CLIMATE, HISTORY AND THE MODERN WORLD

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THROUGH VIKING TIMES TO THE HIGH MIDDLE AGES

ASYMMETRY OF THE MEDIEVAL WARMTH OVER THE NORTHERN HEMISPHERE

As indicated in the last chapter, there seem to have been some regions of the world – particularly in low latitudes and in the Antarctic, possibly also around the north Pacific and in parts of the Arctic – where the rather greater warmth of the climate established around AD 300–400 continued, with variations but more or less unbroken, for several centuries longer and in some cases right through to AD 1000–1200. In Europe and much of North America, as well as in the European Arctic, there clearly was a break. But by the late tenth to twelfth centuries most of the world for which we have evidence seems to have been enjoying a renewal of warmth, which at times during those centuries may have approached the level of the warmest millennia of post-glacial times.

China and Japan evidently missed this warm phase. A warm period can be discerned in the historical records in those countries from about AD 650 to 850, more or less covering the time when Europe had its colder break. But in the eleventh and twelfth centuries the data collected by the late Dr Chu Kochen make it clear that the climate of China took a much colder turn, with frequent references to snow and ice in the winters and snows a month later in spring than in the present century. The plum trees were disappearing in north China; frosts killed the mandarin trees in the coastal province near Shanghai and the lychees in parts of the south. In Japan the long records of the dates of the cherry blossom in the royal gardens at Kyoto indicate on average the earliest springs in the ninth century and the latest springs of the whole record in the twelfth century, when the mean date was a fortnight later than it had been three hundred years earlier. There are hints that this was a cold time generally in and around the wide expanse of the North Pacific Ocean. If so, part of the explanation of the medieval warmth in Europe and North America, extending into the Arctic in the Atlantic sector and in at least a good deal of the continental sectors on either side, must be that there was a persistent tilt of the whole circumpolar vortex (and of the climatic zones which it defines) away from the Atlantic and towards the Pacific sector, which was rather frequently affected by outbreaks of polar air.

In this chapter we shall concentrate our study on the Atlantic side of the hemisphere and the lands where the warmth of the high Middle Ages was most marked, since it happens that these are the areas where both the climatic and the human historical record are at present most accessible.

THE MEDIEVAL SEQUENCE IN NORTHERN EUROPE AND THE NORTHERN ATLANTIC

The reconstituted western empire of Charles the Great did not coincide with a particularly favourable climatic period. Nor did it last very long. The campaigns by which it was established between about 770 and 800 seem to have been in a time with more than usual tendency to cold winters; the other seasons, although perhaps more often dry than wet, revealed both drought years and some years when floods created difficulties. There is a suggestion in this that it may have been one of those times when 'blocking of the westerlies' by anticyclones in this or that longitude in 45–65 °N was frequent, with a consequent disposition to extreme seasons of various, even opposite, sorts depending on where the stationary anticyclone lay: but further evidence is required before we can be sure of this.

Where there is no reasonable doubt is that over the next three to four centuries, as reports indicating the character of the seasons in Europe become more numerous, we see that the climate was warming up (cf. figs. 30 and 59), until there came a time when cultivation limits were higher on the hills than they have ever been since. Trees seem also to have been spreading back towards the heights. Certainly the upper tree line in parts of central Europe (cf. fig. 53) was 100–200 m higher than it became by the seventeenth century. The isotope record from the Greenland ice-sheet (fig. 36) shows us that the climate had already been in a relatively warm phase in the far north since AD 600, though the warmth there too was becoming more sustained and was increasing. On the heights in California the tree ring record (fig. 52) indicates that there was a sharp maximum of warmth, much as in Europe, between AD 1100 and 1300.

The variations shown by the more than one-thousand-years'-long record of the tree rings in European oaks from the lowlands of Germany are harder to interpret climatically, because both temperature and rainfall come into it. The records from different areas agree in producing the extreme narrowest and the extreme widest ring series both within the times covered by this chapter. The extremely narrow rings prevailing in the tenth century, especially between about 910 and 930 and again in the 990s, must surely indicate prolonged and repeated drought. One cannot suggest that any general coolness of the summers was responsible; the sparse documentary

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records point more to some of the summers being notably hot. The impression on present data is rather that the tenth century saw a remarkable amount of anticyclonic weather over Britain, Germany and southern Scandinavia, giving low rainfall, rather warm summers and rather cold winters. The latter point seems to be confirmed by the numerous bone skates revealed by the archaeological investigations in York from the Anglo-Scandinavian period in that city. The other extreme of the German oak chronologies occurred between about the years 1052 and 1160, when the decade average ring widths were 35–80 per cent wider than in the tenth century. We may deduce, if not excessive wetness (apart from isolated years), at least more moisture than in the 900s and general warmth of the growing seasons. Of this warmth we shall see further evidence in the following pages.

There is no mistaking the fact that there was a general opening out of the European world in the period we are considering in this chapter. How much of it was directly dependent on the more genial climatic regime which developed?

There had been European seafarers occasionally wandering out over the northern Atlantic long before Viking times. Prominent among them were Irish monks apparently seeking peaceful shores on which to establish a foothold far from the troubled times of cultural decay and barbarian migrations in Europe in the fifth and sixth centuries and after. It has been suggested that the annual migrations of the wild geese to and from Iceland and the Arctic gave them confidence that there was land to find in the north. One must suppose that there is some substratum of fact in the legendary voyage of St Brendan at some time between around AD 520 and 550 and that he got far enough in the direction of Greenland to encounter icebergs. Certainly Dicuil, an Irish monk writing AD 825,[1] assures us that

> there are many other islands in the ocean . . . which can be reached in two days and two nights direct sailing from the northernmost parts of the British Isles with full sails and a fair wind. . . . Some of these islands are very small . . . separated from one another by narrow sounds. On these islands hermits who have sailed from our Scotia [i.e. Ireland] have lived for about a hundred years. But, even as they have been . . . uninhabited from the world's beginning, so now because of Norse pirates, they are empty of anchorites, but full of innumerable sheep and a great many different kinds of seafowl.

