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## **STORM SURGES, HIGH TIDES AND STORMS AS EXTREME WEATHER EVENTS, THEIR IMPACT ON THE COASTAL ZONE OF THE NORTH SEA AND THE HUMAN RESPONSE, 1350 TO 2000**

*Abstract:* Focusing on documentary sources, this paper shows that no overall picture of storm surges, storms and high tides in the North Sea area for the period of 1350 to 2000 has been reconstructed. Five separate storm surges are being examined in more detail from which it appears that no clear pattern in geographical distribution nor on a time scale can be distinguished. Furthermore human response is quite different pro storm surge and pro region. Results of new research from historical evidence for the south western coast of the North Sea area from the 17th and 18th centuries show how the time series of storm surges, storms and high tides can be completed. Finally, it is considered necessary to extend this kind of research for the entire North Sea area covering the period under consideration in order to connect the results to other kinds of time series in the same area.

*Key words:* storm surges, historic storms, high tides, extreme weather events, North Sea area, historical evidence, storm frequency.

### **1. Introduction**

This paper focuses on weather extremes in the North Sea area (Fig. 1). Using documentary sources an attempt is made to reconstruct a time series of high tides, storms and storm surges for the period of 1350 to 2000. The storm surges of 1530, 1682, 1715, 1717 and 1906 are studied in more detail trying to distinguish a pattern in the distribution of these kinds of weather extremes in the North Sea area and trying to see whether there is a difference in human response to the disasters as well. Firstly, does this imply that studies such as Gottschalk (1971, 1975 and 1977), Lamb (1991), Gram-Jensen (1985) and De Kraker (1999) can supply us with an overall picture of storminess in the North Sea area? And if this would not be the case, how can research for the period under consideration using historical evidence contribute to filling up the gaps in our knowledge? Secondly, whereas the regional landscape and its continuous remaking by man in the south western part of Holland e.g. is quite different from the

Fig. 1. North Sea area. The river mouth west of Antwerp (Flanders or Belgium) is called the Westerscheld, which with its surrounding polders is part of the Province of Zealand (Holland). The lake district east of Amsterdam is called IJsselmeer (ancient Zuiderzee). The German part of the North Sea stretches as far as north a hundred miles north east of Hamburg. The isles on the Dutch and on the German part of the North Sea are called Wadden Isles.

one in the German part of the North Sea, it is difficult to assess the importance of each weather extreme using the consequences of each natural disaster exclusively to make comparisons. Nevertheless, it remains important to look at the consequences in order to understand the real cause of the disaster.

So first five different storm surges will be discussed in order to know how they came about, to which consequences they led and to see whether the extreme weather event had a general or more local character in the North Sea area. Then the possibility

of reconstructing a time series of high tides, storms and storm surges for the entire area will be looked upon, including some of the latest results from continuous research in the Westerscheld region.

## 2. The Documentary Sources

The kind of historical evidence that is used for the reconstruction of extreme weather events such as storm surges, storms and high tides consists of dike accounts and correspondence of all kinds of incidents ranging from small scale damage to the flooding of entire areas (Pfister et al. 1994; Pfister et al. 1999; De Kraker 1999). In spite of the fact that the series of dike accounts only supply us with proxies, this source is uniform and continuous, sometimes even for a period of two or three centuries. As far as the Dutch part of the North Sea area is concerned the number of dike accounts is almost inexhaustible. Of the 18th century storm surges there are damage reports for the German part of the North Sea area as well. Furthermore chroniclers have recorded the extreme weather events. Their reports can be used only if they have witnessed the event or at least if they were contemporaries. Finally, for the 18th century instrumental recording of weather, especially wind direction began at Bilderdam (near Amsterdam) which observations can be used to verify wind direction during storm surges such as those of 1715 and 1717.

## 3. The Storm Surge of 1530

The 1530 storm surge that occurred on 5 November has been recorded many times in the Dutch and Flemish historical sources.

