Part 1

Introduction and analysis

1

Introduction

Background and basis of the study

The regions here examined are close to, and to varying extents experience, the most frequented storm tracks of the northern hemisphere. The storminess of the North Sea in particular is known from the succession of storm flood disasters on its coasts catalogued by various compilers from Arends (1833) to the three-volume work of Gottschalk (1971, 1975, 1977), the latter particularly distinguished by the author's thorough critical examination of the original manuscript sources. The partly known history goes back at least to the Cymbrian flood of the coasts about the German Bight around 120 BC, which set off a migration of the Celtic tribes previously settled there. And both Aristotle and the early Greek navigator, Pytheas, who sailed round Britain in about 330 BC, had already reported the acquaintance of the Celtic tribes then living along the same part of the North Sea coast of the continent of Europe with its storms.

It is probable that, because of the seriousness of the disasters, lists of historic sea floods are the nearest approach we have to a homogeneous list of a series of great storms of the last 300 to 500 years. Before that the sea defences were so much less effective that the situation was hardly comparable at all, but ever since that time the effectiveness of dykes and sea walls and the dredging of channels must have affected the flow of tidal currents and storm surges.

There are other striking effects of great storms upon the landscape, particularly through blown sand, the formation and shifting of dunes sometimes forming a continuous coastal barrier, the scouring of sand or dry soil and spreading of drift-sand into nearly flat expanses; also the drift of sand and gravel by water currents at or along a coast and in other shallow-water areas – a process which is liable to produce offshore sandbanks and bars across harbour mouths that are open to scouring by any storm winds occurring at times of very low tide. But the effects along these lines of any individual severe storm are generally more local than the great sea floods.

Erosion of coasts takes place not only by wave battering and scouring in storms, but by slow continuing wastage through water current action. It is also affected at varying times and rates by processes that may have nothing to do with storms: by heavy rain and run-off, by frost and thaw, and by landslides. And the rates of these are clearly influenced by the topography and geological structure as well as by the variations of storminess in space and time. Exceptional cases of coastal recession due to marked erosion of cliffs or of low-lying promontories – as near river mouths – appear in the records from time to time, and these have been used to identify some of the severe storms in this compilation. But these too are characteristically localized events and do not provide readily comparable evidence of the severity of a storm. In such cases this usually has to be established, if it can be at all, from meteorological evidence or reported wave heights etc.

The storms examined in this compilation were picked from the records of great sea floods and other coastal disasters in collections already known to the scientific literature (e.g. Gottschalk, 1971, 1975, 1977; Gram-Jensen, 1985; Petersen and Rohde, 1977) or reported soon after their occurrence in the standard journals (including the *Meteorological Magazine* and the *Monthly Weather Reports* of the Meteorological Office and similar sources in neighbouring countries). Others were discussed through commemorative articles in the *Meteorological Magazine*, in *Weather*, or in the equivalent journals in Denmark (*Vejret*) and Norway (*Vaeret*), or in the organs of shipping interests, recalling historic storms long after the event (as at hundredth and hundred and fiftieth anniversaries) and gathering together details from old newspapers and diaries. Others again were found in various local histories and archives, while a few were picked up from the early compilations of great weather events by Hennig (1904), Lowe (1870), Mossman (1898), Short (1749). Such reports need corroboration by independent accounts or other circumstantial evidence or – better by far – by collected simultaneous weather observations and weather map analysis. This has been the main policy of this investigation. Other sources used have been Brazell's *London Weather* (1968) and the manuscript detailing daily weather observations in London from 1723 to 1811 put together by the late Professor Gordon Manley and deposited with the Meteorological Office in the 1970s. Lists of extreme winds observed in the British Isles given by Bilham (1938) and Chandler and Gregory (1976) have also been used. Yet other information was gleaned from early newspapers, from port records and local archives from the countries around the North Sea, as well as some farm diaries kept at places near the coasts and the notes of scientific observers such as Gilbert White at Selborne in Hampshire and Thomas Barker in the east Midlands of England, whose weather journals between 1733 and 1795 are described and partly reproduced by Kington (1988). Storm reports from such miscellaneous sources need the verification and amplification that can best be provided by synoptic mapping of simultaneous observations, as has been possible in the great majority of cases in this study.

Circumspection is needed in accepting the reports even of very able men among the early observers when they were writing from memory of events witnessed many years before. Thus Defoe (1704), whose reporting on the great storm in southern England in 1703 is of great value, refers at length to what he remembered as a somewhat parallel case in February '1661' (1662 according to our modern reckoning of the beginning of the year); in fact, the records show that the 1662 storm passed across England on a quite similar west-to-east track, causing much destruction, but over a decidedly narrower belt than in 1703, and we have no word of effects on the continent. In another place, Defoe (1724) wrote of a storm encountered 'about the year 1692 (I think it was that year) . . . by 200 sail of light colliers bound northward out of Yarmouth Roads for Newcastle . . . when some turned back . . . some but very few rid it out . . . ; the rest being above 140 sail were all driven on shore, and dash'd to pieces . . .'. Luckily we have sufficient reports of the storm of 22 September 1695 (q.v.) for it to be reasonably clear that that was the storm which Defoe meant to refer to.

