Storminess in the Low Countries, 1390–1725

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ABSTRACT

This paper looks into the historic storms of coastal Flanders and the south-western part of the Netherlands between 1390 and 1725. High quality information about these weather extremes has been retrieved from administrative documents concerning the annual maintenance of sea walls. Because the period under study deals with non-instrumental storm data, a method has been applied to assess this information, from which a picture emerges of annual storminess and of changing storminess throughout this long time period. Thus, periods of increasing and declining storm frequency can be distinguished. These fluctuations are compared with the storminess of the present period and some consideration is also given to possible links between historic storm frequency and temperature. Finally, attention is paid to the second decade of the eighteenth century, with its unusually high number of gales, and options for further research are explored.

KEYWORDS

Weather extremes, storminess, proxy data, flooding events, coastal defence, Low Countries, Little Ice Age, historical climatology

INTRODUCTION

This paper discusses storminess in the coastal areas of the south-west Netherlands and Flanders between 1390 and 1725. The study of storms is of particular interest, because these weather extremes can cause huge damage; today this is covered by insurance, but in the past it was not. Until half a century ago storm surges usually led to the flooding of vast areas, the loss of livestock, the destruction of buildings and many casualties. The sixteenth century is notorious for the large number of storm surges, of which the floods

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of 1509 and 1511 were the first two. In order to discover whether this was a period of unusual storminess, storm events over a much longer time period have been reconstructed, to help identify possible storm patterns in space and time and even possible storm trajectories. Although the time period under consideration was a generally colder era than the preceding Medieval Warm Epoch, the Little Ice Age does show some variability in temperature. Therefore it could also be relevant to look for a relationship between variability in reconstructed temperature and a possible variability in storminess. The article goes on to explore how knowledge of past storminess can illuminate present climate change and can provide building blocks for a better understanding of storminess in the future. Finally, this paper looks at ways in which future research might extend the storm information in time and space.

ISSUES

There is a long-standing tradition of storm research in the Low Countries. In particular, the 1953 storm surge and flooding disaster boosted research into historic storms. This resulted in a three volume study of storm surges from 516 until 1700: analysing most of the available chronicles Gottschalk managed to distinguish between fact and fiction, establishing a time series of historic storm surges that had really occurred in the Belgian and Dutch coastal areas.[1] However, she did not believe it would be possible to quantify the impact of these weather extremes. In the United Kingdom Hubert Lamb compiled a listing of great storms that hit the British Isles.[2] On the one hand his study lacked a historian's critical knowledge of sources, and Lamb was far from comprehensive in identifying the great storms in each century: for the seventeenth century he only counted 19 storm events. On the other hand he successfully reconstructed synoptic maps of some of the great storms, such as the 1588 storm that dispersed the Spanish Armada and the 1703 storm that ravaged the British Isles. Moreover, he tried to lay down some criteria for assessing the impact of historic storms.[3]

Continuing research into historical weather data in the Netherlands carried out during recent decades has led to a compilation of annual weather information from the oldest known records up to the mid-eighteenth century.[4] This research, carried out by Jan Buisman, has resulted in five volumes containing numerous weather data covering a wide range of variables: many storm events

1. M.K.E. Gottschalk, *Storm Surges and River Floods in the Netherlands* (Assen: Van Gorcum, 1971–1977) 3 vols.
2. H.H. Lamb and Knud Frydendahl, *Historic Storms of the North Sea, British Isles and Northwestern Europe* (Cambridge: Cambridge University Press, 1991).
3. Lamb and Frydendahl, *Historic Storms of the North Sea*, pp. 7–8.
4. J. Buisman and A.F.V. van Engelen (eds.) *Duizend jaar weer, wind en water in de Lage Landen* (Franeker: Van Wijnen, 1995–2006) 5 vols.

occur among these data. As Buisman wrote his study for a broad audience, he did not further analyse his data; this part of the reconstruction was carried out by Van Engelen, who directed the volumes.[5] However, the latter's focus was mainly on the reconstruction of temperature, rather than of storminess through the centuries. In addition to this project, some studies of single events, or their impact and perception, have been published. The impact of the storm events of 1675–1676 has been studied for the small area of West Friesland. [6] Also, the storm surges of 1825 and 1916 have been studied for the Zuiderzee area and flooding events in the Dutch river area, but these studies mostly focus on impact and perception.[7] Another paper looked at the causes, impact and dating of a severe eighteenth century storm event that hit the Dutch coast.[8] A further paper compared the floods of 1682 and 1715 in the south-west Netherlands.[9] Finally, Petra van Dam has addressed the issue of an amphibious culture having developed in the Low Countries.[10]

A further step in storm research was made within the framework of the CLIWOC project. This project aimed at analysing ships' logs of the Netherlands, the UK, Spain and Portugal for the period from the mid-eighteenth century onwards. The focus of this research was to make the data available on the internet. Some additional case studies focusing on particular storm events or

5. A.F.V. van Engelen, J. Buisman and F. IJnsen, 'A Millennium of Weather, Winds and Water in the Low Countries', in P.D. Jones, A.E.J. Ogilvie, T.D. Davies and K.R. Briffa (eds.) *History and Climate. Memories of the Future?* (New York, Boston / Dordrecht / London / Moscow: Kluwer Academic Publishers / Plenum Publishers, 2001), pp. 101–125; M.V. Shabalova and A.F.V. van Engelen, 'Evaluation of a Reconstruction of Winter and Summer Temperatures in the Low Countries, AD 764–1998' *Climatic Change* **58** (2003): 219–242.

6. J. de Bruin and D. Aten, *Een gemene dijk? Verwikkelingen rond de dijkzorg in West-Friesland. De watersnood van 1675–1676* (Purmerend, 2004) 21[e] uitgave van de vrienden van de Hondsbosche, Kring voor Noord-Hollandse waterstaatsgeschiedenis.

7. M. de Roever, 'Watersnood in Waterland. Dijkdoorbraken van de Zuiderzee in 1825 en 1916,' *Jaarboek van het Centraal Bureau voor Genealogie* **64** (2010): 71–94. Some other research focuses on impact, especially flooding events in the river area: Toon Bosch, 'Changing Societies Produce Changing Rivers. Managing the Rhine in Germany and Holland in a Changing Environment 1770–1850', in T. Tvedt and R. Cooper (eds.) *A History of Water Series 2, Volume 2: Rivers and Society: From Early Civilizations to Modern Times* (London, 2010). The same author has developed a theory of how perception of large scale flooding has changed through time, in which the national Dutch state has played a major role. Leo Wessels and Toon Bosch (eds.) *Naties, staten en nationalisme. Europa vanaf circa 1800 tot heden* (Nijmegen, 2012).

