[TABLE] Table of maximum 'globally corrected' significant wave height in ranked storm list	Scheur west Wandelaar, Euro platform, IJmuiden munitiestortplaats, Eierlandse Gat, (Schiermonnikoog Nord	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 2014b, 48 pp
[TEXT] Maximum wave height	Vaderoarna	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 signifcant wave height	Wave buoy 1_1 Amelander Zeegat	5-7 Dec 2013	van Rooijen A, A Oost, Memo: Regionale advisering Ameland Noordwest, Deltares, 1209381-008-ZKS-0008, 43pp, 18Dec2014 [PDF document properties: titl=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.

			Civil Engineering, Delft University of Technology, 2015.
[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, 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
[FIG] Time series of significant wave height	[FIG] Time series of significant wave height	5 Dec 2013	Dissanayake 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 significant wave height	Liverpool Bay Wavenet waverider	5 Dec 2013	Dissanayake 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 significant wave height	Liverpool Bay Wavenet waverider	1 Dec 2013-31 Jan 2014	Dissanayake 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 significant wave height	Strip profile through North Sea	6 Dec 2013 0447UTC	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 data	FINO1	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 significant wave height from RADAC, Waverider buoy, AWAC	FINO1	4-7 Dec 2013	Fischer, JG, C Senet, A Schneehorst, O Outzen, 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]
[FIG] Significant wave height, wave period and wave direction; maximum Hs 4.5m (instrument failure)	Fjaltring	7 Nov 2013 – 7 Dec 2013	Gierlevsen 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	Gierlevsen 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, Happisburgh, 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 Moller, 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	Mai 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	Matelski, Birgit, Erfahrungen aus der Sturmflut Xaver von 5. und 6.12.2013 und dem Weihnachshochwasser 2014 in Shleswig-Holstein, IWASA 2016 Tagungsbeitrag, (46. IWASA, 7-8 Januar 2016; Internationales Wasserbau-Symposium Aachen. [pdf document properties: autor=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

[FIG] Time series siggnificant wave height from ADCP	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 significant wave height	Elbe station, Westerland station	2-8 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 significant wave height; maximum 9.5m 05Dec2013 23:30	FINO1 waverider checked	2-9 Dec 2013	Peter Frohle & Norman Dreier, EarlyDike - Sensor - und risiko basiertes Fruhwarnsystem fuer Seedeiche, Teilprojekt: Wellenmonitoring und Wellenbelastungssimulator (AP2), Hamburg, April 2017
[FIG] Time series significant wave height; maximum 7.9m 06Dec2013 02:00	Aussen Elbe buoy checked	2-9 Dec 2013	Peter Frohle & Norman Dreier, EarlyDike - Sensor - und risiko basiertes Fruhwarnsystem fuer Seedeiche, Teilprojekt: Wellenmonitoring und Wellenbelastungssimulator (AP2), Hamburg, April 2017
[FIG] Spectrum of wave energy; wind waves at 11s, swell at 13s (highest), highest observable energy at 20s	FINO1 waverider buoy	5Dec2013 22:44UTC	Peter Frohle & Norman Dreier, EarlyDike - Sensor - und risiko basiertes Fruhwarnsystem fuer Seedeiche, Teilprojekt: Wellenmonitoring und Wellenbelastungssimulator (AP2), Hamburg, April 2017
[FIG] Time series of signficant 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. Bidlot, A North Sea-Baltic Sea Regional Coupled Models: Atmosphere, wind waves and ocean, in Proceedings of the Eigth EuroGOOS International Conference (Operational Oceanography. Serving Sustainable Marine Development), 3-5 October 2017, Bergen, Norway, 2017b.
[FIG] Time series graph of signficant wave height	FINO1	3-7Dec2013	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 significant wave height from SARAL-AltiKa	North Sea axis 53 - 60N	6 Dec 2013 04:46:55UTC	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 significant wave height	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 signficant wave height	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).
[FIG] Time series of significant wave height	Untjehoern 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
[TABLE] Highest significant wave height 8.6m	Nymindegab	5-9Dec2013	Kystdirektoratet, Shoreface nourishment effects. An analysis of the 2011 nourishment performed at Skodbjerge. Kystdirektoratet, Hojbovej 1, 7620 Lemvig, Dec 2018 [pdf document properties: title=Shoreface nourishment effects_Skodbjerge_20.12.2018, datestamp=20/12/2018]

Table S13. Wave period and other wave data (arranged by year and then alphabetically)

Data type	Location	Time Interval	Full Reference and Notes
[FIG] Wave period (15s) from high frequency radar gauge trace	FINO1	6 Dec 2013 00:09-00:11	BFG, Orkan Xaver: BfG beobachtet extreme Wellen in der Nordsee (06.12.2013)
[FIG] Time series of average wave period and peak period	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]
[FIG] Time series of average wave period; maximum of 30 minute	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

average wave period 11.1s			Kopmann (eds), Bundesanstalt fuer Wasserbau, 2014. ISBN 978-3-939230-32-8
[TABLE] Wave peak period and energy	Newbiggin Ness, Tyne Tees, Whitby waverider	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 mean period, peak period, and wave direction	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] Wave spectra grapshs 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	2-9Dec2013	Luecht, Fabian and Ove Peters, Bericht ueber die Sturmflut vom 05.-0.6.12.2013 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]
[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' - Seegangsstatistik 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' - Seegangsstatistik 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	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.
[FIG] Time series of average upcrossing period and wave peak period	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 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 OO [pdf properties: author=Miros AS; date stamp: 08/01/2014]
[FIG] Average upcrossing period and primary wave peak period	Norne	1-31 Dec 2013	MIROS, Maanedsrapport Norne, 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 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 OO.
[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 waver period	Scheur west Wandelaar, Euro platform, IJmuiden, Platform K13a	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 2014b, 48 pp
[TABLE] Table of maximum 'globally corrected' wave periods in ranked storm list	Scheur west Wandelaar, Euro platform, IJmuiden munitiestortplaats, Eierlandse Gat, (Schiermonnikoog Nord	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 2014b, 48 pp
[FIG] Time series of wave peak period	Wave buoy 1_1 Amelander Zeegat	5-7Dec2013	van Rooijen A, A Oost, Memo: Regionale advisering Ameland Noordwest, Deltares, 1209381-008-ZKS-0008, 43pp, 18Dec2014 [PDF document properties: titl=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	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.
[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, 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
[TEXT] reference to peak period and wave direction information for 2012 to 2013 across storm period	FINO1	?	Fischer, JG, C Senet, A Schneehorst, O Outzen, 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]
[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=IOC; subject: IOC/2016/MG/14 vol.5; datestamp: 18/04/2017]
[FIG] Time series of wave period	Seeganssmessstation Westerland	4-8 Dec 2013	Matelski, Birgit, Erfahrungen aus der Sturmflut Xaver von 5. und 6.12.2013 und dem Weihnachshochwasser 2014 in Shleswig-Holstein, IWASA 2016 Tagungsbeitrag, (46. IWASA, 7-8 Januar 2016; Internationales Wasserbau-Symposium Aachen. [pdf document properties: autor=sonja; datestamp: 26Apr2016]
[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, Deltares, 117pp, July, 2016
[TEXT] wave peak period 10s from ADCP	Hornbaek	5Dec2013	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] Two dimensional graph of wave spectral density versus frequency and time	Elbe buoy and FINO1 buoy	2-8 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] Two dimensional graph of wave spectral density versus frequency and time	Elbe buoy	1-8 Dec 2013	Staneva J, C Schrum, A Behrens, S Grayek, 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 Eigth 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- und risikobasiertes Fruhwarn-system fuer Seedeiche (EarlyDike), AP1 - Sturmflutmonitoring und Sturmflutssimulator - Fachbericht 2016, Siegen, April 2017
[TABLE] peak period	Nymindegab	5-9 Dec 2013	Kystdirektoratet, Shoreface nourishment effects. An analysis of the 2011 nourishment performed at

			Skodbjerge. Kystdirektoratet, Hojbovej 1, 7620 Lemvig, Dec 2018 [pdf document properties: title=Shoreface nourishment effects_Skodbjerge_20.12.2018, datestamp=20/12/2018]

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, Brunsbuettel, Hamburg, Zollenspieker, Buesum, Eidersperrwerk, Husum, Dagebuell	5-7Dec2013	BSH, Die Nordseesturmfluten von 5. und 6.12.2013, 3pp, prepared by Stockmann,K. (title: Sturmflut 2011_bm1101; author stamp: bm1101; document time stamp: 12/102013 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 Warnemuende	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, Dagebuell, Husum, Buesum, Eidersperrwerk, Cuxhaven	5-6 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.
[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	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]
[FIG] Saral-AltiKa strip map of water level	North-south transect of North Sea	06Dec2013 04:47UTC	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/website/home/News/DAT_2087062.html (last accessed: 19Nov2019, 28Jun2020)
[FIG] TIme series of water level anomaly	Helgoland Suedhaven, Leuchtturm Alte Weser	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/website/home/News/DAT_2087062.html (last accessed: 19Nov2019, 28Jun2020)
[TEXT] Maximum water level NAP	Vlissingen	6Dec2013 04:00MEZ	NOS, Hoogste waterstand sinds 1953, 06/12/2013, 09:52, 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, Stormverslag 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, Emssperrwerk, Knock,Emden, Vareler Schleuse, Fedderwardersiel, Wilhelmshaven, Cuxhaven, Huntesperrwerk, Ochtumsperrwerk, Spieka Neufeld, Otterndorf, Stader Sand	Midnight flood, 6 Dec 2013	NLWKN, Schwere Sturmflut gut Ueberstanden, Waserstaende zwischen Zweieinhale und Knapp vier metern registriert // presseinformation von 6. Dezember 2013, (Ansprechpartnerin: Herma Heyken), 06/12/2013.
[TEXT] Maximum water levels	Wiken, 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, 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, updated 20Mar2017; original datestamp 10Dec2013.
[TEXT] Maximum flood	Hamburg-St Pauli	6 Dec 2013	Unwetterzentrale, Orkantief XAVER - ein weiterer schwerer

water level at 6.09m NN and skew surge at 3.98m uMH			Wintersturm der letzten Jahrzehnte, Thomas Savert and Stefan Laps, Dec. 2013 http://www.unwetterzentrale.de/uwz/928.html
[TEXT] Skew surge 3.54 m uMH	Cuxhaven	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
[TABLE] water level, expected, tide, residual surge	Lerwick, Wick, Aberdeen, Leith, North Shields, Immingham, Cromer, Lowestoft, Dover.	5–6 Dec 2013	ABP mer, Ensuring Flood Resilience. An overview of the 5/6 December 2013, Associated British Ports, Marine Environmental Research, July, 2014
[TEXT] base of water 20 feet above normal with 15 foot above that.	Hemsby UK	Night 5-6 Dec 2013	BBC, East coast surge: what happened next? (report by Richard Haugh), 5Dec2014
[TEXT] Highest storm flood water levels	North Shields, Whitby, Scarborough	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]
[FIGURE] Time series tide gauge water lvel	North Shields, Whitby, Scarborough	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]
[FIGURE] Time series surge residual	North Shields, Whitby, Scarborough	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]
[MAP WITH DATA] Maximum water levels	Immingham, Cromer, Lowestoft, Harwich, Sheernes, Dover, Kingston Upon Hull	5-6 Dec 2013	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]
[TIMESERIES] Water level	Holbaek and Roskilde	6-7 Dec 2013	Eriksen J, Rekordvandstande i Isefjorden og Roskilde Fjord, Vejret, 138, 2 40-48, 2014
[TEXT] Highest surge water level	Borkum	6 Dec 2013	FINO1, 15-m wave damaged FINO1, 08Jan2014. http://www.fino1.de/meldungen/alle-meldungen/137-15-meter-welle-beschaedigt-fino1
[FIG] Time series of measured water level	Terschelling Noordzee, Nes, Wierumerwad, Lauwersoog, Eemshaven, Nieuw Statenzijl	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
[TIMESERIES] Observed water level and astronomical tide	Vlissingen	2Dec2013 0000UTC to 12Dec2013 0000UTC	Hewson T, L Magnusson, O Breivik, F Prates, I Tsonevsky, 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	Norderney	5-6 Dec 2013	Knaack H and H Heyken, Xaver hatte sehr schwere Stumflut im Gepaeck, Jahresbericht 2013. Der Zukunft verplichtet, NLWKN, Niedersaechsischer Landesbetrieb fuer Waserwirtschaft, Kuesten- und Naturschutz, pp.8-9, document date stamp 24Apr2014.
[TEXT] Maximum water level over average high water 2.83m	Norderney	5-6 Dec 2013	Kristandt, J., B. Brecht, H. Frank, H. Knaack, Optimization of empirical storm surge forecast-modeling of high resolution wind fields, Die Küste, 81, 301-348, 2014
[TABLE] Highest absolute water levels and MTHW skew surges	List, Hoernum, Wittduen, Dagebuell, Hooge Anleger, Husum, Eidersperrwerk, Cuxhaven, Buesum, Stoersperrwerk, Glueckstadt, Schulau, St. Pauli	5-6 Dec 2013	Luecht, Fabian and Ove Peters, Bericht ueber die Sturmflut vom 05.-0.6.12.2013 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 data	FINO1, FINO2, FINO3	1-8 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 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.
[FIG] Time series of water level	FINO1, Borkum-Suedstrand	4-9 Dec 2013	Mai S, J Wilhelmi, T Zenz, U Barjenbruch, Orkan 'Xaver' - Seegangsstatistik an den Stationen FINO1 und Borkum-Suedstrand, 19. KFKI-Seminar, Bremerhaven 11.11.2014 (presentation slides)
[FIG] Time series of the measured water level, modelled tide, and surge residual	Wyk, Hamburg St. Pauli, Husum	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.
[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.
[FIG] Time series of water level	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 water level from 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 water level from altimeter	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 OO [pdf properties: author=Miros AS; date stamp: 08/01/2014]
[FIG] Time series of water level from 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 OO.
[TABLE] Highest storm surge water levels with times	Vlissingen, Zandvliet, Kallo, Prosperpolder, Liefkenshoek, Antwerpen, Boom, Hemiksem, Tielrode, Sint-Amands, Walem, Mechelin Benedinsluis, Dendemonde, Hombeek, Duffel, Lier Molbrug, Schoonarde, Waasmunster Manta, Emblem, Kessel, Wetteren, Melle	6 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]
[FIG] Time series of observed water level, astronomical tide, true surge residual	Vlissingen	4-8 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 water levels	Roskilde Haven, Torminde, Harnbaek, Klampenborg, Tolboden Kobenhavn, Sjaellands Odde, Grenaa, Odense Fjjord	5-6Dec2013 Various times	Pelt AS, BODIL's stormflod i de indre dansk farvande, Vejret, 138, 24-29, 2014
[TEXT] Extreme low water levels	Koge Bugt, Flensborg, Rodby, Ronne og Tegn	5-6Dec2013	Pelt AS, BODIL's stormflod i de indre dansk farvande, Vejret, 138, 24-29, 2014
[MAP TEXT] Highest coastal water levels	Lerwick, Wick, Aberdeen, Leith, North Shields, Whitby, Immingham, Cromer, Lowestoft, Harwich, Herne Bay, Sheerness, Dover, Ostend, Borkum, Heligoland Binnenhafen, Cuxhaven, Hirtshals, Gothenburg, Torshamnen	5-6 Dec 2013	RMS, 2013-2014 Winter Storms in Europe. An Insurance and Catastrophe Modeling Perspective. RMS White Paper. [PDF TIMESTAMP 11Mar2014]
[TABLE] Maximum water level, astronomical tide, skew surge for successive storm tides	Vlissingen, Roompot buiten, Hoek van Holland, Dordrecht, Den Helder, Harlingen, Delfzijl	5–7 Dec2013	RWS, Watermanagementcentrum Nederland, Stormvloedflits 2013-07 van 5 t/m 7 december 2013, Rijkswaterstaat (document time stamp: 07Jan2014), 2014a
[TABLE] Maximum water level, astronomical tide, skew surge for successive storm tides	Vlissingen, Roompot buiten, Hoek van Holland, Den Helder, Harlingen, Delfzijl	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 2014b, 48 pp
[FIG] Time series of measured water level, modelled astronomical tide, residual	Vlissingen, Roompot buiten, Hoek van Holland, Dordrecht, Den Helder, Harlingen, Delfzijl	5-7 Dec 2013	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
[TEXT] Highest water levels	Viken, Barseback, Halmstad	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] 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 Staithe, Burnham Deepdale, Burnham Overy Staithe, Holkham Gap, Well 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, Rncon 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	Lauwerzoog	4-9 Dec 2013	van Rooijen A, A Oost, Memo: Regionale advisering Ameland Noordwest, Deltares, 1209381-008-ZKS-0008, 43pp, 18Dec2014 [PDF document properties: titl=Regional advisering: Ameland NW; author=Arnold van Rooijen; keywords: 1209381-008-ZKS-0008; date stamp: 18/12/2014]
[FIG] Time series of water leve 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, Memo: Regionale advisering Ameland Noordwest, Deltares, 1209381-008-ZKS-0008, 43pp, 18Dec2014 [PDF document properties: titl=Regional advisering: 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	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=filiz; date stamp=07Aug2015]
[FIG] Time series measured water level, astronomical tide, surge residual	Cadzand	5-7 Dec 2013	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.
[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 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 water level from tide gauge	Liverpool Gladstone Dock	5 Dec 2015	Dissanayake 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	Dissanayake 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	Dissanayake 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, L Mendoza, M Becker, J Lillibridge, 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, L Mendoza, M Becker, J Lillibridge, Cyclone Xaver seen by geodetic