An Antwerp chronicler (1) recorded that on a Saturday when there was a full moon a NW storm coincided with a high tide at noon in the harbour of Antwerp. This led to the flooding of four villages north of the city, of which he mentioned the name. Furthermore in the provinces of Zeeland, Flanders and Holland at least 404 parishes were submerged. In Zeeland even the city of Reimerswaal was wiped away.

Another contemporary chronicler (2) living some fifty miles east of Antwerp recorded that there had already been a storm on Thursday which gained force during the next day and finally became a storm surge on Saturday coinciding with a full moon. The high tide reached a level that surpassed the height of the dikes by a Hamburger beer barrel (3 ft.), and consequently led to the flooding of large areas. Near Antwerp the storm surge caused the bursting of the dikes at three different places. The chronicler was horrified to see the drowning of so many people and beasts of which the bodies floated by.

Looking at the damage which was caused by the storm surge in the Low Countries and the coastal plain of the North Sea it becomes clear that the disaster predominantly hit the southern part. So the larger part of the isles south of Rotterdam, the main part of the province of Zeeland and the coastal areas of Flanders (Fig. 2) were flooded. Even as far south as Calais in France, some lowlands were flooded. The region north

Fig. 2. Mouth of the Westerscheld and the Easterscheld. Except for the Westerscheld the other rivers mouths have been closed shortly after the 1953 storm surge. Zuid-Beveland and large parts of what is now called Zeeuws-Vlaanderen used to consist out of a number of smaller isles during the 14th to 19th centuries.

of Rotterdam only suffered damage as far as the coastal dunes were concerned of which large quantities of sand were washed away. The entire northern part of the North Sea area from Friesland to the Danish coast suffered no damage at all.

Unfortunately it is not possible to assess the damage more exactly. Because the number of acres of arable land in the areas that were hit by the storm surge is not known, consequently the number of flooded acres cannot be assessed either. Still it may be assumed that more than half of the arable land along the coast of the Westerscheld was flooded west of Antwerp (De Kraker 1997). Looking at the province of Zeeland, taking into account its archipelago shape and the fact that the sea reaches far above the dikes, it may be assumed that perhaps over 75% of the area was flooded. Another aspect of damage is the number of people and cattle drowned. Unfortunately, no reliable source has been studied yet. Perhaps the wildest guess was over 150,000 people killed by the 1530 storm surge, which was recorded by an Italian chronicler, which in turn would have meant over 10% of the entire population perished.

If we turn to the human response to the 1530 disaster, it is obvious that authorities turned their attention to the south western part of the Low Countries. Firstly the

most urgent concern was repairing the damage as fast as possible by closing the breaches and getting rid of the water. The approach of winter, being the most unfavourable season for repairing the dikes was well underway. Moreover a new storm hit the area at the end of November 1530, again damaging repairs. So some dikes had to wait until the spring of 1531 to be repaired. Eventually some areas could not be reclaimed at all. So an area of some 18.000 acres was never to be reclaimed again and is now a protected wetland known as the 'Submerged Land of Zuid-Beveland'.

The government, headed by emperor Charles V, took some measures to coordinate the repairs and in a very modest way helped to finance some. According to dike-law the emperor took care of the abandoned lands. Most dikes were rebuilt a little bit higher and for a three or six years' term large parts of the disaster area enjoyed some kind of tax reduction. Charles V did not think it necessary to take any further measures in preventing future disasters of the same kind. These were left to be taken by the local authorities, which only went as far as to readjust some dikes and build them a little bit higher in order to compensate for their gradual sinking during the last decades.

#### 4. The Storm Surge of 1682 (3)

Perhaps the major storm surge of the 17th century occurred in 1682. On 26th of January at 5.00 p.m. a severe NW storm coincided with high tide and caused large scale flooding in the south western part of the coastal plain of the North Sea. Three days earlier there had been a full moon. Many letters were written in which the disaster is recorded. From these accounts it appears that large areas were flooded and many people and cattle were drowned. However, it remains very difficult to make simple comparisons with the 1530 disaster.