8. F. Baart, M.A.J. Bakker, A. van Dongeren, C. den Heijer, S. van Heteren, M.W.J. Smit, M. van Koningsveld and A. Pool, 'Using 18th Century Storm-surge Data from the Dutch Coast to Improve the Confidence in Flood-risk Estimates'. *Natural Hazards and Earth System Sciences* **11** (2011): 2791–2801.

9. Adriaan M.J. de Kraker, 'Two Floods Compared. Perception of and Response to the 1682 and 1715 Flooding Disasters in the Low Countries', in Katrin Pfeifer (ed.) *Forces of Nature and Cultural Responses* (Dordrecht, Heidlberg, London, New York: Springer, 2013), pp.287–302

10. P.J.E.M. van Dam, *De amfibische cultuur. Een visie op watersnoodrampen* (Amsterdam, 2010).

periods have subsequently been published.[11] In addition, a more comprehensive study of ships' logs of the period 1685–1750 for the English Channel area has yielded some fine results concerning dominant wind directions and storm frequency throughout the period.[12] In England some significant recent work has been carried out on historic storms and flooding in the Thames Estuary, a study which goes back to the mid-thirteenth century,[13] while for Scotland historic storms have been reconstructed from 1500 onwards.[14] In Central Europe, and in particular the former German lands, older research usually focused on the long-term reconstruction of historic storms, or on single storm events.[15] More recent research on storms focuses on impact and perception of natural hazards, in which context Oberholzner's paper on hail-storms should be mentioned.[16]

Finally, the reconstruction of historic storms of the sixteenth century has been undertaken for the Belgian coast and the south-western part of the Netherlands (stretching from Dunkirk in France north as far as Goeree Overflakkee in the Netherlands), from which it has proved possible to develop a grading method to assess the magnitude of historic storms for the non-instrumental period of weather observation.[17] This research continues to build on the work carried

11. D. Wheeler, 'British Naval Logbooks from the Late Seventeenth Century: New Climatic Information from Old Sources'. *History of Meteorology* **2** (2005): 133–146. D. Wheeler, 'The Great Storm of November 1703: A New Look at the Seamens' Records'. *Weather* **58** (2003): 419–427. Gaston R. Demarée and Robert Muir-Wood, 'De Grote Storm van December 1703 in de Lage Landen – een stormachtige periode in de Spaanse Successieoorlog', in Adriaan M.J. de Kraker and Henny J. van der Windt (eds.) *Jaarboek voor Ecologische Geschiedenis 2008. Klimaat en atmosfeer in beweging* (special issue) (2008): 33–54.
12. D. Wheeler, R. Garcia-Herrera, C.W. Wilkinson and C. Ward, 'Atmospheric Circulation and Storminess derived from Royal Navy Logbooks: 1685 to 1750'. *Climatic Change* **101** (2010): 257–280.
13. J.A. Galloway, 'Storm Flooding, Coastal Defence and Land Use around the Thames Estuary and Tidal River c.1250–1450'. *Journal of Medieval History* **35** (2009): 171–188. J.A. Galloway and J. Potts, 'Marine Flooding in the Thames Estuary and Tidal River c.1250–1450: Impact and Response'. *Area* **39** (2007): 370–9.
14. K.R. Hickey, *Documentary Records of Coastal Storms in Scotland, AD 1500–1991.* Unpublished D.Phil, thesis (1997), Coventry University, UK; A. Dawson, L. Elliott, S. Noone, K. Hickey, T. Holt, P. Wadhams and I. Foster, 'Historical Storminess and Climate "see-saws" in the North Atlantic Region'. *Marine Geology* **210** (2004): 247–259.
15. I.B. Gram-Jensen, *Sea Floods. Contributions to the Climatic History of Denmark* (Kopenhagen, 1985). M. Jakubowski-Tiessen, *Sturmflut 1717. Die Bewältigung einer Naturkatastrophe in der Frühen Neuzeit* (München: R. Oldenbourg Verlag, 1992); D. Hagen, *Die jämmerliche Flut von 1717. Untersuchungen zu einer Karte des frühen 18. Jahrhunderts* (Oldenburg, 2005).
16. Frank Oberholzner, 'From an Act of God to an Insurable Risk: The Change in the Perception of Hailstorms and Thunderstorms since the Early Modern Period'. *Environment and History* **17** (2011): 133–152.
17. A.M.J. de Kraker, *Landschap uit balans. De invloed van de natuur, de economie en de politiek op de ontwikkeling van het landschap in de Vier Ambachten en het Land van Saeftinghe tussen 1488 en 1609* (Utrecht: Matrijs, 1997). A.M.J. de Kraker, 'A Method to Assess the Impact of High Tides, Storms and Storm Surges as Vital elements in Climatic History. The Case of Stormy Weather and Dikes in the Northern Part of Flanders, 1488 to 1609'. *Climatic Change*

out by Gottschalk and Lamb. While the former managed to compile a reliable overview of historic storm surges, she was not convinced that a grading method could be developed, while Lamb demonstrated which characteristics of historic storms were vital for a possible grading. He also demonstrated that synoptic weather during extreme events could be reconstructed and that from these maps the storm trajectories could be reconstructed. The present paper uses a grading method, and its first aim is to reconstruct storm trajectories. The second aim is to consider whether the data on historic storm events and the reconstruction of their frequency and trajectories across the centuries can be linked to variability of reconstructed temperature during the Little Ice Age. The third aim is to compare historic storm frequency with variability in storminess in the more recent period. Finally, this paper considers the possible use of the knowledge of historic storms for the modelling of future storm frequency and trajectories. This last object can only be achieved once there exists an extended database of storms throughout the period under consideration and extending beyond, either further back into the past or forwards into the present.

DATA

Research on historic storms and storminess for periods in which no instrumental records exist is seriously hampered and therefore needs to identify non-instrumental information or proxy data. This is the case for the period under study, which runs from 1390 to 1725. In the Low Countries, in particular in the coastal area of the Netherlands, the observation of wind started at the beginning of the eighteenth century at Bilderdam, near Amsterdam. This observatory was installed by the Rijnland Water Board, which wanted to know more about the damaging effect of storms upon the water level in Haarlemmermeer (*meer*: lake) south of Amsterdam. For other areas of the Low Countries there is no instrumental evidence from the early eighteenth century at all. The oldest reliable observations on wind and wind direction were carried out systematically by ships' stewards on commercial and naval ships and date from the late sixteenth century. Unfortunately these observations are outside the area discussed here. Moreover, weather observations recorded in ships' logs are usually about the weather on regular routes to and from the East Indies and Africa. As the ships were mostly underway, the observed weather conditions also relate to changing locations.[18] However, ships' logs do become of great

43 (1999): 287–303; A.M.J. de Kraker, 'Reconstruction of Storm Frequency in the North Sea Area of the Pre-industrial Period, 1400–1625 and the Connection with Reconstructed Time Series of Temperatures'. *History of Meteorology* **2** (2005): 51–69.