	Borkum Fischerbalje, 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	FINO1	3-7Dec2013	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	Saeby/ Fredrikshavn	1 Nov 2013 – 31 Dec 2013	Gierlevsen 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] Time series of water level	Wandelaar	1-31 Dec 2013	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 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, Sturmflutdienst der Betriebstelle 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.5, 2013: Water levels, waves, and coastal impacts, Earth Science Reviews, 146, 120-145, 2015
[TABLE] Highest water level referenced to ODN; skew surge	All class A stations around the UK; other stations from Channel Coastal Observatory and Associated British Ports	5–6 Dec 2013	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.
[FIG] Time series of gauge water level, calculated astronomical tide, and true surge residual	Liverpool, Lowestoft	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.
[TABLE] High water, 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.
[TABLE] Absolute water levels referenced Ordnance Datum Newlyn ODN	UK tide gauge stations	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 true surge	Hoek van Holland	4-8 Dec 2013	F Zijl, J Sumihar, 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 Moller, 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 water level, astronomical tide, true surge residual	Norderney	5–6 Dec 2013	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
[FIG] Time series of water level	Lighthouse Alte Weser, Borkum Suedstrand	5-8 Dec 2013	Mai 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 water level, astronomical tide, and surge residual	List auf Sylt	5-7 Dec 2013	Matelski, Birgit, Erfahrungen aus der Sturmflut Xaver von 5. und 6.12.2013 und dem Weihnachshochwasser 2014 in Shleswig-Holstein, IWASA 2016 Tagungsbeitrag, (46. IWASA, 7-8 Januar 2016; Internationales Wasserbau-Symposium Aachen. [pdf document properties:

			autor=sonja; datestamp: 26Apr2016]
[FIG] Time series of water level, astronomical tide, and surge residual	Husum	5-6 Dec 2013	Matelski, Birgit, Erfahrungen aus der Sturmflut Xaver von 5. und 6.12.2013 und dem Weihnachshochwasser 2014 in Shleswig-Holstein, IWASA 2016 Tagungsbeitrag, (46. IWASA, 7-8 Januar 2016; Internationales Wasserbau-Symposium Aachen. [pdf document properties: autor=sonja; datestamp: 26Apr2016]
[FIG] Time series of water level, astronomical tide, and surge residual	Holmersiel, Nordstrandischmoor-Hallig, Nordstrandischmoor	4-8 Dec 2013	Matelski, Birgit, Erfahrungen aus der Sturmflut Xaver von 5. und 6.12.2013 und dem Weihnachshochwasser 2014 in Shleswig-Holstein, IWASA 2016 Tagungsbeitrag, (46. IWASA, 7-8 Januar 2016; Internationales Wasserbau-Symposium Aachen. [pdf document properties: autor=sonja; datestamp: 26Apr2016]
[FIG] Maximum nontidal residual and skew surge as point on scatterplot	Immingham	5-6 Dec 2013	Mawdsley RJ and ID Haigh, Spatial and temporal variability and long-term trends in skew surges globally, Frontiers in Marine Science, 2016, doi: 10.3389/fmars.2016.00029
[FIG] Time series of water level	Terschelling, Wierummergronden, Nes	5-8 Dec 2013	Nederhoff K, E Elias, T Vermaas, Erosie op Ameland Noordwest. Modelstudie: simulaties met Delft3D en XBeach, Deltares, 117pp, July, 2016
[FIG] Time series of water levels with text indicating highest water level 1.96 m DVR90	Hornbaek	4-6Dec2013	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 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.
[FIG] Time series of water level and computed surge	Helgoland	4-8 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
[TEXT] 5.2 m surge; water level 6.08m ODN	Boston UK	5-6 Dec 2013	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/bostonbarriertwao/results/appendix-1---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/bostonbarriertwao/
[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 Alan, O Breivik, J-R. Bidlot, A North Sea-Baltic Sea Regional Coupled Models: Atmosphere, wind waves and ocean, in Proceedings of the Eigth EuroGOOS International Conference (Operational Oceanography. Serving Sustainable Marine Development), 3-5 October 2017, 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 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
[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 Skodbjerge. Kystdirektoratet, Hojbovej 1, 7620 Lemvig, Dec 2018 [pdf document properties: title=Shoreface nourishment effects_Skodbjerge_20.12.2018, datestamp=20/12/2018]

[FIG] Time series of true surge and tide	Dagebuell, Norderney, Husum, LT Alte Weser, Wyk, Helgoland, Wittduen, Emden, Hoernum, Wilhelmshaven, Cuxhaven, List	5-7 Dec 2013	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] 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. Windstaustatistiken und Haufigkeit von Sturmfluten 2012-2015 https://www.bsh.de/DE/PUBLIKATIONEN/Nordseezustand_Aktuell/_Anlagen/Downloads/3_4_4_Windstatistiken.pdf?__blob=publicationFile&v=2 [pdf document properties: author=Ludwig Schenk; datestamp=14Feb2019]
[TEXT] Maximum water level	Ostend Belgium and Viken Hoganas Kommune	5-6 Dec 2013	Wikipedia, Stormen 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 Whitwham]
[TABLE] Maximum water levels with times	Lerwick, Wick, Aberdeen, Leith, North Shields, Whitby, 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 astronomical tide, skew surge, and return period	Dover, Immingham, Whitby, 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 S15. Water current information (arranged by year and then alphabetically)

Data type	Location	Time Interval	Full Reference and Notes
[FIG] Time series of the ADCP water currents at 4, 6, 14m	FINO1	1-7 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]

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 -Hamberg water levels 1976>2013>1962
Gccapitalideas (20131209)	gccapitalideas, Windstorm Xaver, 9Dec2013, https://www.gccapitalideas.com/2013/12/09/windstorm-xaver/ -worst flooding in Dover Kent in more than 100 years
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. -Rank 2 water level Hamburg St Pauli after 03 Jan 1976; measurement start 1825 -New records: Dagebuell, Husum, Buesum, Eidersperrwerk, Cuxhaven
NLWKN (2013)	NLWKN, Schwere Sturmflut gut Ueberstanden, Waserstaende zwischen Zweieinhale 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 -water level Vlissingen highest since 1953
Oceanografisch Meteorologisch Station (2013)	Oceanografisch Meteorologisch Station, Stormverslag 05-06 december 2013, 26pp, 2013 [pdf document properties: author=Myriam Sys; datestamp=15Dec2013] -water level in Oostende was the highest since 1 Feb 2013
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. -Viken: rank 1 water level (1.67m) since record start 1976 -Barseback: rank 1 water level since record start 1993 -Skanoor: rank 1 minimum water level -1.58m; previous record -1.55m from Dec 1999
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 -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 (20131212)	The Lowestoft Journal, Suffolk MP hits out at environment secretary in statement about the floods, 14Dec2013, correspondent: Annabelle Dickson. -UK environment minsiter Owen Patterson claims surge was freak event with 1 in 500y return period -MP 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 tde 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 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] -1953 surge was most serious for at least 250years. -Thames Barrier 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 100 year 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 40-48, 2014 -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. Deltares, 2014, 197pp. Project 1209433-007, Reference 1209433-007-HYE-0005 -maximum water level Delfzijl assessed at 1 in 50 year to 1 in 100 year recurrence interval
Knaack and Heyken (2014)	Knaack H and H Heyken, Xaver hatte sehr schwere Stumflut im Gepaeck, Jahresbericht 2013. Der Zukunft verplichtet, NLWKN, Niedersaechsischer Landesbetrieb fuer Waserwirtschaft, Kuesten- und Naturschutz, pp.8-9, document date stamp 24Apr2014. -Xaver rank 2 event at Ems; rank 3 event at Weser- and Elbemuendung
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. 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, BODIL's stormflod i de indre dansk farvande, Vejret, 138, 24-29, 2014 -rank 1 water levels: Roskilde Havn, Hornbaek, Klampenborg, Tolboden, Sjaellands Odde, Odense Fjord -rank 2 water level: Grenaa -5 surge events in Kobenhavn 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)	RWS, Watermanagementcentrum Nederland, Stormvloedflits 2013-07 van 5 t/m 7 december 2013, Rijkswaterstaat (document time stamp: 07Jan2014), 2014a -Delfzijl: 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 -Hoek 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, Stormvloedrapport van 5 t/m 7 december (SR91) Sint-Nicolaasvloed 2013, Watermanagementcentrum Nederland, Rijkswaterstaat, prepared by Ing. J. Kroos, 19 Mar 2014b, 48 pp -high water per 1000 years: Den Helder 240, Harlingen 130, Delfzijl 15, Vlissingen 53, Roompot buiten 79, Hoek van Holland 120, Dordrecht 130
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: titl=Regional advisering: Ameland NW; author=Arnold van Rooijen; 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.
NLWKN (20151210)	NLWKN, Sturmflutdienst der Betriebstelle Norden-Norderney, Niedersaechischer Landesbetrieb fuer Wasserwirtschaft, Kuesten- und Naturschutz, Niedersachsen, 12/2015 [document date stamp 10Dec2015] -Norderney return period >20y -Emden return period >20y -Cuxhaven return period 2-20 years
Patzer (2015)	Patzer, Marianne, Storm surge forecasting at DMI and perspectives on teh use of Earth Observations, ESA eSurge Sympositum, Deltares, the Netherlands, (powerpoint presentation) January 21, 2015 -1000year water level event in Danish fjords and Sealand north coast

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 -Storm Xaver water level rank 1 even in most tide gauge stations in UK
Haigh and Bradshaw (2015)	Haigh I and E Bradshaw, A century of UK coastal flooding, Planet Earth, Winter 2015, (pdf document properties: 13Jan2016) -sea level for 5-6Dec2013 and 3Jan2014 were in top 10 water levels of 96 surge events in data base for last century
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 period of absolute water level
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 -FIG3. [MAP] Variations in tidal ratio with stations plotted (right), Grimsby to Southend on Sea and extreme water level (from Environment Agency 2011b). Return periods of extreme water levels Inset top: tides in the North Sea as derived from observations. Red lines are phase line of the M2 tide, labelled in hours after the moon's transit through the Greenwich meridion. Blue line give the mean tidal range at spring tide. -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 -Wick, Aberdeen: 1 in 25y event -Whitby to Lowestoft: return periods 1 in 200y to 1 in 1000y -Whitby, Immingham: ~1000y flooding evnts
Van massenhove (2015)	Vanmassenhove, Niels, Storm surge measures ports Flemish coast, Blankenberge, Tuesday February 3rd, Maritieme Sientverlening en Kust, Coastal Division, Flanders Hydraulic Research.[document properties: title=Geintegreerd Kustveiligheidsplan; author=Maarten; datestamp=27/02/2015] -water level for Dec2013 corresponded to 50 year flood event -map of Belgiam flooding for 1000 year flood event (7m TAW)
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. -return period of waters referenced to 2008 (because of significant sea level rise; 2008 sea level 0.11m higher than 1953 levels)
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: return period water level 196 years -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)
Brooks et al (2016)	Brooks SM, T Spencer, A McIvor, I Moller, Reconstructing and understanding the impacts of storms and surges, southern North Sea, Earth Surface Processes and Landforms, 41, 855-864, 2016. -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 -Coastal protection structures designed for return period events 100-10000 years depending on national standards -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.
ECMWF (20160316)	ECMWF (20160316), 201312 - Windstorm - Xaver/Bodil/Sven, North-western Europe https://confluence.ecmwf.int/pages/viewpage.action?pageId=28315390 -highest water levels on east coast of England for 60 years.
Matelski (2016)	Matelski, Birgit, Erfahrungen aus der Sturmflut Xaver von 5. und 6.12.2013 und dem Weihnachshochwasser 2014 in Shleswig-Holstein, IWASA 2016 Tagungsbeitrag, (46. IWASA, 7-8 Januar 2016; Internationales Wasserbau-Symposium Aachen. [pdf document properties: autor=sonja; datestamp: 26Apr2016] -highest water level on List auf Sylt reached rank 5 in record extending back to 1900
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: Universitaet Siegen, 2016 -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 McCarroll -water level at Hornbaek at 1000y level during storm Xaver
Ditlevsen et al (2018)	Ditlevsen C, MM Ramos, C Sorensen, UR Ciocan, T Pionkowitz, Hojvandsstatistikker 2017, Miljo- og Foedevaremnisteriet, Kystdirektoratet, Lemvig, Februar, 2018 -Storm Xaver water levels presented with return period analysis curves.