Non-meteorological evidence above all needs meteorological corroboration. In the eighteenth century, the great church at King's Lynn and the cathedral in Hereford were both extensively damaged when their southwest towers fell across the nave of the building, as if felled by a WSW'ly storm. The storm at King's Lynn on 19 September 1741 (New Style)* is abundantly supported by reports from Lynn and places in neighbouring counties. But the day when Hereford cathedral fell, 17 April 1786, was fine, with a light NE breeze! The cathedral records speculated that bad soil and weak foundations might have been the cause, but the place also has a history of earth tremors.

In a number of cases before about 1725 (see Lamb, 1977, pp. 48–50) the precise date of some severe storms seems never to have been recorded, and in others the calendar change introduced uncertainty into the date. When this is not known, it is of course impossible to assemble and analyse simultaneous observations. These difficulties and the extent to which it may have been possible to resolve them are discussed in the text of our storm reports. The one remaining case of more than doubtful authenticity seems to be the 'violent gale' in London on 1 December (Old Style) 1737 reported by Lowe (1870) and quoted by Brazell (1968).

Greater difficulty surrounded the firm establishment of the date and details of the S'ly storm of blown sand which obliterated the centre of the medieval town of Forvie on the east coast of Scotland north of Aberdeen, reputedly on the 10 August (Old Style) 1413. However, the calculation by Dr J. Vassie of the Tidal Institute, Birkenhead that that date coincided with an unusually extreme low tide suggests that it may be the true date of the storm. The difficulties, however, indicate that the fifteenth century should be considered beyond the limit of our ability to establish certainty. In the case of at least the severest storm disasters after AD 1500 interpretation may be adjudged safer, although the reasonably firm evidence of conjunction with extreme exposure of sand to the wind in the 1413 case should be noted.

Observations and instruments

The earliest storms mapped came within a few decades of the invention of the barometer and thermometer, and for over a century thereafter none of the available ships' observations at our disposal included instrument observations. In some cases, however, notably in the storm in 1717, the ships' reports of wind and weather, commonly recorded for each 4-hour watch of the day and night, were so numerous that only a small proportion of them could be shown on our maps, and in the 1703 case as well as in 1717 it will be seen that the wind reports received from ships at sea were of great value to the analysis. What could be done with such reports to determine the synoptic weather pattern will be understood from a careful reading of the report on the great storm in 1694 which is interpreted as the probable cause of the Culbin Sands disaster in northeast Scotland. A preliminary diagnosis of the meteorological situation was first sketched on the basis of the good series of weather observations reported in London from 29 October to 4 November 1694 (New Style) – partly listed in our text on that storm – taken together with the close descriptive account of the progress of the storm at the disaster site in northeast Scotland. The London observations indicated a long-lasting NW'ly wind, preceded by a light W'ly on the 29th–30th, the NW'ly outbreak becoming increasingly stormy and sleety until 2 November. This sequence suggests the arrival of fresh Arctic air from the north, which would presumably have been felt more severely in northeast Scotland. There the experiences of the people whose work in the fields (and whose homes) were overwhelmed by the storm at Culbin suggest that the rising wind may have been initially W'ly, and that it became strong at an early stage. The arguments for the direction then becoming N or NNW are given in the text of our analysis of the storm. Other, circumstantial evidence hinted that the storm affected the eastern side of the North Sea much less if at all. The wind

*The modern (Gregorian or 'New Style') calendar was adopted first in the Catholic countries of Europe – in France, Italy, Portugal and Spain in 1582; and in the German Catholic states, Austria, Flanders and the (then Spanish) Netherlands from 1 January 1583. Poland adopted it in 1586, Hungary in 1587. The German Protestant states followed suit in 1700 as did the free Netherlands, Denmark and Norway. Sweden changed gradually by omitting 11 leap days between 1700 and 1740. Britain and her American colonies, and Ireland made the change in September 1752.

Bulgaria went over to the New Style calendar in 1915, Turkey and Soviet Russia in 1917, Jugoslavia and Rumania in 1919, Greece in 1923.

The corrections needed to convert the Old Style dates to New Style were:

Between '29 February' 1400 and 28 February 1500 ADD 9 days.
Between '29 February' 1500 and 28 February 1700 ADD 10 days.
Between '29 February' 1700 and 28 February 1800 ADD 11 days.
Between '29 February' 1800 and 28 February 1900 ADD 12 days.
Between '29 February' 1900 and today ADD 13 days.

More information on this topic is given in Lamb (1977, p. 49).

The Russian observations (e.g. at St Petersburg) printed in the Ephemerides of the *Societas Meteorologica Palatina*, published for the years 1781 to 1792, appear to be dated on the Old Style calendar, unlike the other places where observations were made for, and assembled in, the Society's publication.