18. A.M.J. de Kraker, 'The Oldest Dutch Ship's Logs (1595–1610): their Interest for Climate History in General and Global Climatic Change in Particular', in T. Mikami (ed.) *Proceedings of the International Conference. Climate Change and Variability – Past, Present and Future*, Tokyo, 13–17 Sept. 1999. (Tokyo: Metropolitan University Tokyo, 1999), pp. 95–101.

interest if the information concerns one particular area, usually one of the busiest shipping routes, for which a large number of logs exist and which provide information that can be quantified.[19]

If such information is not available. data has to be retrieved from other documentary sources of a rather variable quality. Sometimes documents provide direct information on storms, usually in terms of the impact they have, but mostly they contain indirect observations, which are generally very inconsistent over time and space. Such non-measured observations are proxy data, which can be made use of if they are systematically processed; this can only be achieved if high quality data are available. Therefore a very strict selection of proxy data and of the kinds of documents they come from is the first major step in the process.

The data used in this paper come from historical records originating in coastal areas of the Low Countries that endure predominantly onshore storms, generally N, NW and W storms coming from the North Sea area. This coastal area comprises sections of the dunes of present-day Belgium together with islands situated in the province of Zealand and in the province of South Holland, both lying in the south-western Netherlands. Most of these islands were reclaimed salt marsh areas and, by building a network of dikes, small islands were joined into bigger ones. Each embanked section of land had its own dikes to maintain. Most of the dikes faced the western winds, some the northern winds and only a few the eastern winds, but all of them ran the risk of flooding during storm surges that occurred during high spring tides. In these coastal lands harbour towns also had to maintain their docks with piers and groynes and even sections of dikes; among these were Flushing, Biervliet, Oostende, Nieuwpoort and Sluice. The southernmost area is that of the town of Nieuwpoort, situated at 51° 9' N and 2° 50' E, while the northernmost area is that of the island of Goeree Overflakkee, situated at 51° 50' N and 2° 50' E. The vulnerable area extends about 90 km from the coast, the town of Antwerp being its most important urban centre.

Sea walls were built to protect the highly productive agricultural lands of the many embanked areas. Both dunes and dikes needed annual maintenance. Sand blown in the dunes had to be fixed by putting sods, straw mats or manure in vulnerable locations. Dikes were protected on the seaward side by sods and extra willow mats, but these could easily be washed out during rough weather. Usually repairs had to be carried out during the storm season (October–March) and twice per year the straw mats were renewed. Local communities that were protected by sea walls had water boards installed. These institutions kept annual records of the upkeep of their sea walls, among which the yearly accounts are of special interest. In these documents the water board accounted for the expense incurred in routine upkeep and the extra repairs in times of need. Usually they give a cause for any damage that had occurred,

19. Wheeler *et al.* 'Atmospheric Circulation and Storminess'.

Figure 1. Map of coastal Flanders and south-west Netherlands in the mid-sixteenth century by Christian sGrooten (section), reproduced courtesy of Royal Belgian Library Albert I, Brussels, Belgium. Numbers correspond with Table 1. Nieuwpoort is located south-west of Oostende (no. 3). On this map, vast areas had already been flooded by the storm surges of 1509, 1511, 1530, 1532 and 1552.

along with its exact location and date, and they regularly provide many additional details. The October 1472 storm event is just one of the many examples. On that day (20 October 1472 new style) a tempest and great flood occurred, causing damage to dikes at the far end of the Western Scheldt, while the harbours of Nieuwpoort and Oostende (Table 1, sections 2 and 3) also suffered severe damage.[20]

A second example is taken from the dike account of Den Bommelpolder (Goeree Overflakkee (Table 1, section 24)) which mentions a storm and high seas on 23 January 1610, causing damage to the sea wall.[21] This storm is not only confirmed by a dike account of a neighbouring polder, but also by dike accounts of polders at the far end of the estuary of the Western Scheldt[22] and

20. National Archives at Brussels (Belgium), Auditor's Office of Flanders, no. 36775 (Nieuwpoort town account, 1472–1473); no 37299 (Oostende town accounts 1472–1473); no. 27929 (Polder van Namen, manorial accounts, 1472–1473).

21. Regional Archives at Middelharnis (The Netherlands) Polder Den Bommel, no. 29 (1609–1610). With regard to the dating of storms, it should be noted that all of the old counties and duchies located in the study area (Holland, Zeeland, Flanders and Brabant) introduced the Gregorian calendar in 1582/3. Accordingly all earlier dates have been changed into the new style.

22. Regional Archives at Middelharnis (The Netherlands) Polder Noord, no. 23 (1610).

Table 1. Accounts of areas and towns providing information on historic storms, 1390–1725.

	areas / towns (Flanders)	**start**	**1390**	**1400**	**25**	**50**	**75**	**1500**	**25**	**50**	**75**	**1600**	**25**	**50**	**75**	**1700**
1	Domain East Flanders	1390														
2	Nieuwpoort (town)	1390														
3	Oostende (town)	1400														
4	Biervliet (town)	1400														
5	Vier Ambachten (dikes)	1460														
6	Nijspolder (dike)	1610														
7	Kruispolder (dike)	1610														
8	Walsoorden (dike)	1648														
	areas (Central Zealand)	**start**	**1390**	**1400**	**25**	**50**	**75**	**1500**	**25**	**50**	**75**	**1600**	**25**	**50**	**75**	**1700**
9	North Beveland	1600														
10	Poortvliet	1601														
11	Goessche Polder	1693														
12	Kruiningen	1690														
13	Scherpenisse	1632														
14	Ellewoutsdijk	1633														
15	St. Maartensdijk	1665														
	areas (North Brabant)	**start**	**1390**	**1400**	**25**	**50**	**75**	**1500**	**25**	**50**	**75**	**1600**	**25**	**50**	**75**	**1700**
16	Geertruidenberg	1641														
17	Dinteloord															
	areas (Goeree-Overflakkee)	**period archive**	**1390**	**1400**	**25**	**50**	**75**	**1500**	**25**	**50**	**75**	**1600**	**25**	**50**	**75**	**1700**
18	Oude polders at Oude-Tonge	1438–1858														
19	Noordpolder	1525–1717														
20	Oude polders at Middelharnis	1556–1890														
21	De polder Dirksland	1577–1920														
22	Oudeland van Ooltgensplaat	1586–1959														
23	De polder Galathee	1589–1857														
24	Oud- en Nieuw Westerloo & Nieuw Oostdijkpolder	1591–1956														