JBA Risk Management (2020)	JBA Risk Management, Storm Xaver 2013. Event Commentary, 2020. [PDF document properties: author=Cameron Whitwham] -record water level at Kingston-upon-Hull at 5.8m -map of return periods of Xaver water level at stations around UK
Surgewave (20200304)	Surgewatch, Storm event 6th December 2013, https://www.surgewatch.org/events/1/ (last accessed 04Mar2020) -list of return periods for: Dover, Immingham, Whitby, North Shields, Lowestoft, Liverpool, Newhaven, Leith, Aberdeen, Llandudno, Portsmouth, Ullapool
Wikipedia (20200502)	Wikipedia, Orkan Xaver, https://de.wikipedia.org/wiki/Orkan_Xaver (accessed 2 May 2020) -Xaver had 2nd highest water in Hamburg record starting in 1825; highest level during Hurrican Capella 1976

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. -bridges designed for 50y return wind speed -survivability in 100y or 10000y event (accidental loading)
Cruz and Krausmann (2008)	Cruz AM and E Krausmann, Damage to offshore oil and gas facilities following hurricanes Katrina and Rita: An overview, Journal of Loss Prevention in the Process Industries, 21, 620-626, 2008. -offshore petroleum platforms design standard 100 y event
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. -storm Xaver wind speed reached the 2-10 year level
Pelt (2014)	Pelt AS, BODIL's stormflod i de indre dansk farvande, Vejret, 138, 24-29, 2014 -Denmarks rank 3 for Torsminde average wind speed
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 -return period of wind speed southern Sweden 5-10 years; locally 10-20 years -map of wind speed return period
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 -highest ever Netherlands wind speed since 1910 recorded at Stavorean (38m/s)

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

Source	Full Reference and Notes
Deutschlander et al. (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. -trajectory of low pressure centre between 4 Dec 2013 18:00UTC and 7 Dec2013 00:00UTC
KNMI (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 -path of low pressure center on snapshot map of sea level pressure field
Oceanografisch Meteorologisch Station (2013)	Oceanografisch Meteorologisch Station, Stormverslag 05-06 december 2013, 26pp, 2013 [pdf document properties: author=Myriam Sys; datestamp=15Dec2013] -FIG1. [MAP] storm track at the 12h intervals
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 -FIG2. [MAP] Situation of the developing low on Wedesday 04Dec2013 2100MEZ with the expected trajectory
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. -FIG2.Trajectory of Storm Xaver and other storms that caused storm surges
RMS (2014)	RMS, 2013-2014 Winter Storms in Europe. An Insurance and Catastrophe Modeling Perspective. RMS White Paper. [PDF TIMESTAMP 11Mar2014] -FIG2. storm trajectory Xaver & other storms during winter 2013-2014
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 -Bijlage 3. Surface pressure 6 Dec 2013 0000UTC with low pressure track 4 Dec 2013 1300MEZ to 6 Dec 2013 0100 MEZ
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. -FIG2.5. [MAP] European Commission forecast and first assessment of the of the Sinterklaas storm (a) Forecast of the path of the storm issued 5Dec. High wind and storm surge alerts issued for England, Germany, Denmark, Ne (b) on 6Dec preliminary assessment issued stating estimated storm levels; flood location and type of damage
Fenoglio-Marc et al (2015)	Fenoglio-Marc L, R Scharroo, A Annuziato, L Mendoza, M Becker, J Lillibridge, Cyclone Xaver seen by geodetic observations, SUPPORTING MATERIAL, Geophys Research Letters, 42, 9925-9932, 2015 -FIG. storm pressure centre trajectory on rectimlinear coordinates
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 cylone 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=Konstantinos Christakos; datestamp: 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, G-J Steeneveld, Offshore wind energy analysis of Cyclone Xaver over North Europe, 13th Deep Sea Offshore Wind R&D Conference, EERA DeepWind'2016, 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 02Jan1990) -developed into powerful extratropical cyclone as it passed N of Scotland -explosive cyclogenesis: central pressure decrease 1010mb to 975 mb in 24h from late Thurs
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 -presure 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; datestamp=15Dec2013] -description of central pressure evolution
Bancroft (2014)	Bancroft, George P, 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 -maximum intensity of 960hPa inland near 59N 12E at 1800UTC 5Dec2013
Hewson et al (2014)	Hewson T, L Magnusson, O Breivik, F Prates, I Tsonevsky, HJW de Vries, Windstorms in northwest Europe in late 2013, ECMWF Newsletter, No 139, pp 22-28, Spring 2014. -6 h deepeing 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, Stormvloedrapport van 5 t/m 7 december (SR91) Sint-Nicolaasvloed 2013, Watermanagementcentrum Nederland, Rijkswaterstaat, prepared by Ing. J. Kroos, 19 Mar 2014b, 48 pp -unusually 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 Suesser, 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] -description of rapid pressure drop during Xaver
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 -atmospheric pressure on 5Dec dropped to 1012 hPa from 1030 hPa one day before
Fenoglio-Marc et al (2015b)	Fenoglio-Marc L, R Scharroo, A Annuziato, 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 Whitwham] -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 Savert and Stefan Laps, Dec. 2013 http://www.unwetterzentrale.de/uwz/928.html -lighting 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

	flashes in E -2 suspected tornado cases: Niedersachsen & Mecklenburg-Vorpommern
FINO1 (20140108)	FINO1, 15-m wave damaged FINO1, 08Jan2014. http://www.fino1.de/meldungen/alle-meldungen/137-15-meter-welle-beschaedigt-fino1 -unusual wave event that damaged 15m working deck -additional damage to 17m access platform from swinging counterweight set in motion by waves? or wind
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 -map showing convective thunderstorm line in front of Netherlands coast
Van Doreland (2014)	van Dorland, R, Zware storm op 5 december, Zenit, p43, Januari 2014 -squall line passage with hail
ECMWF (20160316)	ECMWF (20160316), 201312 - Windstorm - Xaver/Bodil/Sven, North-western Europe https://confluence.ecmwf.int/pages/viewpage.action?pageId=28315390 -FIG5. [TIMESERIES] These figures show 10m wind speed for Ekofisk in the North Sea and Torsminde in western Denmark. The HRES forecast in in red and observations in blue. The forecast is initialized 04Dec 00UTC. One interesting figure in the model for both sites, is the large variations from hour to hour close to the peak of the storm.
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 -reference to tornado threat in Poland; worst ever tornado Lublin 20July 1931 with 111 m/s

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 20160105	Caithness Windfarm, craigdr, Detailed accidents to 31 December 2015. Document time stamp 5Jan2016, 175pp -Burradale Wind Farm Shetland, UK: lightning caused fist-sized hole
WIKI (20200124)	WIKI, Cyclone Xaver, https://en.wikipedia.org/wiki/Cyclone_Xaver accessed 24Jan2020 -easyjet flight Bristol to Edinburgh hit by lightning and diverted to Newcastle
Wikipedia (20200502)	Wikipedia, Orkan Xaver, https://de.wikipedia.org/wiki/Orkan_Xaver (accessed 2 May 2020) - FIG3. [MAP] Trajectory of hurricane front anhand der Blitzentladungen in the area of the Netherlands

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, HJW de Vries, Windstorms in northwest 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 Dube, 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 -Timmerman (1971): cold fronts over S part of North Sea can produce 'gust bumps' -water level increases only occur for propagation speed 29-36kt (54-67 km/h) -numerical simulation oof event 13Dec1956 -FIG7.18.Sudden water level changes (gust bumps) during Mar27 1966 at several locations on the Netherlands coast (Timmerman, 1971) maximum amplitude 1m -FIG7.20.Sudden water level changes (gust bumps) at several locations on the Netherlands coast on 13Dec1956 (Timmerman 1971) maximum amplitude 56cm at Katwuk aan Zee
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 stormflod i de indre dansk farvande, Vejret, 138, 24-29, 2014 -water rose suddenly with character of little flood wave at Torsminde

	-seiches or skvulper; water masses in motion between Kattegat and Nord Sjaeland
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 -buistoot/meteotsunami 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 meteotsunami threat for Denmark
Wikipedia (20200429)	Wikipedia, Stormen Sven, https://sv.wikipedia.org/wiki/Stormen_Sven#cite_note-15, accessed 29Apr2020 -restaurante 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] -analysis of long period waves: energy, equivalent wave height, spectra
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 -one of key objectives of SWAN model study to assess penetration of low frequency waves from North Sea into Wadden Sea -spectra graphs show indication of high energy 30s waves in front of Delfzijl
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. -mention of infragravity waves of 35s period as important mechanism for dune damage
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). -waverider 2D spectra indicating short episodes of infragravity waves at the Elbe and FINO1 buoys with wave periods >25s

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/sturmschaeden-auf-sylt-xaver-holte-sich-land-1.1844100 -40m of coast line retreat at Hoernum Odde -57% of 21km stretch of Sylt west coast with dune collapse damage -line of the border dunes broken through in 5 places -Keitum on east side of Sylt: water inbreak after cliff collapse requiring sand bag
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. -gap in dune line at Het Zwin and overwash phenomenon
Brooks et al. (2016)	Brooks SM, T Spencer, A McIvor, I Moller, Reconstructing and understanding the impacts of storms and surges, southern North Sea, Earth Surface Processes and Landforms, 41, 855-864, 2016. -FIG 4. aerial photo interpretation shows large along shore differences with characteristic spatial scale 100-1000m
Dreier and Foehle (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 -measurements of water level, significant wave height, wave runup at Untjehoern -wave runup 2m above waver level and 1m above significant wave height
Surgewatch (20200304)	Surgewatch, Storm event 6th December 2013, https://www.surgewatch.org/events/1/ (last accessed 04Mar2020) -50 instances of breasched (manmade and natural) defences across UK coastline; multiple overtopping -'flooded from wave overtopping': Boston, Great Yarmouth, Lowestoft, North Berwick, Jaywick, North Wales, Blackpool, Cleveleys, Walcott, Cromer, Whitstable, Portgordon, New Brighton (JBA, 2014)

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 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. -precip Hamburg-Fuhlsbuettel 5Dec2013 11.9mm; no information that this contributed to Elbe water levels at Hamburg -reference to flooding in Elbe and Danube in June 2013.
Noosent 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. WL Rapporten, 00-119, Waterbouwkundig Laboratorium, Antwerpen, Belgie. October 2014, WL2014R00_119_5 [document date stamp: 15Oct2014; author= Deschamps, Maarten] -focus on Belgian precipiation and river heights/flow in Antwerp estuary during Storm Xaver

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. -dike breaches in Suffolk occurred along rivers in two areas and not on the open coast -river levels high because of heavy precipitation during period -1953 flooding would have been worse if there had additonally been alot of rain.

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, 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 -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 durign 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 Frierich, S Haeseler, C Lefebvre, Orkantief XAVER ueber 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, 17:34CET? -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

Kristeligt Dagblad (20131205)	Kristeligt Dagblad, Stormen blaeser Skotland omkuld: Doodsfald og nebrud, (contributor: Ritzau), 05Dec2013 12:50 https://www.kristeligt-dagblad.dk/udland/stormen-bl%C3%A6ser-skotland-omkuld-d%C3%B8dsfald-og-nedbrud -1 transport truck driver killed when truck overturned in Wesst Lothian near Edinburgh -at least two other injuries as consequence of fallen trees
Kunz et al (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. -6 deaths
National Wind Watch (20131210)	National Wind Watch, 10Dec2013, Xaver zerstoert ein Windrad bei Vlatten, original source: Aachener Zeitung, 6Dec2013 https://www.wind-watch.org/news/2013/12/10/xaver-zerstort-ein-windrad-bei-vlatten/ -woman injured
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 -three people lightly injured 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-a-937576.html# -3 storm-related deaths in UK and Denmark FIG14.Scotland also say high winds on Thursday. Here, rescue workers at the scene a truck accident near Bathgate (AP)
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 fallen off Dutch cargo vessel off Ystad
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 -10 people killed across Europe: 5 in Poland, 4 in Germany, 1 in UK
ABPmer (2014)	ABP mer, Ensuring Flood Resilience. An overview of the 5/6 December 2013, Associated British Ports, Marine Environmental Research, July, 2014 -no fatalities on coast; 2 fatalities inland from high winds
AON Benfield (2014)	AON Benfield, Impact forecasting. December 2013 Global Catastrophe Recap, 2014. [document properties: abrandt; date stamp: 10Jan2014] -15 fatalities Europe
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 -15 fatalities across Europe
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. -FIG2.5. European commissiion info sheet with 7 fatalities
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. -15 fatalities in NW Europe but non from coastal flooding
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 -Poland: 4 fatalities & 53 injured
DEMA (2018)	Danish Emergency Management Agency DEMA, National Risk Profile for Denmark, April 2018 -one fatality Denmark
Rucinska (2019)	Rucinska D, Describing Storm Xaver in disaster terms, International Journal of Disaster Reduction, 34, 147-153, 2019 -Poland 4, Germany 7, UK 2, Netherlands 3 (including people swept out to sea)
Wikipedia (20191002)	Wikipedia, Stormen Bodil, https://da.wikipedia.org/wiki/Stormen_Bodil#cite_note-39 (accessed 02Oct2019) -15 fatalities across Europe with description of circumstances
JBA Risk Management (2020)	JBA Risk Management, Storm Xaver 2013. Event Commentary, 2020. [PDF document properties: author=Cameron Whitwham] -15 fatalities across Europe; 2 fatalities UK
WIKI (20200124)	WIKI, Cyclone Xaver, https://en.wikipedia.org/wiki/Cyclone_Xaver accessed 24Jan2020 -5 Poland, 2 UK, 1 Denmark, 7 Sweden
Wikipedia (20200429)	Wikipedia, Stormen Sven, https://sv.wikipedia.org/wiki/Stormen_Sven#cite_note-15, accessed 29Apr2020 -listing and description of fatalities in Sweden
Wikipedia (20200502)	Wikipedia, Orkan Xaver, https://de.wikipedia.org/wiki/Orkan_Xaver (accessed 2 May 2020) -listing fatalities across Europe, with some brief descriptions -Germany: 82y old woman died in ambulance accident during storm -Denmark: 72y old woman died in truck traffic accident -Austria: truck driver killed when gusts blew truck into head-on collision with bus. -UK: man killed by falling branch Nottinghamshire