The islands here described are by general agreement the Faeroes, which were therefore settled by Irish monks as early as about AD 700–25. (I have used the translation given by Gwyn Jones in *A History of the Vikings*, Oxford University Press, 1968.) But they left around 800, when the Vikings first appeared. The Vikings' first recorded exploration to Iceland (under Floki Vilgerdason) was not until about 860, though two earlier Scandinavian voyages had been blown there accidentally a few years before. The Norse settlement on the island seems to have begun during the 860s. But they found that Irish monks had preceded them. Dicuil reports one visit as early as the 790s. The Irish account records that the sea was frozen one day's sail north from Iceland, and Floki's party observed one of the big fjords of northwest Iceland (Arnarfjord) choked with ice. But after that time there is little mention of ice – only brief and, according to Lauge Koch,[2] doubtful reports of it in 1010–12, 1015, 1106, 1118 and 1145 – on the seas near Iceland until the 1190s, when it reappeared in some strength between Iceland and Greenland, and in July and August of the year 1203 it was at the coast of Iceland.

It seems likely that the beginning of the era of Scandinavian sea-going explorations, as of the rough story of Viking raids which harried the coasts of Europe from the 790s onwards, came with the mastery of sail by the northern peoples. Even then, they had no lodestone or compass until centuries later. But the spread of their voyages north into the Arctic and west to Greenland, and ultimately to Newfoundland and apparently into the Canadian Arctic north of Baffin Island, surely owed a great deal to the long period of retreat of the sea ice and probably a relative immunity from severe storms. Ottar, or Othere, whose home was in north Norway, told King Alfred in England of an exploration he had made about AD 870–80 beyond the customary range of the whalers of those days, evidently to the White Sea. And Harald Hardråde who was king of Norway and England is reported by Adam of Bremen to have explored 'the expanse of the Northern Ocean' some time between 1040 and 1065 with a fleet of ships, beyond the limits of land (Spitsbergen or Novaya Zemlya?) to a point where he reached ice up to 3 m thick and 'there lay before their eyes at length the darksome bounds of a failing world'. The medieval Icelandic sailing directions covered voyages, reckoned to take four days, north to Svalbard 'in the polar gulf', which it seems from the sailing time must have meant the east Greenland coast between 70 and 72 °N (not the Spitsbergen archipelago, to which the name is now applied). This coast was discovered in 1194; and seals, walrus and whales were hunted there already before the year 1200. Very soon, however, the increasing ice evidently put a stop to this, and the same coast seems to have been rediscovered in an easier year about 1285; but by 1342 the ice was so much increased that the old sailing route from Iceland to Greenland at the 65th parallel of latitude had to be abandoned for one farther south. Later, communication with Greenland was lost altogether.

The North American coast, Vinland (or Wineland) to the Norsemen, like Iceland and Greenland (where the first Norse settlement was established in the 980s) before it, was discovered by accident, by ships being blown off course, about AD 1000. The site of only one settlement, at L'Anse aux Meadows in northern Newfoundland, has so far been discovered, though another farther south is also referred to in the sagas. It seems, in any case, that the settlement and the America voyages were discontinued after a few years, and it appears that difficulties with the native inhabitants rather than weather or sea ice were the cause. Further accounts indicate that crossings from the Old Norse settlements in west Greenland to Markland (Labrador) were resumed much later, in the fourteenth century (one as late as 1347), when the climate and ice conditions had deteriorated and communications with Europe had almost ceased, to collect timber for building.

That the waters off west Greenland in the heyday of the Norse settlements were at least as warm as in the warmest periods of the present century is indicated by the abundance of cod which the inhabitants caught, the bones of which are found in their middens. We may probably safely conclude that an even greater warm anomaly occurred in the quiet waters within the fjords of southern Greenland west of Cape Farewell from another circumstance, a rare case where the limits of tolerance of man himself may yield reliable information on past temperatures. For it is recorded in the *Landnámabók*, a book written in Iceland about 1125 cataloguing the settlement of Iceland a couple of centuries earlier and describing the Old Norse settlement of Greenland between AD 985 and 1000, that one of the first Greenland settlers, Thorkel Farserk, a cousin of Erik the Red who founded the colony, having no serviceable boat at hand, swam out across Hvalseyjarfjord to fetch a full-grown sheep from the island of Hvalsey and carry it home to entertain his cousin. The distance was well over two miles. Dr L. G. C. E. Pugh of the Medical Research Laboratories, Hampstead, has given his opinion, from studies of the endurance of Channel swimmers and others undertaking similar exploits, that 10 °C would be about the lowest temperature at which a strong person, even if fat, not specially trained for long-distance swimming, could swim the distance mentioned. As the average temperatures in the fjords of that coast in August in modern times have seldom exceeded 6 °C (+3 to +6 °C being more typical), it seems that the water must have been at least 4 °C warmer than this limit in the year in which Thorkel swam it and brought home his sheep.