	areas (Goeree-Overflakkee)	period archive	1390	1400	25	50	75	1500	25	50	75	1600	25	50	75	1700
25	De polder Den Bommel	1594–1890														
26	De Weipolder	1594–1857														
27	De polder Klinkerland	1599–1933														
28	Den Grooten Blok / Battenoord	1599–1953														
29	Alteklein	1602–1857														
30	Molenpolder (Den Bommel)	1614–1956														
31	De Rooklaasplaat	1621–1956														
32	De Kruispolder	1626–1959														
33	Het Rietveld	1646–1959														
34	De Heerenpolder	1647–1953														
35	Den Nieuwen Blok	1652–1953														
36	De Suyspolder	1656-1890														
37	Roxenisse	1665-1919														
38	Oud-Kraaijer	1676-1919														
39	Polder Noordland at N-Tonge	1684-1890														
40	Diederik	1699-1959														
41	Committee Re-Embankment	1718-1737														
42	De Krammerpolder	1719-1953														

Complete coverage of the period

Part of period is missing or gaps

Dinteloord (Table 1, section 17) in north-west North Brabant.[23] This recording of a storm event in several sources relating to different locations is very helpful in determining both its date and spatial range. Commonly the documents merely mention the occurrence of storm events per winter season and sometimes only damage is recorded, which is generally a result of storminess. If an event was recorded at several locations, however, there is no doubt about the event having happened. Moreover the dating can be precise, and it may also be possible to reconstruct the spatial range. Thus in the Kruispolder (Table 1, section 31) on the island of Goeree Overflakke, a 'high flood' is mentioned as occurring during the winter of 1633–1634, but at neighbouring Den Bommel and Weijpolder (Table 1, sections 24 and 25) the exact date (18 January 1634) can be retrieved; moreover, the event is described as a 'storm and high flood'.[24] It becomes problematic if only a single source mentions a storm event, or just damage which sounds like it has been caused by storm. Thus at Poortvliet (Table 1, section 10) a storm seems to have caused significant damage during the winter season 1616–1617, but the event is not confirmed anywhere else.[25] Unfortunately there is no mention of a date and no description of the event is given, just that it caused heavy damage. In such cases it is likely that damage to dikes, or even the collapse of a dike, could have been caused by landslide on the seaward side.[26]

Information on storm events extracted from town accounts usually refers to the maintenance of sections of dike, piers, groynes and quay walls of their harbours. Some towns also maintained sections of the dunes; for example, during the first week of January 1407 strong winds blew pits in the piers, dunes and the dike at Oostende, while on 8 November 1410 (17 November 1410 n.s.) a lot of sand was again blown out.[27] At Christmas 1417 sand was blown out of the high dunes at Nieuwpoort.[28] During very severe storms public buildings were often damaged, especially their thatched roofs. From the town account of Biervliet (Table 1, section 4) special information is obtained on strong winds and drought during the long summer season. In Biervliet many people worked in salt refineries which had open fires beneath the pans in which salty water was evaporated. Consequently windy and dry weather conditions could be very dangerous, causing large-scale fires. The town hired men to watch over the fires for periods, the precise duration of which are recorded in the town

23. National Archives, The Hague (The Netherlands) Nassause Domeinraad, no. 11611 (Dinteloord manor, 1610).
24. Regional Archives Middelharnis (The Netherlands) Kruispolder no. 13 (1633–1634); Den Bommel no. 31 (1634–1635); Weijpolder no. 13 (1633–1634).
25. Zealand Archives, Middelburg (The Netherlands) Polder Poortvliet no. 82 (1616–1617).
26. de Kraker, *Landschap uit balans*, pp. 199–208.
27. National Archives, Brussels (Belgium) Auditor's Office of Flanders, no. 37242 (Oostende, 1406–1407); no 37246 (Oostende, 1409–1410).
28. National Archives, Brussels (Belgium) Auditor's Office of Flanders, no. 36720 (Nieuwpoort, 1417–1418).

Figure 2. Map of the south-western coastal area of the Netherlands by Johannes Blaeu (section), about 1640. Areas and other numbers correspond with Table 1. Geertruidenberg (no. 16), which is not on this map, is more to the east of Dinteloord (no. 17).

account. As salt making took place between April and October, recorded dry and windy episodes are typically summer weather events. For example from 12 until 19 July 1417 (21–28 July1417 n.s.) extra men had to supervise the town because of a major drought; unfortunately eight days later the big fire which they had hoped to prevent broke out.[29]

The major storm events stand out.[30] They are recorded in nearly all of the contemporary accounts. Analysing the consequences of those extreme events,

29. National Archives, Brussels (Belgium) Auditor's Office of Flanders, no. 32071 (Biervliet, 1417–1418).

30. A.A. Beekman, *'De Stormvloed van 13/14 januari'* in Zuiderzee-Vereeniging (ed.) *De Watervloed van 13-14 januari 1916.* (Leiden, no year); M. van der Staal, *Januari-vloed 1916*

which were usually flooding, and the very detailed information given, enables a lot to be said about their impact. As there have been many storm surges in the past, in particular in the sixteenth century, we can make comparisons and even assess their impact in terms of severity. If such events succeeded one another, contemporaries often made comparisons themselves. However, it can be hazardous to rely too heavily on such observations without knowing the full spatial and temporal context of these extreme events.