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 but say 500 people could still be in need of help (Reuters). FIG10.[PHOTO] Elsewhere in England, high tides followed the storm's tidal surges, hitting 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 (Laura Steen)
BBC (20131206)	BBC20131206, Deadly storm and tidal surge batter northern Europe, BBC 6 Dec2013 (report by Anna Holligan) -eastern England: 10000 homes evacuated Norfolk & Suffolk; houses collapse Hemsby -north Wales: residents rescued by lifeboat crews -Hamburg: Fish Market and some streets near river flooded -Netherlands: limited flooding, sea dykes held; some flooding Dordrecht and Rotterdam
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 -thousands evacuated from coastal areas of UK during night 5-6Dec2013 -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-strikes-Europe-causing-death-destruction-leading-cancellation-hundreds-flights.html -flooding Thorsminde, Hamburg Fischmarkt, Bensersiel
Deutschlander et al (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. -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 Whitby; also Scarborough, Great Yarmouth, Lowestoft -Germany: damage from coast flooding in Hamburg; historic fish market flooded -Netherlands: some flooding in Dordrecht, Rotterdam, Vlaardingen
Kunz (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. -thousands evacuated from lowland areas in UK -Fish Market and Elbstrasse in Hamburg completely flooded -pollutant release hazard -Borkum: evacuation of residents of the roadsted prepared
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# 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) FIG4. Floodwaters in Hamburg early on Friday morning. City officials closed off flooded areas and some people reportedly had trouble reaching work in the morning (DPA) FIG6. Streets also flooded in the northwestern 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 Dagebuell 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 weiterer 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)	ABP mer, Ensuring Flood Resilience. An overview of the 5/6 December 2013, Associated British Ports, Marine Environmental Research, July, 2014 -Immingham 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: 600homes; Humber: 400homes; 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
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] -extensive areas of Whitby town centre flooded
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] -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.i-iv -coastal flooding at Boston (Lincs), Jaywick (Essex), Rhyl (Denbyshire),
Eriksen (2014)	Eriksen 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 Hansestadt Hamburg, Nr. 16/2014, 26pp. -flooding in Hamburg
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 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. -'Hallig lowlands were flooded'
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. WL Rapporten, 00-119, Waterbouwkundig Laboratorium, Antwerpen, Belgie. October 2014, WL2014R00_119_5 [document date stamp: 15Oct2014; author= Deschamps, Maarten] -Antwerp quayside flooded
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 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=filiz; date stamp=07Aug2015] -UK: 10000 houses evacuated -Hamburg: Fischmarkt and Elbstrasse flooded
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 Titley, 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 Linolnshire 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 & Seasalter
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, Sussex/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 discrict: 170 properties flooded
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: Universitaet Siegen, 2016 -Xaver impacted other parts of Denmark compared with Britta 2006 -some houses uninhabitable for some time and still are

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 -mention of flooding in Thyboron during Dec 2013 flood
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/bostonbarriertwao/results/appendix-1---history-of-flooding-sources.pdf -desription 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, Isefjord, Copenhagen
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 -coastal floodign 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
Wikipedia (20191002)	Wikipedia, Stormen Bodil, https://da.wikipedia.org/wiki/Stormen_Bodil#cite_note-39 (accessed 02Oct2019) -flooding of Viking ship museum in Roskilde -Frederikssum & Jyllinge Nordmark 600 families lost their home -in low lying areas water was being fought up to a week after the storm -Belgium: evacuation of 2083 people from Bredene 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
JBA Risk Management (2020)	JBA Risk Management, Storm Xaver 2013. Event Commentary, 2020. [PDF document properties: author=Cameron Whitwham] -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 alond coast
WIKI (20200124)	WIKI, Cyclone Xaver, https://en.wikipedia.org/wiki/Cyclone_Xaver accessed 24Jan2020 -ecavuations: Rhyll Wales; Belgium: Bredene 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, Llanddulas, Conwy, 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 Sven, https://sv.wikipedia.org/wiki/Stormen_Sven#cite_note-15, accessed 29Apr2020 -worst coastal flooding in Malmo and Helsingborg
Wikipedia (20200502)	Wikipedia, Orkan Xaver, https://de.wikipedia.org/wiki/Orkan_Xaver (accessed 2 May 2020) -parts of Bremen susceiptable 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 140m on southern Baltic coast

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 Gerkensmeier, J-M Mueller, Ermittlung des Sturmflutbemesungswasserstandes fuer den oeffentlichen 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 Thyboron (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. Deltares, 2014, 197pp. Project 1209433-007, Reference 1209433-007-HYE-0005 -map 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, Deltares, 1209381-008-ZKS-0008, 43pp, 18Dec2014 [PDF document properties: titl=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 stuifdijk at east end of dunes
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.

	-'The safety assessment against flooding in the Netherlands requires all component of the so-called ring dike (i.e. dikes, dunes, levels, etc) to be able to cope with the hydraulic conditions associated to a return period of 10000 years.'
Van Massenhove (2015)	Vanmassenhove, Niels, Storm surge measures ports Flemish coast, Blankenberge, Tuesday February 3rd, Maritieme Sientverlening en Kust, Coastal Division, Flanders Hydraulic Research.[document properties: title=Geintegreerd Kustveiligheidsplan; author=Maarten; datestamp=27/02/2015] -current quayside height Zeebrugge 6.68m, 7.31m TAW; proposed surge barrier height 8.0m, 9.0m TAW -map of Belgian coast flooding for a 1000y water level event 7m TAW
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. * -after Waverley report from 1953 floods; flood defences to withstand 100y still water level -joint sea level & wave condition method; standard 50-100 years -more recent risk management & insurance policy; defences should not breach with 1 in 200y event -wave overtopping of promenades & seawalls accepted * -locally more stringent design criterion: 1000y for London; 10000y for power stations -Munich Re will pay out on reinsurance claims to limit of 1 in 200y level
Nederhoff et al (2016)	Nederhoff K, E Elias, T Vermaas, Erosie op Ameland Noordwest. Modelstudie: simulaties met Delft3D en XBeach, Deltares, 117pp, July, 2016 -height of protection dunes in northwest Ameland: lowest 6.5m; variation 7-25m NAP
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: Universitaet Siegen, 2016 -all Denmark underlain by soft sediments except Bornholm -Waddensee dikes: dike materials and profile; surge protection at 20-500 year extreme water level -Jutland west coast: Thyboron dike protects at 1000y level; rest of coast at 100y level -Jutland west coast: dune protection minimum 40m wide & 5 m high; dune safety depends on wave runup -inner Danaish seas: 1872 surge (4000 year event) used as basis of design criterion for modern dikes
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 protected by dikes at the 1000 year level.
Kystdirektoratet (2018)	Kystdirektoratet, Shoreface nourishment effects. An analysis of the 2011 nourishment performed at Skodbjerge. Kystdirektoratet, Hojbovej 1, 7620 Lemvig, Dec 2018 [pdf document properties: title=Shoreface nourishment effects_Skodbjerge_20.12.2018, datestamp=20/12/2018] -Denmark policy to protect from sea flooding on the North Sea west coast at the 100y return period except for Thyboron (1000y return period)
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 -dike heights 6.50-8.40 m ASL

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/ (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)	BBC20131206, Deadly storm and tidal surge batter northern Europe, BBC 6 Dec2013 (report by Anna Holligan) -Thames Barrier closed for second day to protect London -eastern Scheldt storm surge barrier closed
Gcapticalideas (20131209)	gccapitalideas, Windstorm Xaver, 9Dec2013, https://www.gccapitalideas.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, 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 -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 Ueberstanden, Waserstaende zwischen Zweieinhale und Knapp vier metern

	registriert // presseinformation von 6. Dezember 2013, (Ansprechpartnerin: Herma Heyken), 06/12/2013. -9 barriers operated by NLWKN closed: Ems, Hunte, Weser, Unterelbe -Emssperrwerke bei Gandersum in Landkreis Leer closed -6 barriers on the Elbe closed -Hunte and Ochtumsperrwerke 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# -Thames Barrier closed late Thursday
ABPmer (2014)	ABP mer, Ensuring Flood Resilience. An overview of the 5/6 December 2013, Associated British Ports, Marine Environmental Research, July, 2014 -Thames Barrier protected 380,000 properties from surge -Thames Barrier closed >50times during period Dec2013–Mar2014 due to prolonged stormy weather. -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'
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] -Thames Barrier closed several times during Xaver; 2m water level differnce across barrier -Hull Barrier: water level at 5.8m; top of barrier at 6.3m
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. WL 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 -Oosterscheldkering
Slingo et al (2014)	Slingo J, S Belcher, A Scaife, M McCarthy, A Saulter, 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] -Thames 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. -Thames 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 Rueckversicherung Aktiengesellschaft, Hansaallee 177, 40549 Duesseldorf, www.deutscherueck.de [pdf document information: author=filiz; date stamp=07Aug2015] -Thames barrier closed -Oostersheldt barrier 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 -Thames 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 Thames Barriers'
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. -Thames 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 -Thames 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 Thames 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 Thames Barrier since start of operation in 1982
Wikipedia (20201002)	Wikipedia, Stormen Bodil, https://da.wikipedia.org/wiki/Stormen_Bodil#cite_note-39 (accessed 02Oct2019) -62 gates of Oosterscheldekering, Thames Barrier, Hamburg 38 flood gates
WIKI (20200124)	WIKI, Cyclone Xaver, https://en.wikipedia.org/wiki/Cyclone_Xaver accessed 24Jan2020 -Thames 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) -Thames 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 Dec2013 (report by Anna Holligan) -houses fall off sand cliff at east Hemsby UK
BT (20131208)	BT, Offer for Bodil: Koebte huset 15.august - nu er det vaek, 08Dec2013, 16:44, (contributor: Morten Eggert) https://www.bt.dk/danmark/offer-for-bodil-koebte-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 ueber Nordeuropea von 5. bis 7. Dezember 2013, Deutscher Wetterdienst DWD, Stand 30. Dezember 2013, 19pp. -Auf den Inseln gab es Duenenabbruuche und Sandabtragungen' -houses in Hemsby 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. 06Dec2013 - Report No.1, Situation Report - 19:00CET, 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 Ueberstanden, Waserstaende zwischen Zweieinhale 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 and Zeltplatzduenen auf Spiekeroog -Harlehoern dune on Wangerooge hit -Westinnengroden 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 Pirotal 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 57% 21km stretch at west side of Sylt
Sylter Rundschau (20131209)	Sylter Rundschau, Folgen des Orkans. Xaver 'knabberte' Sylt massiv an, 09Dec2013 06:00 (from Friederike Reussner) https://www.shz.de/lokales/sylter-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. -Dikjen Deel: dunes broken -List Moevenberg 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)	ABP mer, 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 sea defences and other coastal infrastructure ' -FIG_p3. [PHOTO] Coastal erosion at Hemsby [Albanpix] -FIG_p3. [PHOTO] Wave damage to Cromer frontage [David Tipling]
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 Stumflut im Gepaeck, Jahresbericht 2013. Der Zukunft verplichtet, NLWKN, Niedersaechsischer Landesbetrieb fuer Waserwirtschaft, Kuesten- und Naturschutz, pp.8-9, document date stamp 24Apr2014. -signficant 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 ueber die Sturmflut vom 05.-0.6.12.2013 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] -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 treibsel
NOZ (20140129)	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-fur-juist-spiekeroog-und-wangerooge-1 -Hammersee on Juist, coast retreat 7m -Wangerooge: coast retreat of 13m at Harlehoernduenen -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 Nordsjaellands Kattegatkyst experienced large erosion and damage. Photo of Rageleje 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 advisering Ameland Noordwest, Deltares, 1209381-008-ZKS-0008, 43pp, 18Dec2014 [PDF document properties: titl=Regional advisering: Ameland NW; author=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
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=filiz; date stamp=07Aug2015] -significant dune losses Juist & Spiekeroog; Wangerooge beach part washed away -significant sand loss from Sylt, Fohr, Amrun -dike damaged at a few places: Buesum
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. -dune damage and overwash at Het Zwin on Belgium Netherlands border -belgian dunes cut back 4-10m; Netherlands dunes 2-20m
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 -dune scarp cut back 8.9m at beach profile 100 and 13.5m at beach profile 104 near Ostend
Dissanayake and Karunarathna (2015)	Dissanayake 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 -Xbeach model of dune damage at Formby Point
Dissanayake et al (2015)	Dissanayake 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. -4m dune retreat at Formby Point in Liverpool Bay
Dissanayake et al (2015b)	Dissanayake 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. -Xbeach model study of beach damage at Sefton 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 cliftop 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 Lincolnshirem 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
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. -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 McIvor, 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 Scolt 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 Weihnachshochwasser 2014 in Schleswig-Holstein, IWASA 2016 Tagungsbeitrag, (46. IWASA, 7-8 Januar 2016; Internationales Wasserbau-Symposium Aachen. [pdf document properties: autor=sonja; datestamp: 26Apr2016] -coastline retreat up to 40m at Hoernum Odde on southern point of Sylt -FIG7. [PHOTO] Aerial photo showing retreat of southern tip of Sylt Island (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, Erosie op Ameland Noordwest. 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: Universitaet 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.
Sorensent 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. *-FIG6. End point rate (m/y) for the barrier coast for the storm periods 2006-2007 (blue), 2007-2008 (pink), and 2013-2014 (orage) for (a) Brancaster Bay (14m), (b) Scolt Head Island (18m), (c) Holkham Bay (16m). Also shown are the cross shore profile locations. (d) end point rate (m/a) for the summer period 2008 to summer 2013, a period of no storm activity along the barrier for Brancaster Bay (blue), Scolt Head Island (red) and Holkham Bay (green).
Jensen et al (2017)	Jensen J, S Niehuser, A Arns, S Dangendorf, Sensor- und risikobasiertes Fruhwarn-system fuer Seedeiche (EarlyDike), AP1 - Sturmflutmonitoring und Sturmflutssimulator - 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] -background 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
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 -wave runup investigation at Untjehoern
Kystdirektoratet (2018)	Kystdirektoratet, Shoreface nourishment effects. An analysis of the 2011 nourishment performed at Skodbjerge. Kystdirektoratet, Hojbovej 1, 7620 Lemvig, Dec 2018 [pdf document properties: title=Shoreface nourishment effects_Skodbjerge_20.12.2018, datestamp=20/12/2018] -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, 2DH model study in Delft3D-FLOW, M.Sc. Thesis, Utrecht University, 01May2018 -modelling study of flow Dutch Waddensee at Ameland and sediment trasnport