The only storm reported in the present survey about which there seemed to be any uncertainty over which calendar was in use in the brief historical account which is all that is here reprinted is the storm in September 1690. In the case of this storm, it is probable that the date given is an Old Style calendar date (since historians who are not dealing with a scientific problem customarily do not convert the dates).

pattern, revealed by the ships' reports received *after* the situation had been outlined, so far verified the diagnosis as to provide a test of the practicable extent of situation analysis with the evidence available.

Of the early instruments in use, the barometer readings were the least troublesome to interpret. Even so, the only values used in our analyses before the 1730s were those in the hands of leading scientists of the day: the Revd William Derham at Upminster, near London, Richard Towneley in the north of England, and the staff of the Observatory of Paris. The instruments were exposed indoors in an unheated environment and seem to have performed well. Many other early instruments gave more or less trouble with the fluid (usually 'quicksilver'/mercury) sticking to the sides of the glass. The units of measurement (length of the mercury column) have been converted to millibars and corrected from the approximately known height of the station to sea level and standard gravity (at 45° N). For the study of early instruments the reader is referred to Knowles Middleton (1969). The historical weather map reconstruction work at the Climatic Research Unit, Norwich by Mr J.A. Kington and the present author has led to the progressive compiling of a gazetteer with particulars of early observing stations, their positions and heights above sea level, instruments and units used, corrections needed, times of observation and some information about the observers.

By the late eighteenth century, with 35 to 40 observation points on our maps and up to 30 of them reporting barometric pressure, it was possible to establish the height above sea level, and correction to sea level appropriate in the cases where that information was missing, by finding the average correction needed to fit the maps drawn from the stations for which such information was known. In several of the months affected by great storms in the 1790s and in 1825, the situations every day for 2 to 5 weeks were analysed and the pressure values at places all over the map were studied for goodness of fit. The daily sequence of the discrepancies at each place from which the observations came and the means and standard deviations of the departures gave a numerical test of the reliability of the individual stations, showing the best performing ones and those with barometers sticking when pressure changed rapidly.

Exposure of the thermometers used was a difficult problem for the early observers and the best practices only really emerged in the late nineteenth century. Before that, the instruments were commonly positioned in unheated north rooms or outside on an open north wall, sheltered in some way from rain and direct sun. But these difficulties caused no serious problem for air mass identification and analysis of the stormy (largely cool-season) situations with which this study is concerned. Conversions had to be made from a great variety of old instrument scales to the centigrade scale used on all our maps.

The problems here discussed, and how they were dealt with, are the subject of special appendices following the texts of our accounts of the storms in 1717 and 1791, where it will be seen how the techniques described above were used also to test the reliability of our analysis and the limits of the area that could be satisfactorily covered by isobars and gradient wind measurements from the network of observation measurements available. Another test of the analysis of an early storm is demonstrated in our account of the great storm in 1839 which was independently analysed in the Irish Meteorological Service in a recent paper.

The indications of wind strength on our maps are given in Beaufort wind force. The Beaufort scale, its equivalence with wind speeds and its correspondence with other, earlier wind scales,* are set out in the appendix note following our account of the great storm in 1703. The wind strengths plotted on our maps relating to storms earlier than about 1850 should not be taken as accurate to nearer than about two points on the Beaufort scale, and indeed nearly all the wind observations before 1900 were not instrument measurements but observers' estimates guided by the standard descriptions of the Beaufort scale. The gradual spread of anemometers after about 1880 is alluded to in a few storm accounts. It is only in the last few decades that actual measurements of surface winds at sea (apart from a few offshore lighthouse observations) enter the study. Over by far the greater part of the period of our survey the most dependable measures of wind are the gradient winds derived from the barometric pressure analysis. A sample estimate of error liability in gradient wind values measured off the maps appears in the appendix note following the account of the 1791 storms. (A description of a statistical method by which some indication of the probable gradient wind strengths in the Spanish Armada storms in 1588 was obtained will be found in an appendix following our account of the storms in that year.)

Tables for the conversion of ancient units have been given by the present author in Lamb (1986) and in Lamb and Johnson (1966), where many more details of the development of the world network of meteorological observations will be found. (For history of the development of the meteorological observation network see also Lamb, 1977.)

Weather diaries kept by people whose dedication is made clear by the regularity, terseness and completeness of their records were also used. The agreement between three independently kept diaries within 40 kms of each other in Norfolk over nearly a hundred days analysed in the 1790s was a tribute to the reliability of the best of such observation records, the only differences being such as fitted the weather situations, e.g. on days when winds were obviously stronger or showers more frequent near the coast.

Wheeler (1988), writing of his use of ships' records from the beginning of the nineteenth century, reports similarly that 'where ships are gathered within the same area their records of the weather conditions are consistent'. That was also true of by far the majority of the logs of the Scandinavian ships around the Skagerrak and neighbouring coasts here used in analysing the storm in December 1717, but it is a finding that depends on dedicated observers. Experience in another study showed, for instance, that the daily weather observations of the Salem, Massachusetts doctor, E.A.

*Frydendahl (1986) has written a useful short account of the historical development of a system for estimations of wind force by observers on ships at sea and of the Danish collection of early observations.

Holyoke, maintained over many decades between the 1750s and the early 1800s were more consistent than those kept by the staff of an official observatory in the area.