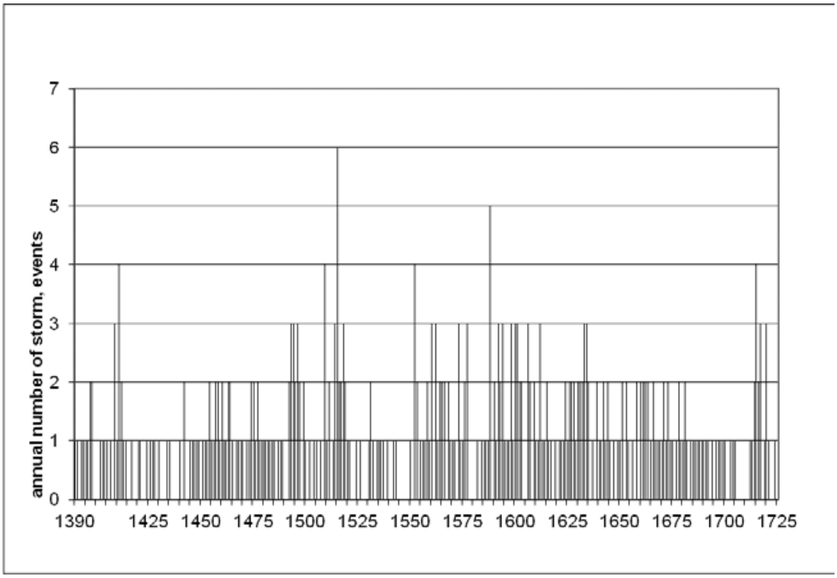
METHOD

Identifying storms and storm chronology

In order to obtain high quality data, the following requirements have to be met. The first is length: the data has to cover a long time span. The worst case here is a time span of just a few decades or even less, the best case is a time span of half a century or more, extending up to one or even two centuries duration. The longer the time period, the better fluctuations and storm patterns can be distinguished. A second requirement has to be met, which is *continuity*: if one year or another short period in the record is missing, it may have contained one or more storm events. Long but quite regularly interrupted series pose a problem that can only be dealt with by studying more than one time series. Therefore the third requirement is the availability of *parallel running series* that enable us to perform the necessary data control. In particular there is the need to cross check the less important storm events that have not made it into the chronicles, but are mentioned in the accounts of dike maintenance, of which the January 1610 storm event mentioned earlier is a good example. A fourth requirement that has to be met is the *homogeneity* of the documents from which the storm information is extracted. This implies that the information has to concern the same location and the same kind of coastal defences, maintained under similar circumstances and using similar hydraulic engineering techniques throughout the period under study. The documents used for the storm research all refer to small embanked areas having their own sea walls to maintain. There was no real change in dike maintenance between 1390 and 1725, in terms of base line, top level width or material used. The final requirement the information has to meet is *uniformity.* This implies that the administering of dike maintenance by both the local water boards and the towns needs to have been carried out subject to similar regulations throughout the period. Sometimes this can be problematic, depending on how much detail of storm events or damage has

(Rotterdam, 1916); Kees Slager, *De ramp. Een reconstructie van de watersnood van 1953* (Amsterdam/Antwerpen: Atlas, 2003); Gottschalk, *Storm Surges and River Flooding*; de Kraker, 'Reconstruction of Storm Frequency'; Adriaan M.J. de Kraker, 'Flood events in the southwestern Netherlands and coastal Belgium, 1400–1953'. *Hydrological Sciences-Journal* **51**/5 (2006): 913–930.

been recorded. The fifteenth and most of the sixteenth century town accounts are very informative because they include very detailed entries on expenditure. Thus, the town accounts of Nieuwpoort usually give a weekly survey of all the public works carried out, including the date and nature of the kind of work being done. Over the course of the sixteenth century the same town's accounts came to exclude most of the details, which from then onwards were recorded in separate documents, subsequently lost. Many dike accounts of the sixteenth and seventeenth centuries also record extra work being carried out after extreme weather events, and specify the date and nature of the repairs. Thanks to the many parallel-running series of accounts uncertainties can be resolved.



Graph 1. Annual number of storm events (N, NW, W, SW) and high tides in the coastal area of Belgium and the south-west Netherlands, 1390–1725, simple count per annum.

Having met the five requirements, an annual inventory of storm events or storm related events can be made. In order to assess the changes in storminess between 1390 and 1725 it would be very easy to stop here and simply count the storm events per year. The gales and storms plotted in Graph 1 are mainly N, NW, W, SW storms, because storms from other directions did not generally harm the coastal defences of the study area at all. Although the recorded storm events occurred between September and mid-April, which was the storm season, in Graph 1 the annual number of storm events is calculated from 1 January until 31 December. From this it is apparent that, on the one hand there are many years during which no storms of any importance could be identified, while, on the other, the number of storm events could mount up to four

(1570), five (1588) or even six storm events (1516) per year. So there are a very uneven number of storm events per year and also per period, which becomes clear if smoothing by means of an eleven year moving average is introduced. However, despite this variability over time, it is still not clear what the impact or magnitude of storminess at certain periods has really been.

Measuring storm intensity

Prior to 1800, historic storminess could not be measured in terms of wind speed, because no Beaufort Scale existed at the time.[31] Therefore a set of criteria is needed using all the information that can be extracted from the documentary evidence, both directly and indirectly, and comparing events. One of the criteria refers to the *terminology* used by contemporaries. Usually a 'great tempest of the sea' refers to a more serious storm event than a 'high tide' or merely 'seasonal winds'. Nevertheless, for the same storm event a variety of terms could still be used; therefore more criteria are needed. A second criterion is the *damage* inflicted on dikes, dunes, dams or piers of port towns, which could range from the removal of earth and sand to the large-scale flooding of an area. Usually the dike and town accounts are informative on this point, because all of the damage had to be repaired and paid for. A third criterion is the *duration* of a storm event. Usually storm surges lasted for two or even three successive high tides, causing water to be funneled to extra heights during the second or third high tide. The duration of a storm event therefore plays a vital role in storm surges. A fourth criterion that is closely connected with the previous one is the *highest level* water reached. This aspect is hard to assess, because the top level of dikes could vary between locations. Usually a dike tended to compact a bit, which commonly led to flooding during the big storm events. In such cases the top level was raised by at least one foot. It was only during storm surges that contemporaries started to compare the highest water levels reached. The 5 November 1530 (15 November 1530 n.s.) storm surge and flooding event provides a good example of this happening at Antwerp, because the level the water had reached during that storm surge was more than one foot higher than the previous flood, which must have been the 1511 or 1509 event.[32] A fifth criterion is the *spatial scale* of a single storm event. Although the flooding of just one polder was itself a serious matter, flooding in an area extending from Nieuwpoort as far north as Goeree was exceptionally severe.

Applying these criteria renders it possible to make a grading model. All information on wind that has contributed to the identification of a storm event can be assessed by giving it a grade, ranging from 1 to 8 (Table 2). A storm or storm-related event that is graded 1 needs to be mentioned in at least one

31. D. Wheeler and C. Wilkinson, 'From Calm to Storm: the Origins of the Beaufort Wind Scale' *Mar. Mirror* **90** (2004): 187–201.