	-no wave, water level, or weather information presented
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 -some damage to Cromer sea defences; there had not been 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 salinization 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 the 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, Spit 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] -several houses at Hemby fell into sea because of excessive cliff erosion.
WIKI (20200124)	WIKI, Cyclone Xaver, https://en.wikipedia.org/wiki/Cyclone_Xaver accessed 24Jan2020 -Happisburgh, Hemsby; holiday homes Norlev strand Denmark undermined
Wikipedia (20200502)	Wikipedia, Orkan Xaver, https://de.wikipedia.org/wiki/Orkan_Xaver (accessed 2 May 2020) -FIG6. [PHOTO] Coast damage at Hemsby, Norfolk -25m of dune retreat at Hammersee/Juist -significant dune damage Langeoog, Spiekeroog, Wangerooge -Nordfriesischen Inseln: land loss at Sylt, Foehr, 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

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/ (accessed 02Jan1990) -power disrupted to 100000 homes Scotland & 6500 in N Ireland
BBC (20131205)	BBC, In pictures: Winter storm hits UK, 5 December 2013, https://www.bbc.com/news/uk-scotland-25231224 -many homes in northern Ireland left without power
BBC (20131206)	BBC20131206, Deadly storm and tidal surge batter northern Europe, BBC 6 Dec2013 (report by Anna Holligan) -Poland: 400,000 homes without power due to severed lines -Sweden and Norway: thousands of homes without power -Germany, Hamburg: 1000s of homes without electricity
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 -Poland: 400,000 households without power
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 -10000s without power Sweden
Gccapitalideas (20131209)	gccapitalideas, Windstorm Xaver, 9Dec2013, https://www.gccapitalideas.com/2013/12/09/windstorm-xaver/ -northern Europe: 500,000 homes lost power at height of storm -UK: 130,000 homes and businesses without power -Poland: 400,000 homes without electricity -Sweden: thousands homes without power
GP (20131206)	GP, Fortsatt risk for halka, 6Dec2013 (correspondent: D Henriksson, K Vikingsson, P Sydvik, TA Akerblom) http://www.gp.se/nyheter/goteborg/1.2201325-fortsatt-risk-for-halka (accessed 1May2020) storm caused big problems for electricity network -28000 customers in Goteborg without power night to Friday -Fjarrvarmeproduktionen? came back again Friday morning -Torslanda, Tuve-Save, Gunnard: 800 customers with power loss Friday -Goteborg Energi report at 23:00 that most have power restored -few 10s of customers still without power in Torslands
Kristeligt Dagblad (20131205)	Kristeligt Dagblad, Stormen blaeser Skotland omkuld: Doodsfald og nebrud, (contributor: Ritzau), 05Dec2013 12:50 https://www.kristeligt-dagblad.dk/udland/stormen-bl%C3%A6ser-skotland-omkuld-d%C3%B8dsfald-og-nedbrud -at least 25000 households without power in Scotland and Northern Ireland
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.

	-4000 customers affected by power outages grid area of Wemag
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/uwz/928.html -tens of thousands of houseas 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 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] -10 000s UK & 100 000's 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 ...'
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, 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. -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, 2017, 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 poer
JBA Risk Managment (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 homes without power across Cumbria and Teeside; 135000 properties across Northeast, Yorkshire, North Lincolnshire had power disruptions -Sweden: 50000 homes without power -Poland: 400000 households with blackout -power outage Middlesbrough -Whitby: electrical substation short 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
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/i/bKEjl/varsler-full-storm-i-soer-norge

	-cancelled flights in Avninor network in southern Norway -Bodo airport closed due to heavy snowfall -closed mountain pass roads souther Norway -cancelled ferries Norway west coast to Denmark -cancelled ferry: Larvik/Kristiansand and Hirtshals -cancelled ferry: Sandefjord-Stromstad -cancelled ferry: Bergen-Stavanger-Hirtshas-Langesund -cancelled ferry: Hirtshals-Sorlandskysten -Basto gerry normal -no cancellation information on ferry Oslo-Kie -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 Dec2013 (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 Nordeuropea 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 Henriksson, K Vikingsson, P Sydvik, TA Akerblom) http://www.gp.se/nyheter/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 Skargarden stopped for carrying cars because of high water levels -flight cancellations and delays at Landvetter and Arlanda
Kristeligt Dagblad (20131205)	Kristeligt Dagblad, Stormen blaeser Skotland omkuld: Doodsfald og nebrud, (contributor: Ritzau), 05Dec2013 12:50 https://www.kristeligt-dagblad.dk/udland/stormen-bl%C3%A6ser-skotland-omkuld-d%C3%B8dsfald-og-nedbrud -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 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.

	-Hamburg port closed night 5-6Dec2013 -St Pauli Elbtunnel closed -locks in Kiel Canal at Holtenau and Brunsbuettel closed -ferries cancelled in Kiel -German-Danish ferry Scandlines stopped serice between Rostock and Gedser until 6Dec20131115 -ferry traffic to East and North Frisian islands nearly shut down 5-6Dec2013 -ferry companies operating trips to other countries in North and Baltic Sea affected (e.g. Stena) -Hamburg and Bremen airport: 50% cancellations 5Dec2013; 20% cancellations 6Dec2013 -Hannover, Duesseldorf, Koeln airport: minor impact -DB cancelled 20 intercity trains night 5-6Dec2013 and 6-7Dec2013 -cancellation of Schleswig-Holstein trains from afternoon 5Dec2013 -no severe rail infrastructure damage
Rtv Oost (20131205)	rtv Oost, Trainverkeer ten noorden van Zwolle stilgelegt vanwege storm 5Dec2013 14:02, https://www.rtvoost.nl/nieuws/177568/Treinverkeer-ten-noorden-van-Zwolle-stilgelegd-vanwege-storm train traffic shurt down from 14:00 5Dec2013 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/tidal-surge-winter-storm-xaver-batters-northern-europe-a-937576.html# FIG11.The UK, Germany, Netherlands, Scandinavia most heavily affected by the severe storm, but cancelled flights and tranins 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 gnarled traffic near Olpe in the state of Nord Rhine Westphalia on Friday morning (DPA)
TheJournal (20131205)	TheJournal, Homes remain without electricity after high winds batter power lines, 05Dec2013 08:20PM, https://www.thejournal.ie/storm-ireland-1207783-Dec2013/ -Wexford-Dublin route closed by dangerous trees
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 -Oresund Bridge closed to train traffic -Malmo-Ystad trains stopped at midday; south Sweden trains stopped at 1500 -some ferry routes to/from 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 Haeseler, S Hagemann, I Bastigkeit, 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. -shipping, rail, air traffic shut down
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=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 Titley, 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 overflowed'
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 -Netherlands: 42 cancelled KLM flights from Schipol -Germany: Hamburg flights cancelled, interrupted high-speed rail between Hamburg & Germany
Wikipedia (20191002)	Wikipedia, Stormen Bodil, https://da.wikipedia.org/wiki/Stormen_Bodil#cite_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 Banedenmark shut rail services Jylland 14:00, Fyn 16:00, Sjaelland 18:00 -Denmark: bridges shut: Storebaeltsbroen, Vejlefjordbroen, nye Lillebaeltsbro, gamle lillebaeltsbro, Svendborgsundbroen, Oresundsbroen, Limfjordsbrown, Alssundbroen

	-Denmark: Copenhagen airport closed for flights 18:30
WIKI (20200124)	WIKI, Cyclone Xaver, https://en.wikipedia.org/wiki/Cyclone_Xaver accessed 24Jan2020 rail: Scotrail, Glasgow Central Station, Skane Sweden, Denmark, Schleswig-Holstein, Suffolk road/bridge:UK, Stavanger ferry: Isle of Man Packet Company, Norway flight: Easyjet Bristol-Edinburgh flight struck by lightning diverted to Newcastle airport: Glasgow, Edinburgh, Aberdeen, Birmingham, Stavanger Goteborg Landvetter, Malmo, Amsterdam Schipol, Hamburg, Berlin Tegel, Denmark Billund, Aalborg, Copenhagen
Wikipedia (20200429)	Wikipedia, Stormen Sven, https://sv.wikipedia.org/wiki/Stormen_Sven#cite_note-15, accessed 29Apr2020 -Malmo Sturup airport closed from evening 5 Dec to lunchtime 6 Dec 2013 -all train traffic in Sweden south of Kungbacka and Nasssjo stopped evening 5Dec and morning 6 Dec
Wikipedia (20200502)	Wikipedia, Orkan Xaver, https://de.wikipedia.org/wiki/Orkan_Xaver (accessed 2 May 2020) keyword ferry: Juist, Sylt, Norderney, Wangerooge; Bornhol Sweden ferry suspended keyword bridges: Rader Hochbrucke, Fehmarnsundebruecke; Oresund bridge keyword airport: Hamburg airport keyword train: DB suspends train services N Germany, Schone Sweden trains suspended, Scotrail

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

Source	Full Reference and Notes
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 -record wind production Germany 06Dec2013 at 26GW; one third of demand 100GW -Britain wind energy production record 02Dec2013 at 6053MW or 14% of electricity on UK system -7900MW of gas-fired stations shut down during storm -UK plans to triple capacity by 2020 -Ireland wind energy record 8Nov2013 at 11564MW; enough for 1 million homes & 45% of demand -IWEA Kenneth Mathews: ...combatting climate change ... Ireland leading way in demonstrating potential of wind energy
IWR (20131206)	IWR, Orkantief 'Xaver' bringt 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) -record wind energy production Germany during storm Xaver -power output equivalent to 26 nuclear power plants -previous day record 28Oct2013 during Storm Christian -highest month wind energy production Germany Nov 2011
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. -wind park Baltic 1 closed 5Dec2013
National Wind Watch (20131210a)	National Wind Watch, 10Dec2013, Xaver zerstoert ein Windrad bei Vlatten, original source: Aachener Zeitung, 6Dec2013 https://www.wind-watch.org/news/2013/12/10/xaver-zerstort-ein-windrad-bei-vlatten/ -1 turbine in 11 turbine array cracked off at wind farm near Vlatten; between Vlatten and Hergarten -wind speed in Kreis Dueren 75km/h
National Wind Watch (20131210b)	National Wind Watch, Sturm 'Xaver': Windrad stuerzt auf Acker, 10Dec2013b, credit: von Manfred Reinnarth, Koelnische Rundschau, 06/12/2013, https://www.wind-watch.org/news/2013/12/10/sturm-xaver-windrad-sturzt-auf-acker/ -Storm Xaver toppled large wind turbine neaer Vlatten; cracked off at 25 m near wleded joint -wind park had 8 similar instations -wind turbine 4 had been operating for 13 years -accident happened 05/12/2013 09:00CET when communications were lost
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/ -wind farm had 8 turbines -on 5Dec2013 21:00CET turbine 4 toppled by Storm Xaver -wind turbine should have been secure against wind speeds of 180km/h; cracked turbine at 25m
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 -previously damaged blade thrown from turbine and landed 150m to north -fist-size ice blocks thrown from turbine onto road 80m away
FINO1 (20140108)	FINO1, 15-m wave damaged FINO1, 08Jan2014. http://www.fino1.de/meldungen/alle-meldungen/137-15-meter-welle-beschaedigt-fino1 -15m access deck had railing bent on north side and decking torn up on south corner -access structure at 17m smashed by swinging 500 kg counterweight -two photos of damage
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 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

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=filiz; date stamp=07Aug2015] -Doehlen Kreis Oldenburg 20t nacelle torn from turbine -Deining Landkreis Neumarkt, Oberpfalz: fallen wind blade from turbine
Fischer et al. (2015)	Fischer, JG, C Senet, A Schneehorst, O Outzen, 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] -PHOTO of damage to the 15m working platform during Storm Xaver
Caithness Windfarm (20160105)	Caithness Windfarm, craigdr, Detailed accidents to 31 December 2015. Document time stamp 5Jan2016, 175pp -Corkmore Wind Farm Donegal, Ireland: broken blade -Northern Bavaria, Germany: blade torn off -Doehlen, Oldenburg, Germany: nacelle torn off turbine; falls 60m -Vlatten Energy Park, Germany: wind turbine crashed in field -Seascale School wind turbine, Cumbria, UK: blade shears off -Burradale Wind Farm Shetland, UK: lightning caused fist-sized hole -Guenter-Ehrhorn Weg in Dohren: wind turbin expladed -Schaeskdorf, Lausitz, Germany: blade tip lost
Christakos et al. (2016)	Christakos K, I Cheliotis, G Varlas, G-J Steeneveld, Offshore wind energy analysis of Cyclone Xaver over North Europe, 13th Deep Sea Offshore Wind R&D Conference, EERA DeepWind'2016, 20-22 January 2016, Trondheim, Norway, Energy Procedia, 94, 37-44, 2016. -record wind energy production Germany from onshore & offshore turbines leads to decrease spot prices -Denmark turbines shut down because of extreme winds & high power consumption leads to increase in spot price. -WRF modelling shows North Sea wind over 25m/s cut-off threshold for 30h/84h of model integraton
Wikipedia (20200502)	Wikipedia, Orkan Xaver, https://de.wikipedia.org/wiki/Orkan_Xaver (accessed 2 May 2020) -data from European Energy Exchange & Fraunhofer Institute for Solar Energy Systems: wind energy production Germany on 5Dec2013 new record value 26.3GW -6Dec2013: 563 GWh energy produced with average power 23.5GW

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 cylone 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=Konstantinos 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 cylone 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 -WRF model to quantify hydropower potential during Storm Xaver -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: Koebte huset 15.august - nu er det vaek, 08Dec2013, 16:44, (contributor: Morten Eggert) https://www.bt.dk/danmark/offer-for-bodil-koebte-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-zerstort-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/tidal-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)
Sylter Rundschau (20131209)	Sylter Rundschau, Folgen des Orkans. Xaver 'knabberte' Sylt massiv an, 09Dec2013 06:00 (from Friederike Reussner) https://www.shz.de/lokales/sylter-rundschau/xaver-knabberte-sylt-massiv-an-id5098481.html -most of beach access stairs at Hoernumer Odde not usable -ground floor damge to baeach restaurant Wonnemeyer the Wenningstedt
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 -some roof damage -Unterfeuer on southern part of Sylt destroyed
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=filiz; date stamp=07Aug2015] -numerous cases roof damage & toppled trees north Germany -Stralsund supermarket lost roof 200000 EUR -clock Marienkirche damaged