Another possible source of inhomogeneity in the early storm situations to be analysed in the present study was in the times of observation. This was resolved by usually mapping the situation as reported about 2 o'clock in the afternoon, this being the observers' commonest choice, and tolerance of an hour or so in either direction. This meant that the difference of natural time over the map area with reports analysed between about 20° W and 30° E could reasonably be ignored.

The plotting model and symbols used for entering the weather and instrument readings observed on the maps are explained in an appendix following our account of the earliest fully analysed storm, in 1703.

Analysis

In approaching the analysis of the daily weather map sequences covering the storms in this compilation, the author was able to draw on much relevant earlier experience of working with sparse data, analysing weather patterns over the North Atlantic Ocean in wartime, then over the remotest regions of the Antarctic Ocean (Lamb 1956, especially pp. 22–3), and monthly situations back to the beginnings of a usable, instrument-observations network around 1700 – methods described in Lamb (1977), Lamb and Johnson (1966) – in all these cases subjected to subsequent tests. The tests were designed to show the magnitudes of the random errors to which the sparsely covered parts of the maps were liable and to identify where the effects of bias and misconceptions came in beyond the limits of any observation coverage. This determined the limits of the area which could be meaningfully analysed at all.

There is no doubt that, in the case of synoptic maps of the situation at a particular time on a particular day, modern understanding of frontal patterns primarily due to Bergeron (1928, 1930), Refsdal (1930), van Miegham (1936), and Pettersen (1936) (verified and continually demonstrated in recent years by satellite imagery (Lamb, 1988)) has materially improved the possibilities of outlining barometric pressure patterns over sparsely covered parts of a synoptic map and has reduced the error margins.

The magnitude of the present survey of historic storms, and of the task of gathering the data and reconstructing the meteorological situations involved, was too great to allow time for very extensive testing. Sporadic testing of various kinds was done in the earlier stages of the work and has been indicated on p. 5. The plan of work in this survey was to explore and demonstrate first how much interpretation was possible, and what its geographical limits were, by particularly thorough synoptic analysis of a rather small number of plainly very severe storms for which data coverage was particularly good: in 1703, 1717, 1791, 1792, 1795 and 1825. In most of these cases conditions at 40 to 60 places were entered on the original working charts. Tests applied to the resulting maps in the 1790s are among those reported with our storm accounts. Later, the difficult early storm in 1694 was analysed step by step (including diagnosis of the precise date of the storm) in a process that supplied some further tests of the method. For each of these storms, sequences generally of 10 days to a month (in 1694, just 7 days; in 1791, 36 days) were submitted to rigorous synoptic meteorological analysis. Developments were traced forwards and back and the maps drawn and corrected through much trial and error until, by successive approximations, the greatest possible continuity from day to day throughout the sequence was attained.

This work is illustrated here by texts covering just the most relevant runs of a few days to show the development of each of these storms. The great majority of other storms studied were analysed over shorter runs of just three to six consecutive days and are illustrated mostly by just one or two days analysed maps.

In the period since the first State meteorological services were founded,* and began publishing daily weather maps (which were soon increased to several times daily), these maps have been used and adapted as necessary to fit a satisfactory frontal analysis. The original maps used have been variously those of the British, Danish, and German weather services, including the remarkable series of daily weather maps stretching across the Atlantic from North America to eastern Europe produced between 1873 and the early part of the twentieth century by cooperation between the Danish Meteorological Institute and the Deutsche Seewarte, Hamburg.

In all, over 166 storms are studied here in the 144 reports. These include:

11 in the sixteenth century
25 in the seventeenth century
32 in the eighteenth century
35 in the nineteenth century
63 in the twentieth century

Among the twentieth century cases some less severe storms have been included to illustrate a greater variety of types of situation.

This draws attention to the need for some system or systems of grading the storms in all stages of the history.

*The first was the department of meteorology in the British Board of Trade, London, in 1855 under Admiral Fitzroy.

2

Grading of storms

While the storms here catalogued were chosen for study because they had acquired historical note in one way or another,[1] it is obvious upon inspection that storms of a considerable range of severity are included. In what follows it has been thought useful to rank the storms separately in terms of:

(i) The *greatest wind speeds* indicated at the surface:
  (a) as measured in gusts
  (b) the greatest mean speeds over a period of 10 minutes or, here usually, over an hour

  In practice, measurements of the pressure gradient, and hence the gradient wind (the wind indicated by the pressure gradient) are often the most convenient way of obtaining representative values for comparisons between many different storms.

(ii) The *greatest area covered at any stage by winds causing widespread damage*. We have used gradient winds of more than 50 knots as our criterion for a damaging wind, since this indicates likelihood of some gusts of 50, to sometimes 60, knots or more at the surface. By definition storm force 9 on the Beaufort scale (38–44 knots) damages chimney pots and branches of trees, force 10 (45–52 knots) uproots trees and causes severe damage to buildings. (For the full Beaufort scale and other windscales see the appendix following the account of the great storm of 1703.)