For one thing, the Eighty Years' War (1568-1648) has entirely reshaped the landscape in the coastal area of Flanders, and renewed human induced flooding e.g. of 1672 added to the confusion concerning the question which parts lay still flooded and which ones were to be flooded by the storm surge of 1682. Another thing is the changing height of the dikes, because it appears that they were on an average 3 feet higher during the 16th century. Nevertheless in the coastal region of Flanders more than half the arable land in the eastern part as far as Antwerp and about a third in the western part was flooded. Unfortunately there are no sources giving exact numbers of people and cattle drowned. Moreover there was much theft in the area.

In the province of Zeeland the isles of Noord-Beveland and Tholen were half flooded or even less, whereas on the remaining isles and those south of Rotterdam the flooding was far less disastrous. North of Rotterdam the storm surges seem to only have damaged the coastal dunes without causing any flooding.

In the northern part of the coastal plain of the North Sea, ranging from Friesland to Denmark, no damage of any kind seems to have been recorded.

Lamb (1991) does not mention the storm surge as such, but referring to Gottschalk (1977) he only characterises it as being a 'serious flood'. No doubt a serious underestimation of the extremity of this weather event in the North Sea area.

Looking at the human response to the 1682 natural hazard, obviously, there was far less assistance by the government in the Flemish region compared to the 1530 hazard. The government only interfered where the fortified towns and small fortifications were at risk. So local authorities were to fend for themselves to organise repairs and finance them. Consequently no extra measures were taken to re-enforce dikes or other kinds of measures preventing future disasters. Only a few polders in the province of Zeeland and in the coastal area of Flanders were given tax reduction for a few years.

## 5. The Storm Surges of 1715 and 1717

On 3rd March 1715 a storm surge hit the south western coastal region of the North Sea, while on 24th and 25th December 1717 a storm surge occurred in the north eastern part of the North Sea.

### 5.1. The 1715 disaster (4)

The observatory at Bilderdam, some km south of Amsterdam already recorded wind directions during the first decades of the 18th century. So on 1st of March 1715 a westerly wind was blowing, turning WSW the next day. On the third day the wind changed NW and continued to be NNW on 4th of March.

In the coastal area near Antwerp and the province of Zeeland (about 150 km south of the Bilderdam) a severe NW storm was recorded on 3rd March 1715 causing a spring tide during which waters ran higher than in 1682. The storm continued battering the coastal area during the next day. Again large parts of the coastal area of Flanders along the Westerscheld and parts of the province of Zeeland and the isles south of Rotterdam were flooded. Because of the long duration of the storm surge the flooded areas were severely extended on the second day of the disaster. Due to the fact that water reached a higher level than in 1682 dikes were more easily overrun, without causing breaches, turning many a polder into a huge pond setting off the flooding of the neighbouring polder.

In order to have an overview of the area flooded and the kind of damage, for the Hulst area detailed damage reports were made. From these reports it is clear that nearly all polders situated directly along the shores of the Westerscheld suffered badly from water running over their dikes for just a short time. Where the storm surge had caused the dike to breach, polders were flooded for quite a longer time. So about a third of this area (3,550 acres) was flooded and the damage, including the loss of winter crops, was calculated at about 128,098 guilders. There are no numbers available of people and cattle drowned or buildings that were destroyed. It is clear that damage reports were made in order to get some kind of relief from the government. In the Flemish coastal area west of Hulst only three polders were flooded, totalling a number of no more than 500 acres (Fig. 2).

In the neighbouring province of Zeeland, a much smaller area was flooded compared to that which was flooded in 1682. Still about 25 polders were flooded totalling a number of around 2,000 acres.

Except for the obvious, no specific or additional measures were taken during the disastrous months of March and April 1715 to repair the damage and reclaim the flooded lands as far as the coastal area of Flanders was concerned. Repairs suffered a slight set back during a gale on 4th April 1715, which according to the observation at Bilderdam was a NW gale turning north on the 5th. By the end of the year most flooded lands had been reclaimed. Only one polder remained submerged, becoming part of what is nowadays the protected wetland of the 'Verdrongen Land van Saeftinghe. Some polders enjoyed some years of modest tax reduction.