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. -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 Weihnachshochwasser 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 Herrmann & J Jensen (eds), Sicherung von Daemmen, Deichen und Stauanlagen: Handbuch fuer Theorie und Praxis (Vol V pp3-21). Siegen: Universitaet Siegen, 2016 -inner Danish seas: Xaver flooding caused houses to be uninhabitable for a long time -inner Danish seas: medieval town centers 1m 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 (20200429)	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 -FIG6. [PHOTO] Many roads have been closed across Scotland due to fallen trees (AP)
Gccapitalideas (20131209)	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/nyheter/goteborg/1.2201325-fortsatt-risk-for-halka (accessed 1May2020) -during night to Friday police received 90 reports of traffic blockages; mostly fallen trees
Krissteligt Dagblad (20131205)	Kristeligt Dagblad, Stormen blaeser Skotland omkuld: Doodsfald og nebrud, (contributor: Ritzau), 05Dec2013 12:50 https://www.kristeligt-dagblad.dk/udland/stormen-bl%C3%A6ser-skotland-omkuld-d%C3%B8dsfald-og-nedbrud -trains in Scotland cancelled by trees fallen on rails
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. -trees and branches on roads and rail tracksin Mecklenburg-Vorpommern & Schleswig-Holstein
National Wind Watch (20131210b)	National Wind Watch, Sturm 'Xaver': Windrad stuerzt auf Acker, 10Dec2013b, credit: von Manfred Reinnarth, Koelnische Rundschau, 06/12/2013, https://www.wind-watch.org/news/2013/12/10/sturm-xaver-windrad-sturzt-auf-acker/ -reference to a few toppled trees in Kreis Euskirchen
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 -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-a-937576.html# FIG12.An uptrooted 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 https://www.thelocal.se/20131205/storm-sven-sweeps-into-southern-sweden -toppled trees cut power lines for trains
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 -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 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=filiz; date stamp=07Aug2015] * -Mecklenburg-Vorpommern: more toppled trees in Xaver (4000 trees or 3mill EUR) compared with Schleswig-Holstein (80% fewer)
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 -Denmark: Bodil with Allan destroyed almost 2500 hectares of forest with over 2 million trees
Wikipedia (20200502)	Wikipedia, Orkan Xaver, https://de.wikipedia.org/wiki/Orkan_Xaver (accessed 2 May 2020)

	- FIG8. [PHOTO] Impact on Handewitter Forst Apr 2014

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/UYXaD -cutter GO-20 grounded ; stowed to Stellendam arrival 0600M -Burak Bayraktar engine problem 00:40M -Balticborg 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 Finnsky (28002 gt) 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 off 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? -Thursday morning 2 sailors swept off Dutch cargo vessel Marietje Andrea off Ystad; search called off after 6 h
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; not an evacuation -BP is considering moving people from the field.
Gcapitalideas (20131209)	gccapitalideas, Windstorm Xaver, 9Dec2013, https://www.gccapitalideas.com/2013/12/09/windstorm-xaver/ -'North Sea oil and gas producers inluding ConocoPhillips, Maersk Oil and Statoil cut production and evacuated staff from some platforms'
GVA (20131205)	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 -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, Vijf containers even op drift op de Schelde, 05Dec2013 20:57, https://www.hbvl.be/cnt/aid1500792/vijf-containers-op-drift-op-de-schelde-2 -ship traffice 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 (20131205)	Reuters, ConocoPhillips cuts some output at Ekofisk field due to storm, 5Dec2013, https://finance.yahoo.con/news/conocophillips-cuts-output-ekofisk-field... -ConocoPhillips relocated number of personnel onshore and to Ekofisk complex; production decreased -PTIL 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) -producton 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, 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=filiz; date stamp=07Aug2015] -Finnlines freighter (190m) headed from Warnemunde to Finnland; 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 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. -Princess Victoria sank in Irish Sea during 1953 storm
Wikipedia (20191002)	Wikipedia, Stormen Bodil, https://da.wikipedia.org/wiki/Stormen_Bodil#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 Frierich, S Haeseler, C Lefebvre, Orkantief XAVER ueber Nordeuropea von 5. bis 7. Dezember 2013, Deutscher Wetterdienst DWD, Stand 30. Dezember 2013, 19pp. -partial malfunction of weather station at Hamburg 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_bm1101; author stamp: bm1101; document time stamp: 12/102013 12:5136PM) -Dagebuell tide gauge failed during evening high tide 6 Dec 2013
Deutschlander et al (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. -partial malfunction of weather station at Hamburg St. Pauli; 5Dec2013 09:45-12:00UTC
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: 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
Oceanografisch Meteorologisch Station (2013)	Oceanografisch Meteorologisch Station, Stormverslag 05-06 december 2013, 26pp, 2013 [pdf document properties: author=Myriam Sys; datestamp=15Dec2013] -large data gaps in Westhinder waverider series -gap in Bol van Heist wave period at 05Dec2013 1300UTC
SMHI (20131012)	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. -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, 2 40-48, 2014 -instrument irregularity Holbaek 7Dec2013 -small decrease in water level graph of Holbaek 06:45CET 6Dec2013
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 -5 of 32 wave recorders had not data during storm Xaver -data gaps in wind speed reports
Luecht and Peters (2014)	Luecht, Fabian and Ove Peters, Bericht ueber die Sturmflut vom 05.-0.6.12.2013 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] -no data for Dagebuell tide gauge during main storm tide
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 -Huibertgat anemometer not functional -no data from Schiermonnikoog
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 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. -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_ekofisk (2014)	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] -low data capture rates epecially for th wave recorders
MIROS_heidrun (2014)	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] -data gaps in water level data during Storm Xaver
MIROS_heimdal (2014)	MIROS, Manedsrapport Heimdal, Desember 2013, Dok. Nr. ND/1047/13/12 (carried out be SRS, controlled by CNE, approved by OO) [PDF document properties: author=Miros AS; datestamp=06Jan2014]

	-all wave data missing above Hs=5m; almost no information during Storm Xave period
MIROS_norne (2014)	MIROS, Maanedsrapport Norne, 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] -no data from waverider buoy during Dec 2013
MIROS_sleipner (2014)	MIROS, Manedsrapport Sleipner A, Desember 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
Fenoglio-Marc et al (2015)	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 -excessive scatter at sites: Emden, Wilhelmsahaven, Hoernum Sylt Island, Cuxhaven, Dagebuell
Fischer et al. (2015)	Fischer, JG, C Senet, A Schneehorst, O Outzen, 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] -gaps in RADAC Hs dara set near peak of storm Xaver
Matelski et al (2015)	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. -tabulated tide gauge station data indicates some instruments failures dduring the storm
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 -something wrong with water level record record at Wells next the Sea to prevent it from being matched to astronomical tide model -'surge associated wave action beneath Cromer Pier made the water level record at this location unusable for subsequent analysis' -'Sheerness tide gauge was offline at the time of the surge' -Immingham figure shows tide gauge went down from afternoon 6 Dec 2013 -FIG7. time series of water levels and significant wave heights at Norfolk/Lincolnshire and Suffolk coast show data gaps
Brooks et al (2016)	Brooks SM, T Spencer, A McIvor, I Moller, Reconstructing and understanding the impacts of storms and surges, southern North Sea, Earth Surface Processes and Landforms, 41, 855-864, 2016. -problems with Cromer tide gauge due to wave effects at pier

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

Source	Full Reference and Notes
Cipollini et al (2014)	Cipollini P, LJ West, HM Snaith, 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-2 altimeter strip map
Deutschlander et al (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.
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-knmi/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 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. -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 1000MEZ FIG8. [MAP] Forecast of pressure on Friday 29Nov2013 for 06Dec2013, 1900MEZ (GFS model) FIG9. [MAP] Gust forecast of the European weather model from Mon 2Dec2013 for 5Dec 1900MEZ & 06Dec0000MEZ 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, Rekordvandstande i Isefjorden 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. Deltares, 2014, 197pp. Project 1209433-007, Reference 1209433-007-HYE-0005

	-SWAN model results for Wadden Sea
Hewson et al (2014)	Hewson T, L Magnusson, O Breivik, F Prates, I Tsonevsky, HJW 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 5Dec2013fro the data times (a) 00UTC on 30Nov, (b) 00UTC on 2Dec and (c) 00UTC on 4Dec. Panel (d) shows, for the same 24h 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 Stumflut im Gepaeck, Jahresbericht 2013. Der Zukunft verplichtet, NLWKN, Niedersaechsischer Landesbetrieb fuer Waserwirtschaft, Kuesten- und Naturschutz, pp.8-9, 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, 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] * -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 0100/0700/1300CET
Pelt (2014)	Pelt AS, BODIL's stormflod i de indre dansk farvande, Vejret, 138, 24-29, 2014 -FIG6. Vejrkort fra 6Dec2013 00UTC from [8] showing height of the 500hPa surface in dm, together with the surface pressure in hPa with 5hPa intervals. Bodil sends a powerful windfield over Denmark from the NW which leads to high water levels.
RWS (2014a)	RWS, Watermanagementcentrum Nederland, Stormvloedflits 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 0400???
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 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 -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 signficant wave height German Bight 3-9Dec2013
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=filiz; date stamp=07Aug2015] -FIG_p51. [MAP] 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, 1/2 Sept 2015 -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 Lillibridge, Cyclone Xaver seen by geodetic observations, Geophys Research Letters, 42, 9925-9932, 2015 -[MAP] North Sea storm surge elevations for BSHmod and HyFlux2
NLWKN (20151210)	NLWKN20151210, Sturmflutwarndienst der Betriebstelle Norden-Norderney, NLWKN Niedersachsischer Landesbetrieb fuer Wasserwirtschaft, Kuesten- und Naturschutz, Niedersachsen, document date stamp 10Dec2015. -[MAP] modelled forecast wspd & wdir for 06Dec2013 0100MEZ (12h forecast).
Patzer (2015)	Patzer, Marianne, Storm surge forecasting at DMI and perspectives on teh use of Earth Observations, ESA eSurge

	Sympositum, Deltares, the Netherlands, (powerpoint presentation) January 21, 2015 -FIG. [MAP] map of storm surge water level, altimeter strip water level & 3 Zeeland tide gauges 07Dec2013 00:00
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. -FIG2. Surface wind and pressure fields in NW Europe from 04Dec2013 1200UTC to 06Dec2013 0000UTC
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. -FIG7. [MAP] Time series of pressure and winds during 4-6Dec2013. The locations of the Liverpool and Lowestoft tide gauges are shown. Plotted from gridded surface wind and pressure data from the NCEP/NCAR re-analysis (Kalnay etal, 1996)
Cheliotis et al. (2016)	Cheliotis, I, G. Varlas, K. Christakos, The impact of cylone 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=Konstantinos Christakos; datestamp: 07/09/2016] -WRF model assessment of Norway precipitation during Storm Xaver
Christakos et al (2016)	Christakos K, I Cheliotis, G Varlas, G-J Steeneveld, Offshore wind energy analysis of Cyclone Xaver over North Europe, 13th Deep Sea Offshore Wind R&D Conference, EERA DeepWind'2016, 20-22 January 2016, Trondheim, Norway, Energy Procedia, 94, 37-44, 2016. FIG5. Sum of hours for wind speed (a) within the range 11-25m/s, (b) exceeding 25m/s for the period 4Dec2013 0000UTC to 7Dec2013 at 1200UTC at simulated by WRF model. FIG6. Avg wind power density (W/m2) for the period 5Dec2013 0600-1200UTC at (a) 100m and (b) 200m
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. mean 10m wind speed 04Dec2013 1800UTC to 07Dec2013 1200UTC for Europe & NE Atlantic Ocean -FIG4. wind speed 06Dec2013 0200UTC from CCLM model over Europe and NE Europe
ECMWF (20160316)	ECMWF (20160316), 201312 - Windstorm - Xaver/Bodil/Sven, North-western Europe https://confluence.ecmwf.int/pages/viewpage.action?pageId=28315390 -FIG1. [MAP] The figures above show analyses of MSLP and Eady index from 04Dec 0000UTC to 06Dec 0000UTC every 12h. The cyclone developed south of Iceland after 1200UTC on 4Dec in a confluent flow of high vorticity.
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. -FIG5. [TIMESERIES] Time series of sea level elevation (SLE) in (m) at four coast stations of the German Bight (ST1-ST4). Black line is tide gauge observations, red is coupled wave-circulation model (WAM-GETM) & green is circulation-only model (GETM), Storm Xaver 2013 -FIG6. [MAP] Sea level elevation (SLE) difference (cm) between the coupled wave circulation model (WAM-GETM) and circulation only model (GETM) for the German Bight on 3Dec2013 at 0100UTC and during Storm Xaver 6Dec2013 at 0100UTC.
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 -FIG3. Meteorological situation during Xaver: (a) DWD 10min wind speed & direction Dec5 1800UTC, (b) sea level pressure on 05Dec2013 1800UTC; (c) DWD 10min wind speed & direction 06Dec2013 0300UTC, (d) sea level pressure 06Dec2013 0300UTC; (e) DWD 10min wind speed & direction 06Dec2013 0700UTC, (f) sea level pressure 06Dec2013 0700UTC [wind jet S coast Norway] -FIG11. Maximum surge over 4 different tidal periods T1-T4
Staneva et al (2017b)	Staneva J, C Schrum, A Behrens, S Grayek, 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 Eigth EuroGOOS International Conference (Operational Oceanography. Serving Sustainable Marine Development), 3-5 October 2017, Bergen, Norway, 2017b. -FIG5. (left) Maximum surge difference in m during storm Xaver between coupled and NEMO model,
Cheliotis (2017)	Cheliotis, I, G. Varlas, K. Christakos, The impact of cylone 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 FIG2. [MAP] (a) Domain of the simulation with orography (m) along with the mean sea level pressure track of cyclone Xaver as simulated by the WRF model (b) Accumulated precipitation (mm) simulated by WRF for the period 4Dec 06:00UTC to 7 Dec 06:00UTC with particular observations.
Jensen et al (2017)	Jensen J, S Niehuser, A Arns, S Dangendorf, Sensor- und risikobasiertes Fruhwarn-system fuer Seedeiche (EarlyDike), AP1 - Sturmflutmonitoring und Sturmflutssimulator - Fachbericht 2016, Siegen, April 2017 -FIG1.1. Map of surface wind and pressure field to drive wave model at 06Dec2013 00:00
Staneva et al (2017)	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. [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 signficant 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] -omparison of wind speed and sea level pressure for COSMO-REA6, ERA5, ERA-Interim, 20CRv2c
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 wisnd 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. https://www.bodc.ac.uk/about/news_and_events/storm_surge_and_coastal_flooding.html -UK Coastal Monitoring and Forecast Service: frequency of severe and extreme events predicted to increase in future due to onset of global climate change
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 airt>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 hotest 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 Haiyin 8Nov2013. Category 5 with max sustained wind 315kph. Storm surge 6m. 8000 people killed or missing.
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/sturmflutgefahr-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 Hurrican Lennart Jan 2013, last great storm surge before Storm Xaver -low storm surge activity 1950'-1960s; high activity 1970s-1980s and 2006—2008
AON Benfield (2014)	AON Benfield, Impact forecasting. December 2013 Global Catastrophe Recap, 2014. [document properties: 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 90years affected SE Brazil killing 48 people; 1.4bill USD -heavy snow & rain China; no fatalities; 90000 homeless from collapsed roofs; 410mill 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.i-iv -in last 100 years there were 10 warmer winters
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. -mention of flooding on Eble and Danube in June 2013
Knaack and Heyken (2014)	Knaack H and H Heyken, Xaver hatte sehr schwere Stumflut im Gepaeck, Jahresbericht 2013. Der Zukunft verplichtet, NLWKN, Niedersaechsischer Landesbetrieb fuer Waserwirtschaft, Kuesten- und Naturschutz, pp.8-9, document date stamp 24Apr2014. -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 11Mar2014] -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 Saulter, 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] -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, Deutsche Rueckversicherung Aktiengesellschaft, Hansaallee 177, 40549 Duesseldorf, www.deutscherueck.de [pdf document information: author=filiz; date stamp=07Aug2015] -unusual flooding in Germany and central Europe in June: Danube, Elbe, Saale -unusual thunderstorms and hail damage in August -heat wave in Europe in July -world wide temperature rank 6 of record since 1850; same as 2007 -for record since 2000, 2013 global temperatures were 13th of 14
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 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 westard 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 28Oct2013 -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, 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 -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 Laps, Dec. 2013 http://www.unwetterzentrale.de/uwz/928.html -new moon on 3Dec 2.5days before storm
Hewson et al (2014)	Hewson T, L Magnusson, O Breivik, F Prates, I Tsonevsky, HJW 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 occu two of three days after the moon is new or full'
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. WL Rapporten, 00-119, Waterbouwkundig Laboratorium, Antwerpen, Belgie. October 2014, WL2014R00_119_5 [document date stamp: 15Oct2014; author= Deschamps, Maarten] -listing of high and low water levels at Antwerp showing spring tide during storm -spring tides about 2.5days after full and new moon; new moon on 2-3Dec2013
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=filiz; date stamp=07Aug2015] -coincidence of the storm surge with spring tide, 3 days after new/full moon
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. -surge peak and tidal maximum are not usually together in the UK -Xaver was anomaly: surge peak was shortly before tidal maximum
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). -Xaver arrival coincided with time of high tide
Wikipedia (20200502)	Wikipedia, Orkan Xaver, https://de.wikipedia.org/wiki/Orkan_Xaver (accessed 2 May 2020) -storm surge several days after new moon spring tide on 3Dec2013