  It seems, however, scarcely possible to assess the *greatest area* covered by damaging winds *at any stage* in the life of a storm in the historical past. It would also be of interest, and perhaps more feasible in some historical cases, to compare the total areas affected by damaging winds in the life of different storms, but this was not feasible in the present study.

(iii) The *total duration of the occurrence of damaging winds* during the life of different storms. For many purposes it must also be useful to compare the duration of winds of damaging strength at particular places of interest.

The severity of storms should also be considered in relation to the expectation (frequency) of high wind speeds in the area concerned. The great storm in 1987, which wrought widespread havoc in the south of England, reminiscent of that in 1703, and produced gusts of 119 knots on the north coast of France, 100 knots on the south coast of England at Shoreham, Sussex, and over 90 knots in the Thames estuary and far inland at Wittering near Stamford, is seen as a far greater extreme when viewed against the averages in that region. Figures in the Climatological Atlas of the British Isles (Meteorological Office, 1952) for the average number of days a year with gale[2] over a sample 20-year period 1918–37 are about two in the London area and most of central England including Wittering, five in the Thames estuary, and ten to 15 on the Sussex coast, compared with over 30 in the Shetland Isles and coasts of northwest Scotland as well as the most exposed coasts of southwest England, west Wales and west and northwest Ireland. Higher figures, up to 40 or more are believed to occur in two areas on the coast of Norway near 62° and 65° N (Børresen, 1987). Our Storm Severity Index figures indicate, however, that storms in the severest class occasionally bring very severe gales to places far outside the zone where such phenomena are most frequent. This is in line also with the fact that the differences between the strongest winds ever so far reported in northern Scotland or about the Norwegian Sea and on the coasts of the southern North Sea, the Channel, and elsewhere around the south of the British Isles is not so very great: about 120 to 160 knots in those northern areas – the values above 130 knots probably all associated with hill-top or other sites affected by convergent air flow – compared with 100 to 120 knots at the southern coasts mentioned.

Storm Severity Indices

From another point of view there seems to be a requirement for *an overall Storm Severity Index*. This should presumably be of the following design:

$$V_{max}^3 \times A_{max} \times D$$

where V_{max} is the greatest surface wind speed
A_{max} is the greatest area affected by damaging winds
D is the overall duration of occurrence of damaging winds (or, alternatively, the duration in some place or area of interest).

We use the cube of the wind speed in conformity with Landsberg's 1941 definition of Wind Power.[3]

[1] The criterion of historic severity has been relaxed a little in the case of some storms, mainly since 1930, the inclusion of which seemed likely (a) to be valuable to demonstrate some further variety in the types of development of severe storms, and (b) to help establish the lower points of our scale of severity.

[2] *Gale* defined as mean wind over a 10-minute period exceeding 33 knots, i.e. Beaufort force 8 or over. The figures for numbers of days with gusts over 50 knots at the British stations here mentioned are almost identical (Meteorological Office, 1968).

[3] The dynamic pressure of the wind is proportional to the square of the wind speed, but the wind power (as, for instance, exercised in windmills or in the destruction wrought by storms) is a matter of the work done by the wind and thus involves the dynamic pressure multiplied by the run of the wind: hence the cube of the wind speed.

To obtain our desired numerical severity ratings it will be sufficient to express each item in the units in which they are commonly measured (knots for wind speed, hours for duration of winds of damaging strength, and metric units for area – in practice, it is convenient to use units of 10^5 km^2 for the areas affected by damaging winds, since this produces a readily manageable range of numbers). There is nothing to gain in this case by conversion to a uniform system of units.*

Clearly, assessments of the areas and durations of damaging winds can only be rather rough in the case of storms from the historical past. They are in nearly all cases best made from measurements of the gradient winds at various stages in the life of the storm or from comparisons with more recent storms which seem to conform to a similar model.

It must be hardly surprising in the case of storms of the past, even of the fairly recent past, that however careful the meteorological analysis there is an awkward margin of uncertainty resulting from inevitably somewhat free-hand estimates of the areas covered by winds of damaging strength and of their duration. The calculations nevertheless do provide the basis for recognizing several grades of severity. They will also serve to indicate what measurements, and what methods of mapping them, should be made to assess the severity of storms occurring in the future.

In order to narrow the margins of uncertainty, the author spent some weeks examining critically the comparability of storms listed in this survey, repeating the assessments and calculations of index values up to five times before being satisfied that the best attainable series of estimates had been reached.

Other assessments of severity

Altogether different ratings of storms which seem likely to be useful in some connexions include rankings in terms of:

(iv) Total damage to the landscape, particularly to coasts, e.g. by sea floods, erosion by wave action, or blown sand and sediment transported by the currents and by waves.
(v) Total damage to property (buildings, agricultural land, orchards and forests).
(vi) Numbers of human and animal lives lost.
(vii) Insurance claims arising and costs (over however many years) of restoration and measures for future protection.

It will be seen from the following lists that the storms found to be the most severe ones on these different criteria produce different lists. Also the different considerations in mind critically affect the perceptions of different observers and the reports they leave to posterity.