Other items point to a similarly great departure of the temperatures ashore in that area: for Old Norse burials took place deep in ground which has since been permanently frozen. It is harder, however, to be sure of the climatic implications of another report from the time of the old Greenland colony. Lauge Koch cites a medieval report that in 1188 or 1189 – i.e. at a time when the climate in the area may already have begun to be colder and the sea ice to reach somewhat farther down the coast towards south Greenland – a ship, the *Stangfolden*, on passage from Norway to Iceland came to be wrecked off the east coast of Greenland. Some years later, about 1200, the dead bodies of seven of the ship's company were found in a rocky cave near that coast, among them the clergyman Ingemond who had left a written report in runic letters on their fate beside him. Ingemond's brother, also wrecked about the same time, is reported to have succeeded, with two other men, in crossing the southern part of the inland ice, only to perish when near the main Norse settlement in Greenland, the so-called East Settlement (actually their southernmost settlement), a little west of Cape Farewell. This suggests that the inland ice in that neighbourhood was not thought of as such a hostile environment that one would not venture on it in an emergency, but nevertheless the going would be easier in the absence of melting and a crossing would doubtless require some days of reasonably good weather without strong winds.

By about AD 1250 the *King's Mirror* (*Konungs Skuggsjá*), a Norwegian work of that time, reports that

> as soon as the great ocean has been traversed there is such a great superfluity of ice on the sea that nothing like it is known anywhere else in the whole world and it lies so far out from the land that there is no less than four or more days journey thereunto on the ice, but this ice lies more to the NE or N outside the land than to the S and SW or W.

A further passage about Greenland around 1250 in the same work reports that 'men have often tried to go up into the country and climb the highest mountains to look about and see whether there was any land free from ice and habitable'. A number of reports indicate that in this period of the early stages of the climatic deterioration the Norse Greenlanders were induced once more to roam more widely afield in search of materials and hunting food, including penetration farther north than before to the west of Greenland, reaching Baffin Bay and making contact with the Eskimos who were tending to move south.

Having to this extent taken the measure of the early medieval warm period at the limits of the Arctic region reached by the contemporary Europeans, let us now look at the evidence from other regions. The northern limits of the cultivation of grains show a corresponding expansion of range during the centuries with which this chapter is concerned. Grain was grown in Iceland from the time of the first Norse settlers there, apparently fairly continuously, until its abandonment in the late sixteenth century. There was also undoubtedly more scrub birch woodland there in the early days of the settlement than at any time since, though the settlers themselves seem to have been largely responsible for its destruction. Its area is believed to have been reduced from perhaps a fifth of the country to 1 per cent by the thirteenth century. Investigation by Dr G. S. Boulton, with colleagues from the University of East Anglia and from Iceland, of a farmhouse site at Kvisker in southeast Iceland that has been occupied for a thousand years revealed that the oldest of the successive houses on the site, dated before the volcanic ash layer of AD 1090, was the biggest and richest.

Fig. 62 One of the ancient farms, Svinafell, in southern Iceland, established in the earliest settlement times on a south slope. A great glacier can be seen now filling the valley close to the site of the farm. (Kindly supplied by Dr Sigurdur Thorarinsson of Reykjavik and reproduced by permission.)

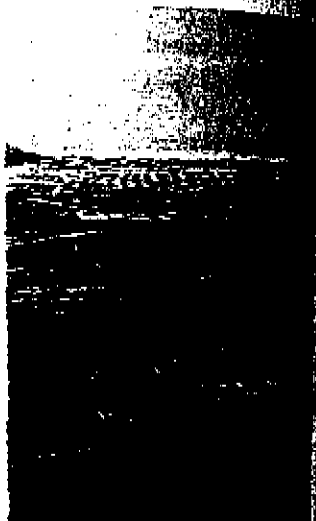
Its midden contained relics of diverse and luxurious foods, including (imported) oysters. And the forest surrounding the farmed land there produced birch stumps of a good size, never attained since. From pollen analysis it appears that the farmer at Kvisker gave up growing oats about AD 1200 and reduced the amount of barley grown by about a half. In the next century much of the ground was covered by river gravels and part of it by a glacier (see fig. 62).

THE PEAK OF MEDIEVAL WARMTH IN EUROPE

In Norway some kind of corn, probably barley, was grown as far north as Malangen (69½ °N) in north Norway, at least from Ottar's time (around 880) until the eleventh century, and wheat in Trøndelag, the district about Trondheim, where pollen studies and other records again indicate that it came to an end sharply in the later Middle Ages. Professor Andreas Holmsen[3] reports that it was just between about AD 800 and 1000 that the area of forest clearance and settled farming in Norway, which had long remained more or less static, spread 100–200 m farther up the valleys and on to the higher ground. Most of this ground was lost again after AD 1300.

Fig. 63 Relics (ridge and furrow) of medieval tilled fields between 350 and 400 m (1150–1300 ft) above sea level on the heights of Dartmoor in southwest England beside the abandoned settlement of Houndtor which lies just to the left of the picture. The Greator rocks are seen in the picture. (Photograph, copyright by G. Beresford, who kindly supplied it for this book.)

Fig. 64 Ridge and furrow, the result of thirteenth-century tillage, seen on the fells on a south-facing slope above Redesdale, Northumberland at 300–320 m above sea level.



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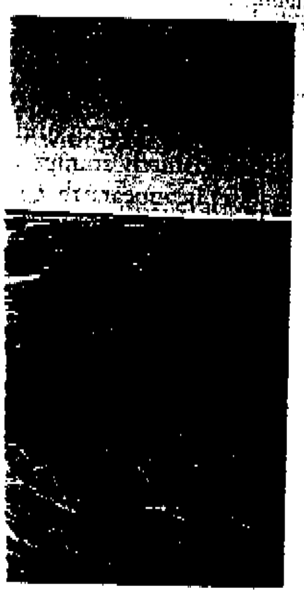