Table S46. Tide analysis (arranged by year and then alphabetically)

Source	Full Reference and Notes
Gonnert et al (2004)	Gonnert G, K Isert, H Giese A Pluess, 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 Thumm, T Wahl, R Weisse, Der Meeresspiegelansteig. Ursachen, Tendezen, und Risikobwertung, 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 tide MThw for tide gauge Cuxhaven using annual avg (Gonnert et al 2007)
Goennert et al (2012)	Goennert G, B Gerkensmeier, J-M Mueller, Ermittlung des Sturmflutbemesungswasserstandes 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 Frierich, S Haeseler, C Lefebvre, Orkantief XAVER ueber Nordeuropea von 5. bis 7. Dezember 2013, Deutscher Wetterdienst DWD, Stand 30. Dezember 2013, 19pp. -MThw and MTnw indicated on diagrams for Husum, Norderney-Riffgat, Flensburg, Warnemuende, and Hamburg St. Pauli
Jensen et al. (2013)	Jensen J, S Niehuser, A Arns, S Dangendorf, Sensor- und risikobasiertes Fruhwarn-system fuer Seedeiche (EarlyDike), AP1 - Sturmflutmonitoring und Sturmflutssimulator - Fachbericht 2016, Siegen, April 2017 -tide components included in DTU10 model: M2, S2, N2 K2, K1, O1, P1, Q1, S1, M4 (shallow water tide)
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] -Doodson X0 filter used for sea level calculation -check of temporal drift of tidal components: M2,S2,N2,K1,O1 and Z0
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. -tidal components included in NEMO model: M2, S2, N2, K2, K1, O1, P1, Q1, M4 -inidividual 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 Suesser, 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 Annuziato, L Mendoza, M Becker, J Lillibridge, 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 (Pawlowicz 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 Oct 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/Poseidon Global Inversion Solution (TPXO): amplitude & phase of 13 harmonic constituents
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 -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'

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. -tide gauge reanalysis over 19 year cycles from 1949-2012

Table S47. Data filtering and discretization issues (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] -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, 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 -UK water level data stored at 15min intervals to overcome seiche and wave effects
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. -BODC 15min sampling interval chosen to remove seiches and waves
Thompson et al (2020)	Thompson F, E Renzl, 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 -Diflzijl had 1m observation overshoot at the height of the storm surge
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 Küste, 81, 301-348, 2014 -new empirical surge level prameterizations give modelled water levels good to 20cm of observations.
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. WL Rapporten, 00-119, Waterbouwkundig Laboratorium, Antwerpen, Belgie. 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 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 -model predicted surge level 35cm under true level for Hoek of Holland
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. -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 (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 -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. Bidlot, A North Sea-Baltic Sea Regional Coupled Models: Atmosphere, wind waves and ocean, in Proceedings of the Eigth 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 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
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 -RMSE at stations range from 0.13m (for Helgoland) to 0.20m (for Husum) -maximum surge model prediction differnces: 78cm for Wyk, 90cm for Husum & Emden, 27cm for Norderney
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)

Source	Full Reference and Notes
Goennert et al (2012)	Goennert G, B Gerkensmeier, J-M Mueller, Ermittlung des Sturmflutbemesungswasserstandes fuer den oeffentlichen Hochwasserschutz in Hamburg, Berichte des Landesbetriebes Strassen, Bruecken und Gewaesser Nr 12/2012. -large land subsidence in German Bight area (sea level rise about twice as great as UK)
The Lowestoft Journal (20131214)	The Lowestoft Journal, Suffolk MP hits out at environment secretary in statement about the floods, 14Dec2013, correspondent: Annabelle Dickson. -MP Peter Aldous says that North Sea storm surges will be more frequent with future sea level rise
ABPmer (2014)	ABPmer, Ensuring Flood Resilience. An overview of the 5/6 December 2013, Associated British Ports, Marine Environmental Research, July, 2014 -UK Climate Projections Report (2009): 'climate change is expected to increase the likelihood of flooding in the future through mean sea level rise and higher river flows' -IPCC2013: 'sea level rise may accelerate coastal erosion and the deterioration of coastal flood defences…'
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] -sea level rise taken into account for assessing 1 in 1000y standard for Thames Barrier
Slingo et al (2014)	Slingo J, S Belcher, A Scaife, M McCarthy, A Saulter, 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] -sea level along English Channel has risen by 12cm during 20th century; further increases 11-16cm expected in period 1990-2030 -'clearly sea level rise from whatever source has to be factored into discussions about resilience to coastal and river inundations'
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 -'the return period for the 1953 surge component at Lowestoft is estimated to be around 50 years, although rising sea level will likely reduce the return period in coming decades' -'Between 1920 and 2012 the Newlyn annual mean sea level rose by 15.2 cm, and by 20.6 cm at North Shields' -Julia Slingo: 'it is uncertain whether these coastal flood events can be attributed directly to climate change' (Slingo, 2014)
Haigh and Bradshaw (2015)	Haigh I and E Bradshaw, A century of UK coastal flooding, Planet Earth, Winter 2015, (pdf document properties: 13Jan2016) -'… risks that will increase over the coming century as sea levels rise and coastal populations continue to grow'
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 -"for future planning, adaptive coastal management strategies need to cope with the progressive acceleration in sea level rise as well as less predicatable impacts of large storms or phases of enhanced storminess'
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. -corrections of sea level to 2008 in calculation of surge return period -sea level rise global 1.8mm/year; also for stations Llandudno, Liverpool, Heysham, Lowestoft; Newlyn -satellite derived sea level rise 3 mm/year from 1990s
Brooks et al (2016)	Brooks SM, T Spencer, A McIvor, I Moller, Reconstructing and understanding the impacts of storms and surges, southern North Sea, Earth Surface Processes and Landforms, 41, 855-864, 2016. -data from Wahl et al (2013) indicates recent acceleration of sea levl rise at Lowestoft; signficant increase in coastline retreat through remainder of 21st century -Horsburgh and Lowe (2013): future climate change will not lead to higher storm extremes; only increase in still water levels to take into account
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 -increase in design water level for stations in Lower Saxony greater than 20th century sea level rise -NOTE: subtraction of 1 year running sea level average to remove long-term trends.
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. -sea lel rise Germany Bight 1949-2012 15-20cm; almost twice as fast as UK number
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 -future sea level rise and flooding threat to Thyboron in Denmark -map of glacial isostatic uplift for Denmark -long term tide gauge records for Thyboron show sea level rise effects
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 -'With ongoing sea level rise, an accumulation of such events can be expected by the end of the 21st century'
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 going to be a thing of the future and we do need to be looking at protecting the most vulnerable areas.'

Table S50. Storm event as manifestation of climate change (arranged by year and then alphabetically)

Source	Full Reference and Notes
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. -'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 increas in the future over several European regons such as Northern Germany'... southern Germany with decrease in storm speeds
Slingo et al (2014)	Slingo J, S Belcher, A Scaife, M McCarthy, A Saulter, 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] -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 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 Titley, 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 Daemmen, Deichen und Stauanlagen: Handbuch fuer Theorie und Praxis (Vol V pp3-21). Siegen: Universitaet 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 going 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 fatalies 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 tfatal traffic accident in N Poland; Poland LOT airline cancels flights.
Deutschlander et al (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. -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 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. -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 Savert and Stefan Laps, Dec. 2013 http://www.unwetterzentrale.de/uwz/928.html -vegetation damage; numerous trees down -gusts and snowfall accumulations for the German Baltic Sea region.
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 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. -meteorological conditions at FINO1.
Pelt (2014)	Pelt AS, BODIL's stormflod 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 (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 -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 Suesser, 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] -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
Gierlevsen et al (2015)	Gierlevsen 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 -Arkona wind speed and direction
Christakos et al (2016)	Christakos K, I Cheliotis, G Varlas, G-J Steeneveld, Offshore wind energy analysis of Cyclone Xaver over North Europe, 13th Deep Sea Offshore Wind R&D Conference, EERA DeepWind'2016, 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), Sicherung von Daemmen, Deichen und Stauanlagen: Handbuch fuer Theorie und Praxis (Vol V pp3-21). Siegen: Universitaet Siegen, 2016 -inner Danish seas: flooding of houses; highest ever water levels at Hornbaek & Copenhagen (series 1890-2015)
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 -impacts of storm Xaver in Poland
Ditlevsen et al. (2018)	Ditlevsen C, MM Ramos, C Sorensen, UR Ciocan, T Pionkowitz, Hojvandsstatistikker 2017, Miljo- og Foedevaremnisteriet, Kystdirektoratet, Lemvig, Februar, 2018 -ranked tide gauge storm levels for both the North Sea and Baltic
Rucinska (2019)	Rucinska 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 (20200124)	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 Schleimuendung -Badewanneeffekt 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 Reussner) https://www.shz.de/lokales/sylter-rundschau/xaver-knabberte-sylt-massiv-an-id5098481.html -Sylt west coast dune loss during Xaver will be partially replaced by natural wind action -bad erosion damge at Hoernum Odde will not recover by wind action -provisional repair to concrete place armour at List Moevenberg Dike.
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 Stumflut im Gepaeck, Jahresbericht 2013. Der Zukunft verplichtet, NLWKN, Niedersaechsischer Landesbetrieb fuer Waserwirtschaft, Kuesten- und Naturschutz, pp.8-9, document date stamp 24Apr2014. * -response: summer 2014: 2.5million Euro & 180000 m3 sand for strengthening dune collapses after Xaver
NOZ (20140129)	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-fur-juist-spiekeroog-und-wangerooge-1 -Ostfriesen island dunes to be strengthened by additional sand summer 2014 -exact sand amounts for Juist, Wangeroog, Spiekeroog -sand-catching 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

Vanmassenhove (2015)	Vanmassenhove, Niels, Storm surge measures ports Flemish coast, Blankenberge, Tuesday February 3rd, Maritieme Sientverlening en Kust, Coastal Division, Flanders Hydraulic Research.[document properties: title=Geintegreerd Kustveiligheidsplan; author=Maarten; datestamp=27/02/2015] -photos of new surge wall protection Ostend -schematics of proposed quayside protection Zeebrugge -map of coastal protection strategies Belgian coast: storm return wall/barrier, stilling wave basin, beach nourishment, dune nourishment.
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. -new 30 million GBP from Suffolk County Council for major flood defence program Lowestoft
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 modified existing design criteria
Soresent 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 -upward revision of 100y water level estimate including Storm Xaver event
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 -between 1958-2005 stat extreme water return period increased from 1.73 to 1.99m DVR90 -Thyboron harbour is flooded at 1.80m threshold
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/bostonbarriertwao/ -supporting document for construction of Boston surge defence barrier
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 -8 million GBP project for refurbishment of Cromer sea defences winter 2013-2014 and 2014-2015; no work in summer or holidays.
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 -Black Swan risk -Project Extremeness -assessment of highest possible storm tide.
BAM (2019)	BAM, Safe arrival of Boston Barrier for tidal flood alleviation scheme, 15Nov2019 11:51, BAM Nuttall Ltd, https://www.bam.com/en/press/press-releases/2019/11/safe-arrival-of-boston-barrier-for-tidal-flood-alleviation-scheme -new Boston Barrier to provide level of flood protection second only to London -new barrier intended to prevent repeat of flooding during Storm Xaver Dec 2013
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 -repair of Sheringham sea defences by engineering firms Mott MacDonald and BAM Nuttall -Council to do reports to sea defences on section of coast between Weybourne and Happisburgh