Were we to confine our attention to the storms affecting different smaller regions, again the ones appearing as most severe would be different. Here, for this first exploratory survey of the storms over a long period of time over the land and seas around northwest Europe, severity index calculations have been applied solely to the whole area between about 45° and 65° to 70° N and between 20° W and 15° to 20° E (Figure 1). Nevertheless, it should be useful to recalculate the severity of each storm in terms of the wind speeds, duration, and the areas affected by winds of damaging strength, within each smaller region of interest, such as Ireland, Scotland, England, North Sea, Denmark and so on.

*To correct square kilometres to square nautical miles one could divide the areas here quoted by 3.5 approximately and the resulting Storm Severity Index figures would all be reduced in the same proportion.

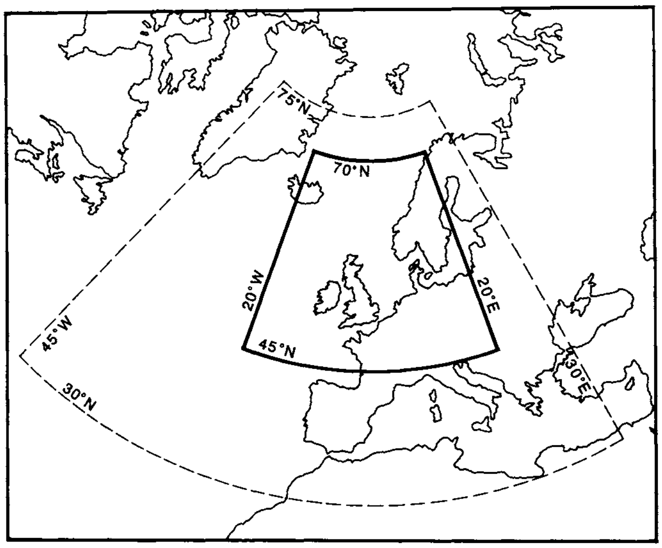

Figure 1. Map to show approximate limits of the main region of interest used in Storm Intensity Index assessments and of the extended area surveyed when the situation permitted.

The resulting lists

A. *The storms surveyed in order of Severity Index ratings*

In this list some early storms with insufficient data for analysis have been given supposed ratings on the basis of analogies with later storms apparently similar in type or the scale of their effects. Such suggested ratings have been placed in brackets. Brackets are also used in this list to indicate uncertainties about the precise date of some early storms. All the dates here listed are on the modern (Gregorian or 'New Style') calendar.

The time distribution of these storms is shown in Figure 2.

Date	*Storm Severity Index*	*Remarks*
15.12.1986	About 20 000	Not within our central region of interest
10–12.12.1792	10 000–20 000 (taken as 12 000)	
4.2.1825	About 12 000	
(31.10–2.11.1694)	(About 10 000)	Much indirect deduction – some basic assumptions open to question
7–8.12.1703	9000	
22.10.1634	(About 8000)	
6–7.1.1839	About 8000	
16.10.1987	8000	
14–16.10.1886	7000	
11–12.11.1570	(About 6000)	Inadequate data – some necessary assumptions about length of fetch of