In the province of Zeeland repairs began as soon as possible, although the human response to the natural disaster went a major step further in taking measures in order to prevent similar disasters in future. So the idea was born to distinguish between polders that were directly at risk of being flooded during storm surges, called calamitous polders, and those that were not directly at risk. A calamitous polder could get financial assistance from the government more easily than an ordinary polder. In turn the government forced the neighbouring polders of each calamitous polder to contribute financially as well. Although it would take a long time yet, before this system of mutual aid was accepted, during the 18th century it was enforced by law. By the end of the 18th century it worked and was even adapted by the French who occupied Flanders and Holland then. The first serious test case came in 1808 during the storm surge that occurred on 15th January.

In the north western and northern part of the Dutch coastal plain of the North Sea there are reports of damage from different regions, such as Harlingen in the province of Friesland and in the Dollard region near Delfzijl and Embden (Germany). Moreover there seems to have been flooding in the lower Rhine area of Holland, in the Betuwe region (Ahrend 1833) as well.

On the German and Danish side of the North Sea the 1715 storm surge does not seem to have caused any serious damage (Gram-Jensen 1985). On the British side of the North Sea the storm surge is not even mentioned at all (Lamb 1991).

## 5.2. The 1717 disaster

The so called Christmas storm surge of 1717 was observed in the southern part of Holland as being just another spring tide or gale which caused very little damage. There was no flooding. Unfortunately no observations of wind direction at Bilderdam are available for December 1717.

In the north eastern part of the coastal plain of the North Sea the picture was quite different. In terms of highest flood, the Christmas storm surge ranks no higher than fifth in the 18th century (Lamb 1991). Water levels stayed at least 0.40 m below the highest recorded level of 1792. In meteorological respect winter was very mild in December 1717. On 22-23 December relatively warm and humid air was passing over France to the North Sea area and on that second day the wind was gaining speed, beginning to blow from the south west. From Iceland relatively cold air masses were shifting rapidly to the southern Baltic. Consequently during the 24th of December the wind still gained speed turning west at 2 p.m. and still turning north west by 4

p.m. and developing into a storm surge (Jakubowski-Tiessen 1992). At 1 a.m. during the following night the storm surge focused on the British, German and Danish part of the North Sea and surrounding regions. Although high tide was not expected earlier than between 6.30 and 8.00 a.m. on the 25th, already several dikes suffered heavy damage and breached. So large areas were flooded before water reached its highest level. In fact a very fast accelerating wind speed, many hours before high tide prevented water from reaching its normal low tide level, caused water to be strongly accumulated at high tide. Because of the long duration of the storm surge, damage was widespread and huge.

Because the storm surge had taken the people completely by surprise, the human response to the large scale flooding was therefore slowly getting underway. For one thing, rescuing people had to wait until the light of the next day (Jakubowski-Tiessen 1992). At the same time it became clear that there were not enough boats for every one to be saved. Moreover, central authorities heard the sad news too late to start wide scale operations, so each local government started its own rescue party. Whereas many people had taken refuge on roofs of buildings and dikes awaiting to be rescued wearing night dress for too long a time, many died from cold. Finally there was much theft in the flooded area.

Looking at the damage and the loss of human life and cattle, about 3,000 houses were destroyed and many more damaged, 9,000 people died, about 7,000 horses, over 31,600 cows, 9,800 pigs and over 15,000 sheep were drowned. There was also heavy loss of crops on the field and those stocked in barns. Many dikes had breached or suffered other kinds of damage. And finally a very large area was flooded of which it appears to be even hard to estimate a rough number of acres flooded. Except for the direct damage, the area soon suffered from hunger and poverty, which triggered an economic decline.

A storm on 24th February 1718 added to the disaster and although repairs began during summer, frequent storms during the autumn undid the entire work. Much disagreement between local authorities and efforts to get the repairs financed that were hardly successful, added seriously to the problems of dealing quickly and efficiently with the natural hazard. No sooner than 1723 finances could be settled and a reorganisation of the dike system in a more centralised way was initiated.