32. National Library Albert I, Brussels, ms. II 1593 (pp. 5–6)

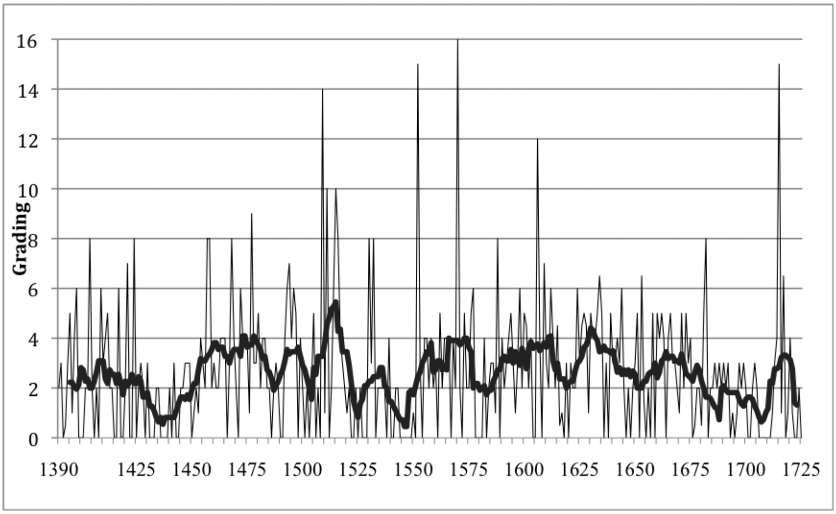
account. It might not necessarily have caused damage, but since it is mentioned it must have been unusual. A 2-graded storm event has caused damage and usually coincides with a strong wind and high tide. From 3 onwards the duration increases, the scale extends and the inflicted damage increases. The highest graded storm events are the big storm surges that have caused large-scale flooding in vast areas.

Table 2. Gradation of storm events

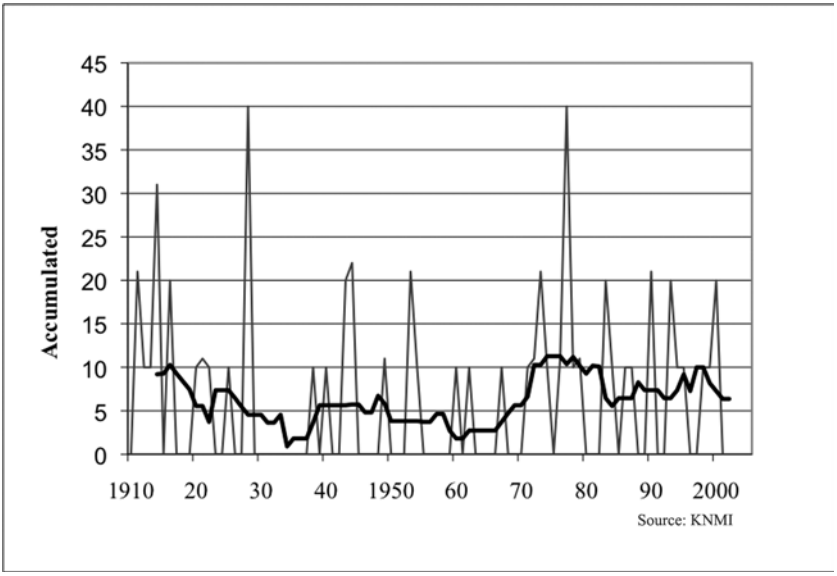
Value	Storm event	Consequences, spatial scale, duration…
1.	High tides	no damage, just mentioned once
2.	High tides	coinciding with storms, causing damage
3.	Storms	causing damage at several places at the same time
4.	Heavy storms	causing damage at several places
5.	Heavy gales	causing severe damage, even flooding
6.	Heavy gales	heavy and large-scale damage and flooding
7.	Storm surges	general and large-scale damage restricted to certain areas
8.	Storm surges	general and large-scale damage in wide areas

Applying the eight category gradation of storms, and adding together the values for individual storms to give an accumulated total value for each year, shows very sharp peaks for certain years (Graph 2). For instance, in 1552 at least four storm events are reported to have happened, resulting in an accumulated annual value of 15, of which the storm surge of 21 January on its own constituted an 8-graded event. In 1570 three storm events occurred, of which the All Saints Flood (11 November) was an 8-graded event, while the other two caused large-scale damage in the study area, producing a total value of 16 for the year. Between 1706 and 1711 no storms were reported, resulting in zero values for six continuous years. The next step is to calculate an eleven-years moving average which allows us to distinguish periods of increasing and decreasing storminess. Again the result is fluctuation throughout the period 1390–1725, but now the stormy periods are much more evident and again they do not necessarily coincide with the famous storm surge years.

The last step is to compare the pattern of fluctuating storminess which emerges from the period 1390–1725 with storm data from the recent era. From the period 1910–2005 severe storms and gales having a magnitude of Beaufort 10, 11 or 12 have been accurately recorded (Graph 3). From this it can be seen that there is significant annual variability of storminess even for the recent period. In 1914 there were three, in 1928 there were four gales of Beaufort 10, in 1977 again four and in 2003 there were again three gales of Beaufort 10. The years without such severe storms, in particular the time period 1929–1937, are

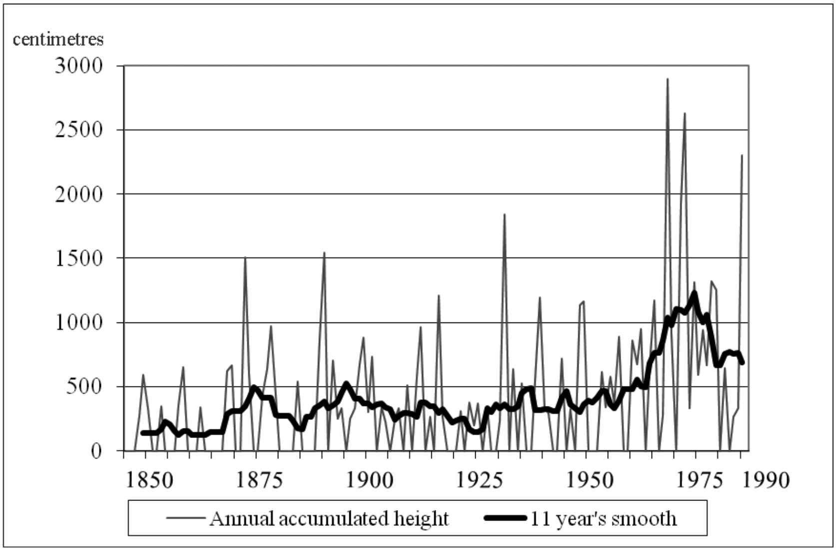


Graph 2. Storm events (N, NW, W and SW) and high tides in the coastal area of Belgium and the south-west Netherlands, 1390–1725, cumulative per annum, graded by severity. Annual values (thin line) and eleven-year moving average (heavy line).



Graph 3. Gales Beaufort 10–12 in the Netherlands, 1910–2005.
Annual accumulated values and eleven-year moving average.

striking too. Using an eleven-year moving average, a significant fluctuation in different shorter time periods again emerges. The first decade was rather stormy, the second period during the 1940s and 1950s shows an increase in storm frequency and then from the mid-seventies onwards storm frequency remains at a high level. Can these data on recent storms be used as a basis for comparison with the historic storms from 1390–1725? For two reasons they cannot. Firstly, storms of a magnitude Beaufort 8 and Beaufort 9 have not been included in Graph 3. A second problem is the spatial scale. The historic storms and high tides have all occurred in the south-west part of the Netherlands and are predominantly westerlies and northerlies. Recent easterly or southerly gales have not been damaging to coastal defences at all.