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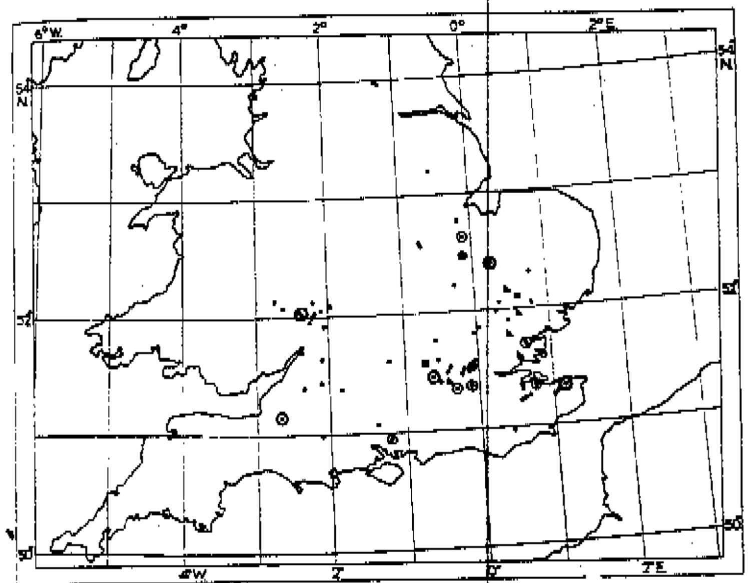

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- Vineyard, usually 1–2 acres or size not known.
- Vineyard, 5–10 acres.
- Vineyard, over 10 acres.
- ○ Denotes evidence of continuous operation for 30–100 years.
- **○** Denotes evidence of continuous operation for over 100 years.

Fig. 65 The distribution of known medieval vineyard sites in England.

In many parts of Britain, also, tillage was extended to greater heights than for some long time previously or since, on Dartmoor in the southwest (fig. 63) to about 400 m (1300 ft) and in Northumberland, near the Scottish border (fig. 64) to 320 m (1050 ft). In AD 1300 one grange at 300 m (roughly 1000 ft) above sea level, belonging to Kelso Abbey, in the south of Scotland had over 100 hectares of tillage, 1400 sheep and sixteen cottages for shepherds and their families. An approximate gauge of the temperatures prevailing in the summer half of the year in England and central Europe, serving as a check upon the figures derived by the method used in fig. 30 and explained on pp. 84–5, may be obtained by consideration of the limits of vine cultivation in the Middle Ages and comparing the present climates of those sites with the modern limits of wine production. Fig. 65 is a map of the distribution of known medieval vineyards in England. The comparison indicates that the average summer temperatures were probably between 0.7 and 1.0 °C warmer than the twentieth-century average in England and 1.0–1.4 °C warmer in central Europe. (The quality

Fig. 66 The medieval English vineyard site at Tewkesbury, Gloucestershire. The ground slopes gently northwards to a ditch in the middle ground of the picture. Surely a frost hollow site, which suggests that the medieval cultivators were not much troubled with late frosts in May after blossom time.

of the English medieval wine is indicated by the efforts of the French trade at that time to have them closed down under a treaty). In England particularly it seems that there must have been less liability to frost in May in the period between 1100 and 1300. (Fig. 66 is interesting in this connection.)

Thus, it seems that the great period of building of cathedrals in the Middle Ages, in what Kenneth Clark[4] has called the first great awakening in European civilization, and the sustained outburst of energy of the European peoples, which produced among other things the more controversial activities of the Crusades, coincided with an identifiable maximum of warmth of the climate in Europe. Hugh Trevor-Roper[5] makes no comment on the climate but notes the time around AD 1250 as the turning point:

> the highest point of the European Middle Ages. . . . Up to that date we see – from about 1050 onwards – only advance . . . growth of population, agricultural revolution, technological advance. The frontiers are pushed forward in all directions. . . . Already in the middle of the thirteenth century the territorial expansion had been halted . . . in 1242 the eastward advance of the Teutonic knights . . . was

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The warm phase, which had already passed its peak in Greenland in the twelfth century, seems to have broadly continued in Europe until 1300 or 1310 though with a marked increase in the incidence of severe storms in the North Sea and the Channel and with flooding disasters on the low-lying coasts. The warmth may even have reached its maximum at this late stage: for there are documentary records to tell us that it was in the 1280s that the tillage reached so high on the Pennines and Northumbrian moors that there were complaints from the sheep farmers that too little land was left for grazing. Such a peak of warmth in the last stages before Europe itself was affected by the down-turn of temperatures in the Arctic would be meteorologically consistent with the development of a strong thrust forward of the Arctic regime in the longitudes of Greenland and Iceland, distorting the pattern of the circumpolar vortex with a sharp trough there and a recurrent warm ridge over western Europe. Something like this pattern seems to have recurred at times in the middle and later parts of the fourteenth century, bringing notable droughts in Europe after an extremely wet phase which had marked the first break in the early part of that century. (It is likely that some of the troubles about this time with the massive buildings – cathedrals, churches and castles, with collapsing towers and cracking walls and arches (fig. 67) – were not so much due to faults of design as to soil moisture changes and consequent settling.)

The occurrence in medieval York of the bug *Heterogaster urticae* (F.), whose typical habitat today is on stinging nettles in sunny locations in the south of England, discovered by the city of York archaeological investigations to have been present there both in the Middle Ages and in Roman times, presumably indicates prevailing temperatures higher than today's. Another revelation from insect studies is the abundance also in medieval York of a beetle *Aglenus brunneus* (Gyll.) whose habitat preferences indicate high temperatures generated in decaying vegetable refuse. Both these discoveries hint at rather high prevailing temperature of the urban environment itself in the tightly built-up medieval city centre.

There are many indications that in eastern Europe, as in Greenland and Iceland, a colder, more disturbed climate set in already in the 1200s. And, indeed, as far west as the Alps, some trouble was caused by advancing glaciers during the thirteenth century. During some part of the warmest period, perhaps in the tenth and early eleventh centuries, there seems to have been concern about drought in the Alps: for a water supply duct, the Oberriederin, was laid from high up near the Aletsch glacier to the valley below, and similar water supply installations were engineered in the Saastal

Fig. 67 An arch deformed by subsidence in Carlisle Cathedral. No movement seems to have occurred after about 1300–50. Compaction of the site through drying out of the soil in the previous centuries has been suspected as the cause of the damage seen (see pp. 197–8).