## 6. The Storm Surge of 1906

During the 20th century several storm surges can be distinguished, such as those of 1906, 1916, 1953, 1962, 1976, 1990 and 1999. The storm surges of 1906, 1953, 1976 and 1990 mainly hit the south western part of the North Sea coast, while those of 1916, 1962, 1976 and 1999 mainly hit the northern part as well. Except for the latter, all of these storm surges have been studied in detail, so only the 1906 and 1916 storm surge will be discussed.

On 12th March 1906 the south western part of Holland was hit by a storm surge. At 4.30 p.m. local time during a WSW wind water reached its highest level. Because on 10th of March there had been a full moon, water continued to run high. And

because of the funnel like shape of the Easterscheld and the Westerscheld, extra water was accumulated in the rear of both river mouths. So in the rear of the Westerscheld water reached a level of 4.60 to 4.83 above NAP (New Amsterdam Mark) or 1.99 to 2.22 above mean high tide. In the rear of the Easterscheld levels reached were 4.52 above NAP or 1.78 above mean high tide. In both rivers levels reached on 12th March were still much higher (resp. 0,62 and 0,32 m) than those reached during the storm surge on 22-23th December 1894.

The damage was wide spread. Firstly eighteen polders were flooded totalling a number of 5,410 acres. Many polders situated along the shores of the Easter- and Westerscheld suffered damage to its dikes, some of them being overflowed by water. Although at some places buildings were destroyed and cattle drowned, no human life was lost which must be attributed to the fact that the flooding happened late in the afternoon. Repairs were carried out fast. This was partly due to the fact that the calamitous polder could get financial assistance from the provincial government very easily. Most important factor in dealing with the disaster was the very efficient way in which the Rijkswaterstaat took prompt action.

Whereas Rijkswaterstaat had been studying the water movements in the Delta area, especially the rising sea level, for well over a century now, the storm surge and its consequences were being analysed thoroughly in order to take measures to prevent similar disasters in future. As a result of the analysis the authorities ordered the dikes to be built much higher than before. New results of the rising sea level obtained during the 1920s again led to the re-adaptation of the dikes. Another lesson learned from the 1906 disaster was the fact that at many places secondary dikes appeared to be too low to prevent the hinterland from flooding whenever the first dike breached. So adaptation was ordered of the height of the secondary dikes as well.

Looking at the remaining storm surges of the 20th century shortly the following may be stated. The 1916 storm surge caused serious damage to the Zuiderzee area of Holland, leading to the closure of this sea and the large scale reclamation of land. The 1953 storm surges led to large scale flooding in the south western part of Holland, over 2,100 people were killed in Holland and on the British Isles. This disaster led to the closure of several river mouths in the south western part of Holland, such as the Easterschelde. The 1962 and 1976 storm surges caused large scale damage in the German part of the North Sea and on the British Isles, leading to the closure of several river mouths, such as the Eider in Schleswig Holstein (Germany). Whereas the coastal plain of the North Sea was already so well protected against storm surges of the worst kind, the 1990 and 1999 storm surges only caused much material damage on land and a few people were killed e.g. by falling trees. No doubt a storm surge of a similar kind around 1900 would at least have caused large scale flooding!

## **7. Discussion of the Extreme Weather Events**

Overlooking the causes of and the human response to the five extreme weather events the following may be concluded.

In all cases wind was coinciding with a full moon and was blowing from a north westerly or westerly direction: only on 3rd March 1906 wind was blowing from a WSW direction. All five extreme weather events finally led to the flooding of arable land. In the south western part of the Netherlands the area flooded was generally restricted to a dozen or more polders. This was due to the fact that the land was divided up into many small polders, each of which having its own dikes. Whereas the landscape in the coastal area of the North Sea on the German side was quite different, the area flooded was much larger.