Graph 4. Annual accumulated height of water levels reached in the Western Scheldt (Flushing) during gales and storm surges, 1850–1990. Annual values and eleven-year moving average.

The other data set concerns high tides and storms from the Western Scheldt area that were observed at Flushing from 1850 to 1990 (Graph 4). It includes all the water levels from 2.00 m above National Ordnance Datum and higher. So in 1936 there were six such events (2.64, 3.24, 2.35, 3.22, 3.36 and 3.60 m NOD) totaling 18.41 m, while in 1973 there were as many as ten, totaling 28.99 m NOD. But during many years no such events occurred at all. Again, the annual variability is striking; likewise there is a slight fluctuation in shorter time periods, of which the 1970s stand out once more. Furthermore, there is a sharp peak in 1990 due to a Beaufort 10 and a Beaufort 11 gale, which, in terms of their duration and the damage they caused, must be assessed as very severe extremes. A comparison between graphs 3 and 4 suggests that only in the 1970s is there a significant correlation between high storm frequency and accumulated high water levels. However, comparing the modern era of storms and high tides with the historic period shows similarities in annual variability and the pattern of fluctuation between periods of higher and lower storm frequency.

DISCUSSION.

Looking at the historic storms that have been reconstructed for the period 1390–1725, the first striking thing is that several years have a score above 8 (Graph 2). So, 1404, 1509, 1511, 1552, 1570 and 1715 have been graded 8, 14, 10, 15, 16 and 15. Those years are notorious for both storm surges and other storms that caused damage. By contrast, in 1515/16 there were several lower-category storms which caused a lot of damage, resulting in a cumulative grading of 10.

The second striking feature concerns the periods of increasing storminess succeeded by relatively calm periods. The stormy periods are: the first quarter of the fifteenth century; about 1450–1485, the 1490s, about 1506–1520, the third quarter of the sixteenth century, about 1588–1613, about 1624–1640 and about 1660–1672; the last two time periods did not have storms that reached the status of a storm surge. After this storminess is low, except for the 1682 event, and again it is stormy during the second decade of the eighteenth century. While the sixteenth century stormy periods are mostly determined by the many storm surges, the seventeenth century highs generally reflect the large number of storm events that have not quite reached the status of storm surge. This might raise the question of whether all the smaller storms of the sixteenth century have been recorded in the documents? Judging from the large quantity of surviving dike and town accounts and copious additional correspondence of military chiefs, there can be little doubt about that. Therefore, there is hardly any noise in the sixteenth century information. Moreover, compared with the sixteenth century, there are three times as many dike accounts for the seventeenth century and yet they show a drop in storminess after 1682, followed by a sudden increase three decades later. Therefore noise is not a problem with the seventeenth century storm information either.

The second decade of the eighteenth century is remarkable. During this short time period a storm surge in March 1715 hit the coastal area, preceded by several other gales and followed by another two in the following two years (Table 3.).

Table 3. Storm events in the south-west Low Countries and German and Danish Wadden area, 1710–1720.

Belgian coast and south-western Netherlands						**Northern Germany (NG) and Denmark**		
Year	Date	Storm Event	Consequences	loc.	gr.	Date	Event/ location	Reference
1710		none	none	0	0	17 June	Flood (NG)	Jenssen (1985)
						26/27 Jul.	Flood (NG)	Jenssen (1985)
						21 Dec.	Flood (Randerup)	Jenssen (1985)
1711	28 Feb.	storm wind	Buildings damaged at Kortrijk	1	1			
						1 Nov.	Flood Heligoland	Jenssen (1985)
1712	19 April	big gale	Dikes damaged in Z. Flanders	1	2			
1713	5 Feb.	big gale/ high tides	Dikes damaged in Z. Flanders	2	2	Feb.	Gale (?) Eidersted	Jenssen (1985)
1714						8/9 Jan.	Flood: Randerup	Jenssen (1985)
	26 Feb.	big gale	Dikes damaged in Zealand and Z. Flanders	4	2	20 Feb.	Flood Denmark	Jenssen (1985)
	7 March	big gale	Dikes damaged in Zealand and Z. Flanders	6	2			
1715	12 Feb.	very windy	Light damage	1	2	13/14 Feb.	Flood: Randerup	Jenssen (1985)
	3 March	storm surge	Flooding in Zealand and N. Fl.	6	8	3/4 March	Damage: Randerup	Jenssen (1985)
	4 April	gale	Dikes damaged in Z. Flanders	3	2			
	24 Dec.	Blocking ice ?	Dike burst on GO	1	4			
1716	26 Sept.	gale (?)	Barges out of order at Veurne	1	1			
	26 Oct.	gale	Barges out of order at Veurne	1	1			
1717	4 Jan.	gale	Dikes damaged on GO	4	2			
	1 Sept.	gale	Flooding on GO	2	4			

continued…

Belgian coast and south-western Netherlands						**Northern Germany (NG) and Denmark**		
Year	Date	Storm Event	Consequences	loc.	gr.	Date	Event/ location	Reference
1717	24/25 Dec.	gale	Dikes damaged/flooding GO	5	4	24/25 Dec.	Flood (NG)	Jenssen (1985) Lamb (1991)
1718		none	none	0	0	25 Feb.	Flood: Schleswig	Jenssen (1985)
						10 Nov.	Flood: Elbe area	Jenssen (1985)
						10/18 Dec.	Flood: Ditmarshen	Jenssen (1985)
1719		none	none	0	0	25/27 May	Flood: Elbe area	Jenssen (1985)
						5 Aug.	Flood: Elbe area	Jenssen (1985)
						12 Nov.	Flood: Elbe area	Jenssen (1985)
1720	27 March	gale	Barges out of order at Veurne	1	1			
						18 July	Flood (?)	Jenssen (1985)
	8 Oct.	gale	Dikes damaged on GO	2	2			
	1 Dec.	very windy	Barges out of order at Veurne	2	1	31 Dec.	Flood: Schleswig	Jenssen (1985)

Loc.: location; gr.: grading

Right after the big storm surge on 3 March 1715 there was an outcry from many polder boards for assistance. The difficult situation was not caused by the severity of the storm surge as such, but by the battering of the local dikes by the many preceding gales; by March 1715, despite having been repaired, the dikes were still too brittle to withstand 'the big one'. An analysis of the storms of the second decade of the eighteenth century demonstrates that at least the 4 April 1715 storm can be directly connected to the New Moon and can therefore be assessed as being a storm surge too. On Christmas Eve 1717 the northern Netherlands and the neighbouring German coastal area were hit very badly by a storm surge. The damage of this extreme event was massive in terms of casualties and economic damage.[33] In the south-west Netherlands and adjacent coastal Belgium the storm surge was also felt, but there was less damage and there were no casualties. Only on the isles of Goeree Overflakkee were some polders flooded, largely the same as those hit in 1715. Comparing