(also in Switzerland) and in the Dolomites only to be overwhelmed by the advancing glaciers between 1200 and 1350.

The ancient gold-mines in the Hohe Tauern in Austria and other high-level mines in central Europe, abandoned before the time of Christ, were opened up and worked again in the warmth of the high Middle Ages, only to be abandoned again later. Underground water began to cause difficulties about 1300; at Goslar it was reported in 1360 that water had been increasing in the mines in the Harz Mountains for more than fifty years. In Bohemia the same difficulty led to some mines being abandoned as early as 1321. In the Alps some of the mine entrances were again closed by the glaciers.

THE CONTEMPORARY SCENE IN THE MEDITERRANEAN, EASTERN EUROPE AND ASIA

In the Mediterranean, as also in the region of the Caspian Sea and on into central Asia, the period of warmth in high latitudes in the Middle Ages seems to have been a time of greater moisture than the present century. Lake levels were high, the Caspian Sea as much as 8 m above its present level during much of the time between the ninth and fourteenth centuries.

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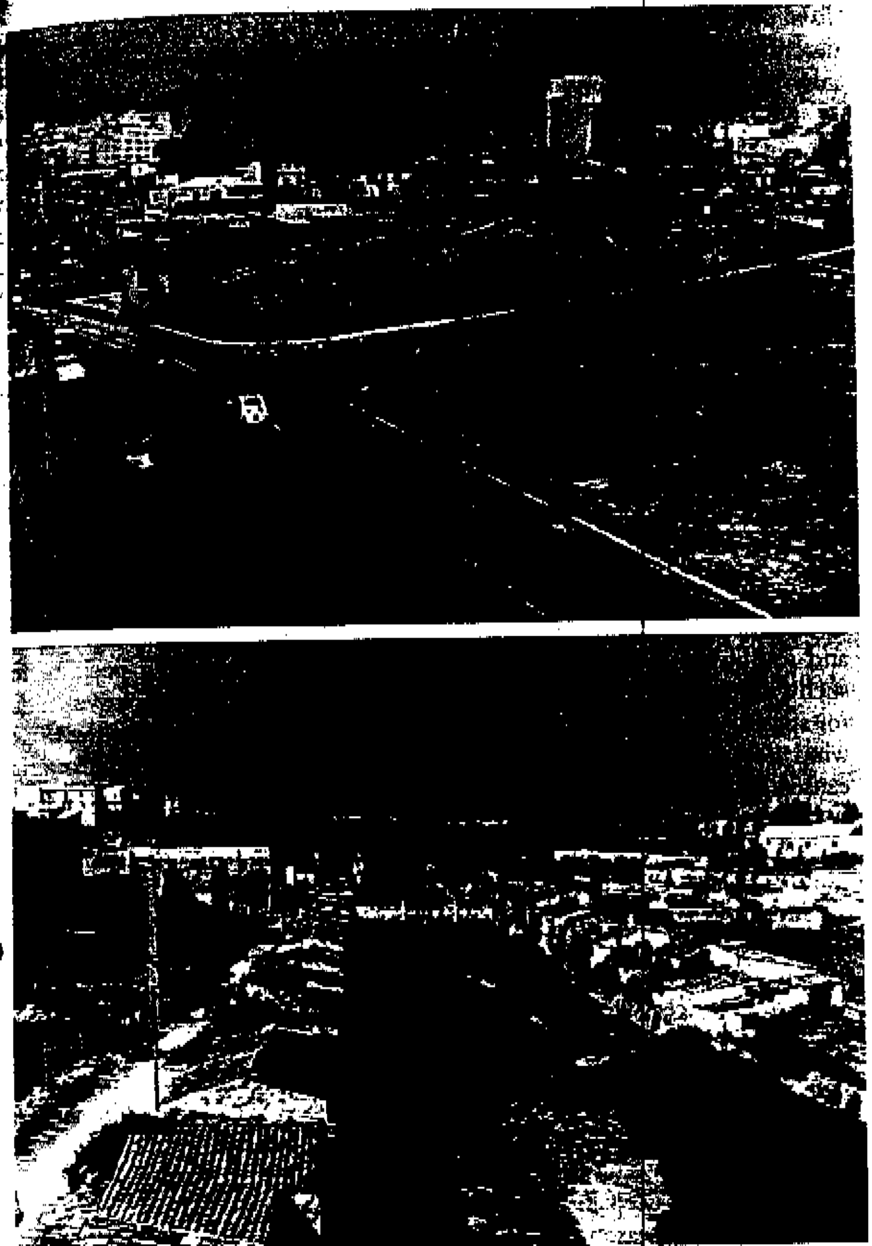

Fig. 68 (a) The medieval bridge (Ponte dell'Ammiraglio – Bridge of the Admiral) at Palermo, Sicily, built in 1113 to span a much larger river than now exists there. The River Oreto, which has now been diverted, as seen in (b), was used by ships up to this bridge when it was first built. (Photographs kindly supplied by General Fea of the Servizio Meteorologico, Aeronautica Militare Italiano, Rome.)