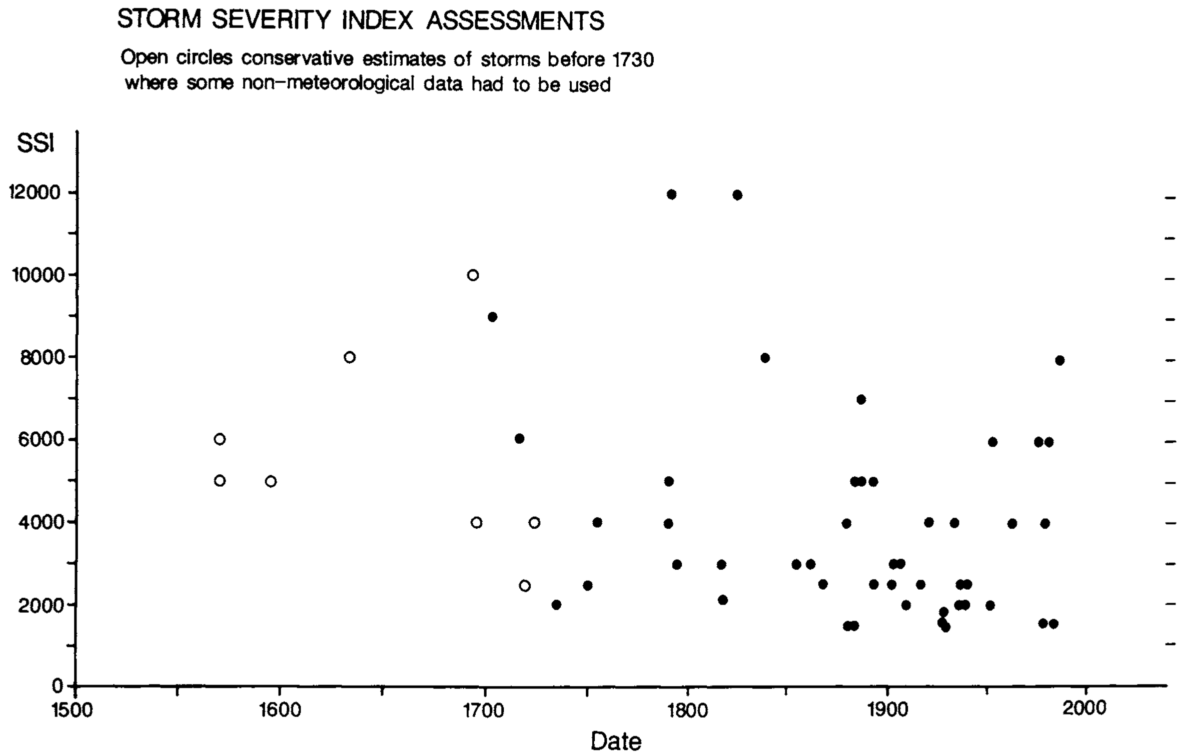

Figure 2. Time distribution of storms among those studied in this survey with Severity Index assessments over 1500.

Date	*Storm Severity Index*	*Remarks*
		the storm over the Norwegian Sea
24–25.12.1717	About 6000	
31.1.–1.2.1953	6000	
2–3.1.1976	6000	
23–25.11.1981	6000	
(About 1570)	(About 5000)	Inadequate data: first of the great inland sand drift episodes in the Norfolk and Suffolk Breckland
21–22.3.1791	About 5000	NW to NNE'ly part of this storm – over the northern North Sea
25–27.1.1884	5000	
8–9.12.1886	5000	
17–19.11.1893	5000	
(Jan. to Feb. 1595)	(Probably 5000 approx.)	
1–2.10.1697	(About 4000)	Assumptions about coherence of the observation data open to question
(In or about 1725)	(About 4000)	Inadequate data
7.10.1756	4000	
21–22.3.1791	About 4000	The W'ly to NW'ly part of this storm – over the southern North Sea
28.12.1879	4000	
26–27.1.1920	4000	

Date	*Storm Severity Index*	*Remarks*
9.4.1933	About 4000	Mainly north of 65° N
16–17.2.1962	4000	
4–5.12.1979	4000	Largely coast of Norway north of 60° N
6–9.5.1795	About 3000	
12–16.1.1818	About 3000	Overall severity rating of prolonged storm with several separate phases
1.1.1855	3000	
26–27.12.1862	3000	
26–27.2.1903	3000	
12–13.3.1906	3000	
(About 1720)	(About 2500)	Imprecise data and no surrounding coverage
11.9.1751	2500	
24.1.1868	2500	
11–12.2.1894	2500	
25–26.12.1902	2500	
16.12.1916	2500	
28.1.1927	2500	
17–19.1.1937	2500	
23–24.11.1938	2500	
15–16.1.1818	About 2200	
19.1.1735	2000	
3.12.1909	2000	
26–27.10.1936	2000	
15–17.12.1938	2000	
30.12.1951	2000	

Date	*Storm Severity Index*	*Remarks*
23–25.11.1928	1800	
6.1.1928	About 1600	
14–15.10.1881	1500	
6.3.1883	1500	
5–7.12.1929	1500	
11–12.1.1978	1500	
1.2.1983	About 1500	
21.9.1588	(About 1200)	Some indirect deduction of wind strengths
27.2.1736	1200	
5.12.1792	1200	
11.3.1822	1200	
27–29.11.1836	1200	
17–19.10.1936	1200	
14–15.9.1786	About 1000	
21–22.12.1792	1000	
23.12.1954	1000	
18.1.1983	1000	
25.1.1739	800–900	
12.11.1740	(About 800)	Data hardly adequate
19.9.1741	(About 800)	Data hardly adequate
12–13.1.1818	About 800	
21.2.1861	800	
28–29.10.1927	800	
13.2.1989	800	
22.9.1695	(About 700)	
12–13.11.1972	700	
2.4.1973	700	
14–18.8.1588	(About 600)	Some indirect deduction of wind strengths
14.8.1737	600	
16–17.9.1961	About 600	
22.10.1702	(About 500)	
18–19.9.1740	500	
28–29.11.1897	500	
16–17.11.1928	500	
10–13.2.1938	500	
9–10.3.1751	About 400	
2–3.1.1784	About 400	
14.10.1829	400	
20–21.10.1846	About 400	
5.12.1938	400	
21–22.12.1954	400	
29.7.1956	400	
23–25.8.1957	400	
20.4.1773	(About 300)	Data hardly adequate
25–26.12.1783	About 300	
7–8.12.1792	300	
25.11.1829	300	
18–19.11.1835	300	
23.11.1836	300	
10–11.11.1931	300	
15.1.1938	300	