33. Manfred Jacubowski-Tiessen, *Sturmflut 1717. Die Bewältigung einer Naturkatastrophe in der Frühen Neuzeit* (München: R. Oldenbourg Verlag, 1992).

the 1715 and 1717 flooding events in terms of material damage and casualties, the second stands out as the most disastrous. One reason for this is the time the disaster occurred: the Christmas disaster of 1717 happened at night and in the depth of the winter. Another reason could be that the polder areas of the south-western Netherlands were better protected against flooding and could deal with the flooding more efficiently than the German coastal area.[34] Moreover, from 1718 onwards the north German economy suffered for several years as a result of the Christmas disaster of 1717.[35]

Looking for connections between storm frequency and temperature is seriously hampered by the fact that there are no temperature reconstructions in the Low Countries based on instrumental measurements before the eighteenth century. Therefore, it would be better to look for the connection between periods of increasing storminess and the North Atlantic Oscillation. However, from this comparison a picture emerges that is too diverse to draw any conclusions, except that about half of the periods of increasing storminess coincide with a high NAO Index and about half of them with a low NAO Index. The reasons for this diverse picture could be that the reconstructions of the NAO Index themselves are too diverse to use as comparison, or that the area from which our storm information comes is too small to demonstrate a clear connection.[36] Besides, the wind flows from NE and E are not included, but this information is vital in order to draw robust conclusions about periods of possible blocking of the North Atlantic Oscillation from the west, which in turn could be held responsible for the coldness in particular of the last decade of the seventeenth century. During that decade, only three storm events occurred in the study area: 1 January 1690, 1 October 1697 (four recordings) and 25 November 1699 (four recordings).

Finally the question remains as to whether there are differences or similarities between the storminess of 1390–1725 and storminess of the most recent period of 1910–2005. For this recent period there is the problem that the data is not quite comparable with the historic storm information. The historic storm data refer predominantly to damage caused by northerlies and westerlies during the autumn/winter season, which usually ran from mid-September to early April. The recent period, by contrast, comprises all storms, including southern storms and easterlies, which generally were not damaging to coastal defences. Moreover, storms of less than magnitude 10 on the Beaufort Scale (even those

34. A.M.J. de Kraker, 'Sustainable Coastal Management, Past, Present and Future or How to Deal with the Tides'. *Water History* **3**/2 (June 2011): 145–164.

35. Marie Louse Allemeyer, "*Kein Land ohne Deich…!" Lebenswelten einer Küstengesellschaft in der Frühen Neuzeit* (Göttingen: Vandenhoeck & Ruprecht, 2006).

36. A.M.J. de Kraker, 'Stormachtig weer in de Lage Landen tussen 1400 en 1625. reconstructie van stormen langs de zuidoostelijke Noordzeekust, de wijze waarop hun invloed wordt bepaald en veranderingen in het stormpatroon', in Adriaan M.J. de Kraker and Henny J. van der Windt (eds.) *Jaarboek voor Ecologische Geschiedenis 2008. Klimaat en atmosfeer in beweging*: 1–33.

coinciding with a storm surge) have not been included in the recent time period either. Therefore comparisons between the historic period and the recent period can only be made in terms of annual variability and the alternation of periods with high and low storm frequency. Finally, there is a significant resemblance between the higher storm frequency of the 1970s and the historic period of the 1710s. Both periods are known to be decades preceded by a cold period; both the 1960s and the Maunder Minimum Period were significantly colder periods, followed by warming.

CONCLUSION AND OUTLOOK

This paper set out to demonstrate that it is possible to quantify information on historic storms of the non-instrumental period by transforming it into proxy data. As the data comes from the coastal area of Belgium and the south-western Netherlands, the storms reconstructed are mainly N, NW, W and SW storms occurring during the storm season (Sept–mid-April). The proxy data can be quantified by using an eight-category grading method. From this, two main features emerge: the annual variability of storms and the fluctuation of periods of high storm frequency and low storm frequency. For the period 1390–1725, nine shorter periods of intensified storminess emerge. Some of these peaks are caused by storm surges alone, but most of them are caused by the fact that sometimes a lot of lesser storms occurred during a storm surge year, shortly before, or soon afterwards. Of the low storm frequency periods the 1430s and 1540s stand out. No clear storm trajectories could be reconstructed, because the information comes from a relatively small area. However, comparing the big storm surges of this area with other regions across the North Sea gives some clear indication of spatial storm trajectories. Storm surges like those of 1682 and 1715 mainly hit the study area, while the Christmas 1717 surge mainly struck northern areas of the Netherlands and Germany.

Another aim was to consider links between fluctuations in storminess and temperature, but this cannot be satisfactorily undertaken due to lack of high-quality data for the latter. However, it is striking that the very windy second decade of the eighteenth century coincided with warming. A comparison between increasing storm frequency and the NAO Index does not suggest a meaningful correlation between the two. Comparison between the period 1390–1725 and the twentieth century was useful in as much as it indicates that both periods were characterised by similar annual fluctuations of storminess and by the alternation between extended periods of high and low storminess. The very windy 1970s do compare with historic periods of high storm frequency. Overall, the study undertaken so far of historic storm activity during the period 1390–1725 does not suggest that a radically different storm regime prevailed during this part of the Little Ice Age, at least not in the small study area of the south-western Netherlands and coastal Flanders.

Looking to possibilities for future research, it is obvious that an extended database of historic storms is needed to serve as the basis for any kind of future modeling of storms and storm patterns. First, there is the need to look for additional information for the period 1390–1725 from the same study-area, which is possible, because data from many archives of water boards and manorial accounts have not yet been utilised. Secondly, the time period needs to be extended further back in time before 1390 and should also include the remainder of the eighteenth and nineteenth centuries, from which the amount of available information is huge, especially that of water boards. Extending the database into the more recent period will enable the comparison of proxy data with instrumental observations on wind, which could lead to refinements of the eight-category grading method. A third option is to extend the search for storm information spatially. This would entail the collection of similar information from other regions in the Low Countries, such as the area around the former Zuider Zee (Amsterdam-Kampen) and the northern area of the Wadden Sea. This would encompass Bilderdam and Amsterdam, where both daily wind-flow observations and the recording of water levels are available from the early eighteenth century onwards. This would enable spatial storm trajectories to be determined more precisely.