Two of the rivers of Sicily, the Erminio and the San Leonardo, were described as navigable in the twelfth century – something which would now be impossible even for the vessels of those times. Bridges were built, as across the Oreto at Palermo in Sicily (fig. 68), of a size not required by the present rivers. (The famous Pont d'Avignon finally built across the lower Rhone in southern France in 1177–85 at a difficult point, where roads converge but the current is always strong and the Romans had been unable to bridge the river, suffered many collapses of parts of the bridge in the following years but was not finally abandoned half destroyed until 1680.) There was also in the high Middle Ages more general flow of the streams in Greece and in the wadis of north Africa and Arabia. Fig. 45 (p. 131) indicates a more adequate rainfall in medieval times also in the dry area of northwest India.

These features seem likely to be explained partly by a displacement of the anticyclone belt of the desert zone during the warm epoch north of its present usual position to an axis from the Azores to Germany or Scandinavia as in some of our modern fine summers. Such partly meridional wind circulation patterns, with a cold trough deformation of the circumpolar vortex, commonly thrust cold surface air south over eastern Europe and western or even central Asia, and from there it would be deflected by the mountains westward and southward towards the Mediterranean. This is an eastern position for such a development in the circumpolar vortex, requiring a longer wave-length (or spacing of the troughs and ridges) than commonly prevails in the upper wind flow from the more or less fixed disturbances over North America caused by the Rocky Mountains. Such a longer wave-length would be likely to occur at a time when the main flow of the winds was displaced towards higher latitudes and particularly when, as in the thirteenth century, Arctic cooling strengthened the thermal gradient and the winds.

Our knowledge of the past variations of lake levels – archaeologically determined in the case of the Caspian Sea – indicates that the barbarian movements out of Asia which troubled the Roman empire over a long period can be associated with times of drought in central and western Asia around AD 300, which also returned around 800. By contrast, the great outbreak of Mongolian tribesmen in the thirteenth century seems to have occurred in a moist period, when the Caspian Sea was rising. The sudden outburst of energy of the peoples of inner Asia, which brought Genghis Khan and his Mongol hordes within the space of twenty years, between 1205 and 1225, deep into European Russia, to the Indus and to the gates of Peking, could reasonably be supposed to have had its origin in a build-up of population in the arid heart of Asia in times when the pastures were in better than usual shape. But its suddenness, and the coincidence of its timing with what we know of the cooling in high latitudes from the isotope record in northern Greenland and the great advance of the Arctic sea ice towards Iceland, raises a suspicion that some more sudden event connected

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with the cooling may have triggered it off. This could have been some invasion of the heart of Asia by colder Arctic air than before, the effects of which would be particularly noticeable if it happened in summer. This is speculation, but China had long been experiencing a cold regime and some scientists have thought that this anomaly gradually spread westwards until it enveloped Europe in the Little Ice Age of later centuries.

There was clearly some difference between the sectors of the northern hemisphere with which these paragraphs have been concerned and the situation over east Asia, where the climatic zones seem to have been pushed south over a long period of which the twelfth century marked the climax. The swing to the southeast of the isotherms and of the flow lines of the circumpolar vortex from a northward displacement (or ridge) over the Indian sector to a southward displacement (or trough) over east Asia is a pattern which seems liable to have introduced an anticyclonic tendency over Thailand and northern Indo-China, reducing rainfall there. This meteorological speculation suggests an explanation of temporarily easier – i.e. drier – conditions favouring the Khmer empire of Angkor in Cambodia (Kampuchea) in the region, which after 1300 returned to jungle.

EFFECTS ON SEA LEVEL AND LOW-LYING COASTS

Our survey of the European scene during the warmer centuries of the Middle Ages would not be complete without mention of the things that suggest a slightly higher stand of the sea level, which may have been gradually rising globally during that warm time as glaciers melted – and particularly in the area around the southern North Sea where the land-sinking due to the folding of the Earth's crust in that basin was presumably going on then as now. Fig. 60 draws attention to the greater intrusions of the sea in Belgium, where Brugge (Bruges) was a major port, and in East Anglia, where a shallow fjord with several branches led inland toward Norwich. The English fenland south of the Wash provided an extensive watery landscape of shallow brackish channels and low islands, fringed by reeds and brushwood, in which the island of Ely was so cut off that the Anglo-Danish inhabitants were able to hold out for seven to ten years after the Norman conquest of the rest of England. And the coastal plain of the Netherlands and Belgium had a fluctuating population in the eleventh and twelfth centuries, as the state of flooding varied, leading finally to a more general emigration to Germany.[6]

THE SEQUENCE IN NORTH AMERICA AND SOME COMPARISONS

In North America east of the Rocky Mountains there is evidence that the prevailing temperatures followed a sequence very similar to that in Europe and that there were interesting and important changes in the moisture climate. Only in northern Labrador and the neighbouring Ungava region is there no sign so far of a medieval interruption in the cooling off that began 3000–3500 years ago and put the forest into retreat before the advancing tundra. In northern Quebec and in the North-West Territories west of Hudson Bay, the extensive pollen-analytical researches co-ordinated by Dr Harvey Nichols of the University of Colorado Institute of Arctic and Alpine Research indicate some recovery of the forest, associated with warming of the summers, from about AD 500 to some time about 1000–1200 or 1250. Farther south, in the Middle West of the United States, the archaeological studies of Baerreis and Bryson at the University of Wisconsin have indicated that the Indian people of the Mill Creek culture grew corn (maize) in northwestern Iowa before the year 1200, in an area which today is somewhat marginal as regards enough rainfall for the crop. Elk and deer, both woodland animals, which they evidently hunted, together accounted for most of the flesh in their diet before about 1100; in the twelfth century the proportion of these among the bones in the middens rapidly declined and was overtaken by bison, an animal of the open plains. The abundance of bison bones increased towards the west where the climates are drier, in the 'rain-shadow' of the Rocky Moutains. But from about AD 700 onwards the climates of the whole region seem to have become moister than before, the prairie giving way to landscapes with more trees, until an abrupt reversal about the year 1200. Farming peoples were spreading their occupation northwestward on the plains, moving northward into Wisconsin and on up the Mississippi and other valleys into Minnesota as early as the eighth century. They maintained a thriving culture until 1200, when their sudden disappearance coincides with evidence of drought and vegetation change. Such a change in the region concerned is readily explained by increased sway of the westerly winds, intensifying and extending the rain-shadow of the mountains, as the thermal gradient increased with the cooling of the Arctic then setting in. We have referred to the evidence of this on Greenland and Iceland waters.