The human response to the extreme weather events was quite different in time and on a geographical scale (Tab. 1). In all cases repairs were carried out. However, if these were carried out too slow the region ran the risk of being hit by a second storm surge of which the consequences would, of course, still be worse such as the 1717 disasters shows. In this respect it must be added that much depended on the exact time a storm surge hit the area. If this happened during day time the consequences could be seen coming and already preventive measures could be taken. If the storm surge happened during the night time people were taken by surprise and the consequences were very serious, such as the 1717 example shows.

Tab. 1. Human response to storm surges in the North Sea area, 1530 to 1906.

Year	Date	Month	North Sea area	Damage	Human response
1530	5	November	Flanders and Holland	large scale flooding many people died cattle drowned	fast repairs co-ordination by the government financial assistance by the government tax reduction
1682	26	January	South western part of Holland	large scale flooding people/ cattle died	fast repairs tax reduction
1715	3	March	South western part of Holland	large scale flooding people/cattle died	fast repairs re-organisation of the dike system in the province of Zeeland tax reduction
1717	24 25	December December	Germany and Denmark	large scale flooding many people died cattle drowned	slow repairs slow financial assistance by the local government tax reduction gradual economic decline
1906	12	March	South western part of Holland	5.410 acres flooded no casualties	fast repairs general raising of the dikes

Finally the kind of measures taken by the government matter very much. This could vary from financial assistance to the regulation of dike rebuilding and even introducing new regulations.

## 8. Variability of Storm Surges, 1350 to 2000

In order to assess the variability of storm surges in time and in space, we need sufficient and reliable data. This touches on the major problem, because the time scale under consideration only supplies us with instrumental weather observations going back as far as the late 18th century for the northern and eastern part of the coastal area of the North Sea and for the Dutch part dating from the beginning of the 18th century. For the earlier period we have to rely on documentary sources only. The second problem touches on the variability in space, because from the pre-instrumental period documentary sources are relatively scarce for the northern and eastern parts of the region. Even for the British Isles the documentary source seems to be insufficient (Lamb 1991), but it is more likely that these have not been systematically studied yet.

Although it seems to be impossible to assess the variability of storm surges during the recent 750-year period, there is still a number of recorded observations, which we shall discuss now.

For the Netherlands and the coastal plain of Belgium Gottschalk (1971, 1973, 1977) has carried out an investigation that has led to a reconstruction of the number of storm surges from the earliest known times until 1700, which may be considered as being reliable.

She also discussed a lot of observations made by contemporaries about all other kinds of storms and gales. However, because she considered many of the dates mentioned unreliable, she actually left these observations aside. Consequently she declined the possibility of reconstructing a time series showing the variability of storm surges.

For the German and Danish part of the North Sea area Rohde (1977) and Gram-Jensen (1985) tried to reconstruct a time series of storm surges by compiling all kinds of storm events. This resulted in a time series of storm surges and floods which actually becomes reliable only from the start of the 18th century. Of course, this time series does not imply that earlier than 1700 no storm surges and floods have occurred: they have simply not been recorded well.

Relying heavily on Gottschalk, Rohde and Gram-Jensen, Lamb (1991) tried again to reconstruct a time series of storm surges for the entire North Sea area. In order to know the impact of a storm surge, he distinguishes between three major criteria, which are: the total duration of the storm, the greatest area covered by the storm and causing damage, the wind speed. For the period of instrumental recording of wind, Lamb's criteria can be applied easily. For the pre-instrumental period they remain insufficient, because hardly ever an exact wind speed is recorded. Therefore De Kraker (1997,1999) using long and uniform series of mainly dike accounts of the pre-instrumental period was able to assess variability of storminess from 1488 to 1609

in a polder area on the Westerscheld. Contemporaries maintaining the dikes recorded every kind of damage that was done by weather ranging from high tides to storm surges. Assessing the kind and the range of the damage caused to the dike system by weather extremes appeared to be a major criterion to assess each individual high tide, storm and storm surge. Furthermore, he suggested taking into consideration the wording - system as well, which applies to the kind of language contemporaries used to record the natural disaster. By systematically assessing each high tide, storm and storm surge and translating this into a value, ranging from one to eight, the variability of high tides, storms and storm surges is shown in Table 2.