Date	*Storm Severity Index*	*Remarks*
7.2.1969	300	
13–14.2.1979	300	
28.12.1849	200–300	
9–10.3.1891	About 250	
5.12.1937	250	
9–10.2.1949	250	
23–25.10.1949	250	
23.2.1967	250	
4.9.1967	250	
27–29.10.1859	200	
24.3.1895	200	
26.10.1949	200	
17.12.1952	200	
13–14.8.1979	200	
9–10.2.1988	200	
3–4.3.1988	200	
10.1.1849	150–200	Data hardly adequate
1.3.1791	150	
3–4.8.1829	About 150	
15–16.6.1869	About 150	
27.3.1878	150	
1–2.6.1938	150	
14–15.1.1968	150	
19.11.1973	150	
6.12.1773	150	
27.3.1980	150	
7.9.1838	About 100	
15–16.1.1818	Under 100	
22–23.12.1937	About 50	
23–24.2.1939	Under 50	
6.3.1967	Under 50	

Classes of severity: suggested definitions

While remembering that one must remain sceptical about the placing of storms assessed near the arbitrarily chosen boundary of any class, it seems reasonable to divide the above list of storms into broadly the following grades or classes of severity:

	Severity Index	*Number in class*
Class I	5000 or over	14 storms fully analysed (15 including the 1986 example over the Atlantic, 20 including indirectly assessed early cases)
Class II	Between about 4000 and 1800	28 storms analysed (31 including early cases indicated)
Class III	Between about 1600 and 700	24 storms analysed (26 including early cases indicated)
Class IV	Between about 600 and 300	24 storms analysed (26 including early cases indicated)

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Class V	Between about 250 and 150	24 storms
Class VI	100 or less	

B. *Greatest wind speeds noted in the storms studied since the earliest cases with either measurable pressure gradients or measured wind observations*

These cases (34 in all) are placed in chronological order rather than in order of wind speeds, since the indications in many cases gave about the same maximum wind speeds, within the accuracy of which the data and methods of analysis allow.

Date	*Strongest wind indicated (knots)*	*Region*
7–8.12.1703	Gradient winds from SW to W c. 150	England and southern North Sea to Denmark
25.12.1717	Gradient winds between SW and NW up to 130	Eastern North Sea and Denmark
19.1.1735	Gradient winds SW'ly perhaps 110	Southeast England and fringe of continent
25.1.1739	Gradient winds from WSW up to 110 suspected. (No map)	Limited zone across British Isles and North Sea 53° to 57° N
11.9.1751	Gradient winds NW'ly over 100, possibly up to 150	North Sea
7.10.1756	Gradient winds from SW to NW over 100, possibly up to 150	North Sea
21–22.3.1791	Gradient winds from WSW probably up to 150	Central North Sea to German Bight
22.3.1791	Gradient winds from N to NNE about 120 to 130	Northern North Sea and Britain's east coast
10–11.12.1792	Gradient winds from WNW to NNW probably 140 to 150	Widely over England and the continental fringe from Flanders to the German Bight
10.12.1792	Gradient winds W'ly 150±30	Faeroes–Shetland region of northeast Atlantic
15.1.1818	Gradient winds W'ly up to 120	Over and around Denmark
1.2.1825	Gradient winds NW'ly about 140	Over Scotland and neighbouring sea areas to north and east
3–4.2.1825	Gradient winds mainly NNW to NNE up to 120 to 140	Over northern, western, central, and southeastern parts of the North Sea
6–7.1.1839	Gradient winds between SW and NW, SE to S at first in southern Scandinavia: 90 to 100, perhaps stronger later in Denmark and Baltic	Over Britain north of 54° N, the North Sea and Denmark
1.1.1855	Gradient winds NW'ly 100 to 120	Over Britain and the North Sea
26–27.12.1862	Gradient winds W to NW'ly possibly up to 150	Over northern Britain, North Sea and Denmark
24.1.1868	Gradient winds S to SW'ly perhaps reaching 140	Over western and northern parts of the British Isles and northern North Sea
25–26.1.1884	Gradient winds from about W probably 120 to 140	Across England and Wales and the Channel and later (SW'ly) over the continental fringe and the North Sea
9–10.3.1891	Gradient winds from E, in a very localized strip near the front, perhaps about 100	Southernmost England and the Channel
27.1.1920	Gust in a S'ly gale at Spanish Point near Quilty, Co. Clare (Ireland) reached 97. Gradient wind about 80	Atlantic fringe of the British Isles
6.12.1929	Gust in a SSW gale in the Scilly Isles reached 96. Gradient wind about 75	All British Isles affected
9.4.1933	Gust in a N'ly gale at Jan Mayen (71° N 8° W) 163 – highest value ever recorded. Gradient wind apparently about 80. Extreme gust probably not widely representative, probably attributable to topographical effects of the great mountain Beerenberg on the island – lateral convergence or lee waves	Greenland Sea–Norwegian Sea
30.12.1951	Gradient wind W'ly perhaps 130 to 150. Gust to 94 at Millport on Bute in the inner isles of western Scotland	Scotland, northernmost Ireland and northern North Sea
31.1.–1.2.1953	Gradient winds from about N 100–130 (regarded as 'phenomenal' measurements at the time). Gust to 109 at Costa Hill, Orkney	North Sea and its coasts and most of the British Isles
16–17.9.1961	Gusts to 98 at Malin Head and over 90 some way inland from the west and	Atlantic fringe of Ireland and Scotland