The climatic history reviewed in this chapter has led one historian[7] to summarize the matter by saying: 'intriguingly, the profile of long-run average temperature in England shows a crude but clear congruence with that of material welfare broadly conceived'. And he goes on 'The medieval expansion, the crises of the fourteenth and late sixteenth centuries, and the revivals of the fifteenth (to early sixteenth), eighteenth and nineteenth centuries, broadly correspond with movements in the trend line of temperature.' Yet, he argues that climatic change has little explanatory value and that one cannot assert that the course of European history would have been much different if the climate had not changed. The period covered by the next chapter will give us an opportunity to examine this contention a little more closely.

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DECLINE AGAIN IN THE LATE MIDDLE AGES

THE DOWN-TURN OF CLIMATE IN THE ARCTIC

The deterioration in their situation which announced itself to the Old Norse Greenlanders in 1197–1203 by the increase of ice encroaching on the seas that were used for their links with Iceland and with Europe, at first in occasional years but later on seeming permanent, clearly had to do with a cooling of the Arctic (see fig. 36, p. 93).

Already during the twelfth century the Eskimos of the Dorset culture, once (about 700 BC) widespread across the eastern Canadian Arctic, who had returned to high latitudes after AD 800–900, had been moving south. Archaeology suggests that this was partly because another Eskimo culture, developed near Thule in northwest Greenland, was more successful in hunting the resources of the far north; but it is probable also that increasing ice and dwindling seal and walrus populations were making the competition more difficult. And so it was around 1200–50 that Norsemen and Eskimos first came into contact in Greenland. At first some trading went on between them. But about 1350 the smaller of the two Norse centres in Greenland, with only about seventy-five farms, the Vesterbygd ('West Settlement'), which was the more northerly of the two areas occupied in west Greenland, was wiped out either by conflict or disease, possibly the plague. (Some cattle and sheep were found wandering unattended by any human owners when a ship visited the area from the other settlement.)

The larger Østerbygd ('East Settlement'), where there were about 225 farms, survived until about the year 1500, though in evident decline: the average stature of the grown-up men buried in the graveyard at Herjolfsnes in the fifteenth century was only 164 cm (5 ft 5 in.) compared with about 177 cm (5 ft 10 in.) in the early period of the settlement. By about 1342 it is recorded that the old sailing route along the 65th parallel of latitude between Iceland and Greenland was finally changed to a route farther south because of the increase of ice. After the wreck off Norway of one of the ships used in the late medieval royal monopoly trade in 1369 regular communication between Europe and the Greenland colony ceased. Some ships bound for Iceland arrived in Greenland in later years after being blown off course, and there is indirect evidence of occasional visits by traders and freebooters from England and elsewhere in the fifteenth century. In 1492 Pope Alexander VI wrote of his anxiety over the situation in that outpost of Christendom:

> the church of Garda is situated at the ends of the Earth in Greenland, and the people dwelling there are accustomed to live on dried fish and milk for lack of bread, wine and oil . . . shipping to that county is very infrequent because of the extensive freezing of the waters – no ship having put in to shore, it is believed, for eighty years – or, if voyages happened to be made, it could have been, it is thought, only in the month of August . . . and it is also said that no bishop or priest has been in residence for eighty years or thereabouts.[1]

In fact, the Herjolfsnes graveyard preserved bodies and clothing in the subsequently permanently frozen ground, the dresses including European models of about the year 1500. But ships from Hamburg beaten off course to Greenland about 1540 found only one dead Norse body and no inhabitants alive. From that time on only whalers, or explorers such as Hudson in 1607, occasionally happened to get through the ice belt to this or that point on Greenland's deserted Arctic shores, until in the 1720s the Danish-Norwegian state once more founded posts, again in southwest Greenland. There were no settlements in east Greenland before the nineteenth century.

It has been suggested that the explorations in the fifteenth century which led the fishermen from Bristol ever farther west across the Atlantic, until as early as the 1470s or 1480s they may been fishing on the Newfoundland Banks,[2] may have started because the fish stocks of the higher latitudes in the northeast Atlantic had deserted their former grounds as a result of the increasing spread of the Arctic cold water. The situation was doubtless aggravated by Hanseatic competition in Iceland-Greenland waters. However that may be, it is clear that the searches of the English sixteenth-century seafarers such as Chancellor in 1553 and the Dutch expedition under Willem Barents in the 1590s to find a North-East Passage, and of Frobisher in the 1570s, of Davis in the 1580s and soon Hudson, to find a North-West Passage through the Arctic to the Indies were undertaken at a peculiarly unfavourable time. The same was true of Hudson's attempt in 1607 to reach the North Pole and still in 1827 of Edward Parry's attempt, and of the renewed efforts around that time to seek out a North-West Passage, as well as the voyage of Sir James Clark Ross in 1831, which succeeded in reaching the north magnetic pole.[3] The severer Arctic climate had then ruled for hundreds of years, though there were still some openings in the polar pack-ice controlled by the wind pattern; the whalers had found some of these in their operations near northeast Greenland, and this