Now recent research in roughly the same area using the same kind of written sources for the period 1600 to 1800 again shows quite an irregular pattern in time. During the 17th century 35 extreme weather events, ranging from high tides to storm surges can be distinguished of which 22 already had occurred during the first two

Tab. 2. Storm surges, storms and high tides in the North Sea area, 1350 to 1800.

Period	Holland	Denmark	Germany	England	Westerscheldt area
1350-1399	4 to 6	0			
1400-1499	17 to 20	0			
1400-1449	7 to 8	1			
1450-1499	11 to 13	0			
1500-1524	8	0		1	31 to 36
1525-1549	4	4		2	7
1550-1574	3	11		2	37 to 38
1575-1599	3	18		3	35 to 38
1600-1624	6	29	9	1	22
1625-1649	1	30	11	2	5
1650-1674	4	13	17	9	6
1675-1699	3	11	13	9	1
1700-1724		23	6	4	11
1725-1749		9	2	10	4
1750-1774		12	2	4	10
1775-1799		10	22	9	5

*Source:* Gottschalk (1971, 1975, 1977), Gram-Jensen (1985), Rohde (1977), Lamb et al. (1991), De Kraker (1997, 1999).

decades. This higher number of storm surges, storms and high tides can only partly be attributed to a more thorough research of the documentary sources available for the two decades in question. During the 18th century only 30 high tides, storms and storm surges could be counted. However, these results are still too preliminary to be fully assessed and compared to those obtained from the previous century. Firstly, the 17th and 18th century observations are from a region that is much smaller than the 16th century area. Secondly, the written sources of the 17th and 18th century are still showing too many gaps, awaiting much additional observations from similar written material from other areas around the Westerscheld.

However, it already becomes clear that this new material can be used very well to verify the reliability of the storms and high tides left aside by Gottschalk (1975, 1977). Compared to the time series of storm surges Lamb (1991) reconstructed and many other weather extremes of the kind he left aside, it also becomes clear that there must be a significant variability in geographical distribution of storms and high tides. Obviously, only detailed research of the written sources can produce a complete time series of high tides, storm and storm surges in the North Sea area in the end, showing a variability in time and in space.

## 9. Conclusion and Prospects for Future Research

This paper shows how little we really know about extreme weather events in the North Sea area during the period of 1350 to 2000. British and German research cataloguing the storms of the recent five centuries tend to stress storms that mainly occurred in their own area, while these compilations show serious gaps for the Dutch part of the North Sea area. On the other hand Dutch time series of storm surges stop around 1700, leaving aside most gales and storms that were not considered as being storm surges. More detailed research on high tides, storm and storm surges has filled up gaps for the period of 1500 to 1800 for the southern part of the Dutch coast. From these results a significant variability in time is shown and compared to what is known from other North Sea area, there is also a significant variability in space. The latter is stressed by the detailed analysis of the storm surges of 1530, 1682, 1715, 1717 and 1906. From these examples the difference in human response is also shown, ranging from huge loss of human life to additional damage and ranging from simply repairing dikes to significant re-organisation of the dike system and during the recent century radical adaptation of the dike system technically and administratively and a complete remaking of parts of the landscape.

Most needed now is a research using documentary sources that focuses on high tides, storms and storm surges in four or five smaller areas of e.g. the Dutch and Belgian coastal area of the North Sea in order to complete a time series of the extreme weather events, enabling us to have a better understanding of the variability in time and space. In this respect results from similar research for the 16th century show an increase in storm frequencies during the second half of that century and results from recent research for the 17th and 18th centuries seem to confirm that strongly fluctuating storm frequency continues during that period. Although we are far from a complete

picture of storm surges, storms and high tides in the North Sea area during the period 1350 to 200, such time series could be linked to time series of extreme rainfall, winters and in the end to the NAO-index as well.

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### Notes

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