Table S53. Worst case storm surge situation (arranged by year and then alphabetically)

Source	Full Reference and Notes
Cruz and Krausmann (2008)	Cruz AM and E Krausmann, Damage to offshore oil and gas facilities following hurricanes Katrina and Rita: An 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 A, A Oost, Memo: Regionale advisering Ameland Noordwest, Deltares, 1209381-008-ZKS-0008, 43pp, 18Dec2014 [PDF document properties: titl=Regional advisering: 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, 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] -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-

(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
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
Luecht and Peters (2014)	Luecht, Fabian and Ove Peters, Bericht ueber die Sturmflut vom 05.-0.6.12.2013 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] -itemized cost of repairs and cleanup for Schleswig-Holstein
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 Suesser, 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] -insured storm damage in Germany less than Hurricane Christian; estimated at 100-200 million EU -insured damage across Europe 759 million EUR
Matelski (2016)	Matelski, Birgit, Erfahrungen aus der Sturmflut Xaver von 5. und 6.12.2013 und dem Weihnachshochwasser 2014 in Schleswig-Holstein, IWASA 2016 Tagungsbeitrag, (46. IWASA, 7-8 Januar 2016; Internationales Wasserbau-Symposium Aachen. [pdf document properties: autor=sonja; datestamp: 26Apr2016] -3.4 million EUR damage cost for Schleswig-Holstein: clearing Treibsel, fising broken deckwork, wave break lengthening
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] -Economics and business -Europe total loss =1.22-1.65 bill GBP (Zurich 2014) -Europe total insured loss=0.662 billion GBP (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)

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, 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). -SARAL/AltiKa data: http://aviso.altimetry.fr, -RADS data: http://rads.tudelft.nl, GPOD data: https://gpod.eo.esa.in -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/de/Meeresdaten/Beobachtungen/MARNET-Messnetz/index.jsp

	-BSH mooring data: http://www.bsh.de/en/Marine_data/Observations/Marine_physical_data/moorings.jsp -Model output of the pre-operational models: http://codm.hzg.de/codm/

Table S56. Context and background information where Storm Xaver not mentioned (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. -10000 year return period design standard for Thames Barrier
Sanders and Gyakum (1980)	Sanders F and JR Gyakum, Synoptic-dynamic climatology of the 'Bomb', MWR, 108, 1589-1606, 1980 -explamation of meteorological bomb
Stull (1988)	Stull, R.B.: An Introduction to Boundary Layer Meteorology, Kluwer Academic Publishers, Dordrecht, 1988.
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. -extensive damage to 3 large wind farms near Porbandar during Gujarat cyclone of June 1998 -recurrence interval of extreme events and design guidelines -accidental loading -free-wheeling and turbine tower collapse -loading depends on quadratic of wind speed
Mueller-Navarra et al (2003)	Mueller-Navarra SH, W Lang, S Dick, KC Soetje, Ueber de Verfahren der Wasserstands- und Stormflutvorhersage. Hydrodynamisch-numerische Modelle der Nord- und Ostsee und ein empirisch-statistisches Verfahren fuer die Deutsche Bucht, promet. Jahrg. 29, Nr 1-4, 117-124, June 2003 -explanation of German tide gauge analysis procedures and water level reporting conventions.
Ishihara et al (2005)	Ishihara T, Tamaguchi, A, Takahara K, Mekaru T, Matsuura S, An analysis of damaged wind turbines by Typhoon Maemi in 2003, The sixth Asia-Pacific Conference on Wind Engineering (APCWE-VI), Seoul, Korea, September 12-14, 2005 -wind farm damage due to typhoon
Rosenthal and Lehner (2007)	Rosenthal, W. and S. Lehner, Individual wave height from SAR, Proc. 'Envisat Symposium 2007', Montreux, Switzerland, 23-27 April 2007 (ESA SF-636, July 2007) https://www.semanticscholar.org/paper/INDIVIDUAL-WAVE-HEIGHT-FROM-SAR-Rosenthal-Lehner/affabe337b05276112fca662375ec8a8b4bba4a6 -return periods for extreme indivual waves >20m predicted to be 40y from Rayleigh distribution; 11y time separation between Alfried Krupp accident 1Jan1995 and FINO1 wave 1Nov2006 means return period for extreme waves in German Bight should be reconsidered.
Lenton et al (2008)	Lenton TM, H Held, E Kiegler, JW Hall, W Lucht, S Rahmstorf, HJ Schellnhuber, Tipping elements in the Earth's climate system, PNAS, 105, 1786-1793, 2008 www.pnas.org/cgi/doi/10.1073/pnas.0705414105
Wilhelmi and Barjenbruch (2008)	Wilhelmi J and U Barjenbruch, 2008, Application of radar gauges to measure the water level and the state of the sea Proceedings of 31st international conference on coastal engineering, Hamburg, Germany -background information on the BAFG radar water level gauges at Borkum Suedstrand, Leuchtturm Alte Weser, and FINO1
De Jong (2012)	de Jong, Matthijs S, Developing a parametric model for storm to determine the extreme surge level at the Dutch coast, Delft University of Technology, June, 2012 -10000 year return period design standard for Netherlands coastal defence from 1960s Delta Committee report
Diamond (2012)	Diamond KE, Extreme weather impacts on offshore wind turbines: Lessons learned, Natural Resources and Environment, 27, fall, pp.1-5, 2012. -failed grouting connection on 80% offshore wind turbines -shifting seabed and sand waves; exposed cables -black-swan hurricane with climate change -cases of blade throw for onshore turbines -offshore turbines only designed to withstand Category 1 hurricanes; economics of replacement
Goennert et al (2012)	Goennert G, B Gerkensmeier, J-M Mueller, Ermittlung des Sturmflutbemesungswasserstandes fuer den oeffentlichen Hochwasserschutz in Hamburg, Berichte des Landesbetriebes Strassen, Bruecken und Gewaesser Nr 12/2012. -storm surge flooding protection level around North Sea -background for MThw skew surge convention in Germany -list of past strom trajectories giveing storm surge floods in the German Bight -storm trajectory types: Scandinavian type, Skagerrak type, Jutland type. -North Sea tide phase map with amphidromic points shown -importance of extermal surge for storm surge levels in German Bight -large land subsidence in German Bight area
Rose et al (2012)	Rose S, P Jaramillo, MJ Small, I Grossmann, J Apt, Quantifying the hurricane risk to the offshore wind turbines, PNAS, 109, 1-6, 2012. -probabilistic model of turbine buckling for offshore turbines on US Atlantic coast and Gulf of Mexico -Hurricane Katrina (2006) -wind farm Okinawa Japan during Typoon Maemi -wind farm China during Typhoon Dujuan
Li et al (2013)	Li Z-q, Chen S-j, Ma H, Feng T, Design defect of wind turbine operating in typhoon activity zone, Engineering Failure Analysis, 27, 165-172, 2013. -Typhoon Saomai 10Aug2006 damaged 17turbines including 6 cases of turbine collapse -most tower collapses due to failure at base of tower -important to have secondary power backup to maintain yawing system. -twisting resonance and blade failure
4Coffshore (20151203)	4Coffshore, Samso turbine collapse, Dec.03, 2015 -nacelle breaks off turbine 7 of 9 turbine array at Paludans Flak offshore wind farm 28Nov2015 0940Z
4Coffshore (20151215)	4Coffshore, Samso turbine collapse due to welding crack, Dec.15, 2015 -offshore wind turbine accident due to welding crack

Chen and Xu (2016)	Chen X and J-Z Xu, Structural failure analysis of wind turbines impacted by super typhoon Usagi, Engineering Failure Analysis, 60, 391-404, 2016 -China onshore wind farm damage during Super typhoon Usagi 16Sep2013
Gosselin (2018)	Gosselin, P., Massive damage ... Large Scale Engineering debacle threatens as North Sea wind turbine breaks apart, 27April2018 https://notrickszone.com/2018/04/27/massive-damage-large-scale-engineering-debacle-threatens-as-north-sea-wind-turbine-breaks-apart/ -turbine housing breaks off Adwen 5MW turbine at Alpha Ventus -Adwen's 126 5MW turbine fleet suspends operations -connecting bolts fatigue failure/corrosion or undersized -possible start of problems at North Sea offshore wind farms
Wind Action (20180425)	Wind Action, Massive damage in the wind farm - cause unclear, NDR.de, Christina Gerlach, 25Apr2018 http://www.windaction.org/posts/48258-massive-damage-in-the-wind-farm-cause-unclear#.XsD_dDl7nIU -possible corrosion damage at AV07 turbine leads to nacelle cover in early April 2018 -prohibited access to same turbine type at Alpha Ventus and 2 other Geman Bight wind farms
Buchana and McSharry (2019)	Buchana P, PR McSharry, Windstorm risk assessment for offshore wind farms in the North Sea, Wind Energy, 22, 1219-1229, 2019 -calculation of number of buckled North Sea wind turbine towers in each offshore wind farm over a 20 year period from extreme European windstorms database.

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 pa Gronland og I Torshavn pa faeroerne, 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, Faeroerne og Nuuk, Groenland - with English translations, DMI, Transport- og Energiministeriet, www.dmi.dk/dmi/tr07-01, 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; 5th 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
Eden (2007)	Eden, P., Weather log, November, 2006, Weather Magazine, 62, i-iv, 2007. -weather log for Nov.2006 -new temperature record autumn quarter, CET=12.6C, 0.8C over previous records 1730,1731 -new sunshine records in central & eastern England
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, Efterarsvejret 2006 (SON autumn quarter summary), 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 Nov1-2 only two cold days; wind blast at Gillileje 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.-0.6.12.2013 an der Westkueste Schleswig-

(2014)	Holsteins, Landesbetrieb fuer Kuestenschutz, Nationalpark und Meeresschutz Schleswig-Holstein, Husum 26Feb2014, 19pp. [pdf document properties: title=Lfd; Author=Thorsten Nommensen; datestamp: 11Dec2018] -typo on p.10, section 3.6.4. year of storm Xaver erroneously reported as 2012 instead of 2013
Fischer et al. (2015)	Fischer, JG, C Senet, A Schneehorst, O Outzen, 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] -data table showing height range of waverider measurements at +/-20m; limitation only for telemetered data -unclear if ADCP should have upper limits to wave period measurements

Table S59. Abbreviations used in manuscript (arranged by year and then alphabetically)

Abbreviation	Full name
BAFG	Bundesanstalt für Gewässerkunde
BSH	Bundesamt für Seeschifffahrt und Hydrolographie
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 Redding Maatschappij
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	Affilation
Beswick, Mark	Met Office National Meteorological Archive
Bluemel, Maria	Landesbetrieb für Küstenschutz, Nationalpark und Meereschutz Schleswig-Holstein (LKN-SH)
Dhoop, Thomas	Channel Coast Observatory (CCO
Eecen, Peter J.	ECN
Egset, Cathrine Netland	MIROS
Fijnaut, Charlotte	Koninklijk 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
Huess, Vibeke	Danish Meteorological Institute (DMI)
McKenny, Collette	JBA Risk Management Limited
Murphy, Aidan	Met Éireann
Pearce, Chris	Associated British Ports Marine Environmental Research (APB MER)
Schaap, Wendy	Noordzeewind
Skaland, Reidun Gangstø	Met.no
Snaith, 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 Redding Maatschappij (KNRM)
Wilhelmi, Jens	Bundesanstalt für Gewässerkunde (BAFG)
Zijderveld, Annette	Rijkswaterstaat (RWS)

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4Coffshore, Samso turbine collapse, Dec.03, 2015

4Coffshore, Samso turbine collapse due to welding crack, Dec.15, 2015

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

Aftenposten, Varsler full storm I Sor-Norge, 5Dec2013 15:03 (correspondent Per Annar Holm) https://www.aftenposten.no/norge/i/bKEjl/varsler-full-storm-i-soer-norge

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)

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

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Badewien T., Long-term observatory @ Pile Spiekeroog ICBM,COSYNA Progress Report 2013, p24. Helmholtz-Zentrum Geesthacht, June 2014

BAM, Safe arrival of Boston Barrier for tidal flood alleviation scheme, 15Nov2019 11:51, BAM Nuttall Ltd, https://www.bam.com/en/press/press-releases/2019/11/safe-arrival-of-boston-barrier-for-tidal-flood-alleviation-scheme

Bancroft, George P, Marine Weather Review - North Atlantic Area, September through December, Mariners Weather Log, volume 58, No.1, April 2014, pp.33-40

BBC, Workers off Talisman Sinopec oil platform Buchan Alpha over bad weather forecast,04Dec2013

BBC, In pictures: Winter storm hits UK, 5 December 2013, https://www.bbc.com/news/uk-scotland-25231224

BBC, Deadly storm and tidal surge batter northern Europe, BBC 6 Dec2013 (report by Anna Holligan)

BFG, Orkan Xaver: BfG beobachtet extreme Wellen in der Nordsee (06.12.2013)

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

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

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

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

Brooks, SM, T Spencer, EK Christie, Storm impacts and shoreline recovery: Mechanisms and controls in the southern North Sea, Geomorphology, 283, 48-60, 2017.

BSH, Die Nordseesturmfluten von 5. und 6.12.2013, 3pp, prepared by Stockmann,K. (title: Sturmflut 2011_bm1101; author stamp: bm1101; document time stamp: 12/102013 12:5136PM)

BT, Offer for Bodil: Koebte huset 15.august - nu er det vaek, 08Dec2013, 16:44, (contributor: Morten Eggert) https://www.bt.dk/danmark/offer-for-bodil-koebte-huset-15.-august-nu-er-det-vaek

Buchana P, PR McSharry, Windstorm risk assessment for offshore wind farms in the North Sea, Wind Energy, 22, 1219-1229, 2019

Caithness Windfarm, craigdr, Detailed accidents to 31 December 2015. Document time stamp 5Jan2016, 175pp

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Cappelen, J., Teknisk rapport 07-01, Danmarks klima 2006 med Torshavn, Faeroerne og Nuuk, Groenland - with English translations, DMI, Transport- og Energiministeriet, www.dmi.dk/dmi/tr07-01, Kobenhavn, 2007b.

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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.

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]

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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 that catalogues 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.

Referee 2 comment

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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