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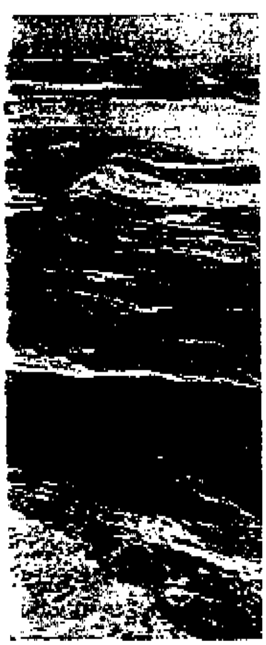
In Iceland the old Norse society and its economy suffered a severe decline which set in first about AD 1200 and could be said to have continued over almost six centuries. The population of the country fell from about 77,500, as indicated by the tax records in 1095, to around 72,000 in 1311. By 1703 it was nearly down to 50,000, and after some severe years of ice and volcanic eruptions in the 1780s it was only about 38,000. The people's average stature also seems to have declined, much as in Greenland, from 173 cm (5 ft 8 in,) to 167 cm (5 ft 6 in,) from the tenth to the eighteenth century. It is clear from the surviving records that years when the Arctic sea ice was close to the Iceland coast for long months (usually between January or March and any time from June to August) played a big part in this. In such years the spring and summer were so cold that there was little hay and thousands of sheep died, especially all over the northern and eastern part of the country. The shellfish of the seashore were also destroyed by the ice. Gradually all attempts at grain growing were given up. The glaciers were advancing. And there were some volcanic disasters besides, when whole areas of the island were covered by volcanic ash or lava flows, the pastures were ruined by the fluorine or sulphurous content of the ash and the sheep and cattle were killed by it. One of the worst cases was the great eruption in Öraefi in the south of Iceland in 1362.

It cannot be denied that the trade monopoly claimed by the Danish-Norwegian crown through most of these centuries must also have had some effect, its restrictions probably contributing to the country's difficulties, but it seems that the main causes of decline were the natural disasters – Iceland's 'thousand years struggle against ice and fire', as Sigurdur Thorarinsson's 1956 article called it.[4]

That there were some easier times as well as periods of great severity during these centuries can be clearly discerned despite the scarcity of records at certain times. For example, the widespread use of polar bear skins in the late Middle Ages for carpeting the church floors in Iceland indicates a large supply of the bears, and therefore presumably of the ice which brought them, in the fourteenth century. A hundred years later the skins were getting scarce, and many were old and in poor condition, but there was some increase in the sixteenth century before this item became restricted by the trade monopoly of the monarchy in Denmark. This information seems to confirm the inference from the direct reports of the sea ice which survive that there was much ice from the late 1200s through the fourteenth century, and then some improvement before the drastic increase of ice in the late 1500s and after. The times of most ice and coldest climate in Iceland seem to have started suddenly in 1197–8 and 1203 and reached culminating phases around 1300, from about 1580 to 1700, especially the 1690s, and again in the late eighteenth and nineteenth centuries.

Fig. 69 Two pictures of North Sea storm waves assailing the sea defences of the small island of Heligoland in a northerly storm, Beaufort force 10, on 10 October 1926. The island is but a remnant of its former size. (Photographs F. A. Schensky, reproduced by kind permission of his daughter Miss L. Schensky of Schleswig.)



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HOW EUROPE WAS FIRST AFFECTED: STORMS

The first symptoms of the change already affecting Greenland and Iceland which may have been noticed by the inhabitants of Europe, particularly around the North Sea, were the increased incidence and severity of wind storms and sea floods in the thirteenth century. Some of the latter caused appalling loss of life, comparable with the worst disasters in Bangladesh and China in recent times. In at least four sea floods of the Dutch and German coasts in the thirteenth century the death roll was estimated at around 100,000 or more; in the worst case the estimate was 306,000. As a result of the floods of 1240 and 1362 it was reported that sixty parishes accounting for over half the agricultural income of the (at that time) Danish diocese of Slesvig (Schleswig) had been 'swallowed by the salt sea'. In some of these storm floods the Zuyder Zee in the Netherlands was formed, and enlarged, and it was not drained until the present century. Islands, and other inlets, were formed by losses of land on the German and Danish North Sea coasts. Other islands were destroyed by the stormy seas. The island of Heligoland (50 km out in the German Bight), which is believed to have measured over 60 km across in the year 800, had been reduced to 25 km by about 1300, perhaps half of it being lost in a storm in that year. Today it measures only about 1.5 km on its longest axis (fig. 69). In England the great ports of Ravenspur or Ravensburgh (east of Hull) and Dunwich (on the Suffolk coast in East Anglia) were lost in successive stages in the sea storms of these centuries. Deaths of 100,000 or more people in floodings of the continental shore of the North Sea were again reported in storms in 1421, 1446 and 1570. In the 1570 storm great cities were flooded, and

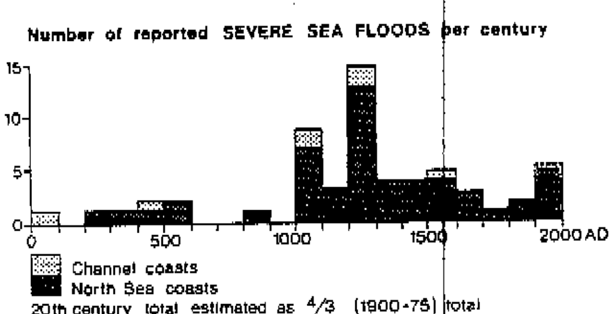

Fig. 70 The distribution by centuries of reports of severe storm floods which caused much loss of life or land on the coasts of the North Sea and English Channel. The data and sources of data on which this diagram is based are fully tabulated in the author's book *Climate: Present, Past and Future*, vol. 2, London, Methuen, 1977, pp. 120–6. Any apparent mistakes by earlier collectors of the data from the distant past producing repetitive reports of the same incident have been cut out in the counts of numbers of storms for this diagram.

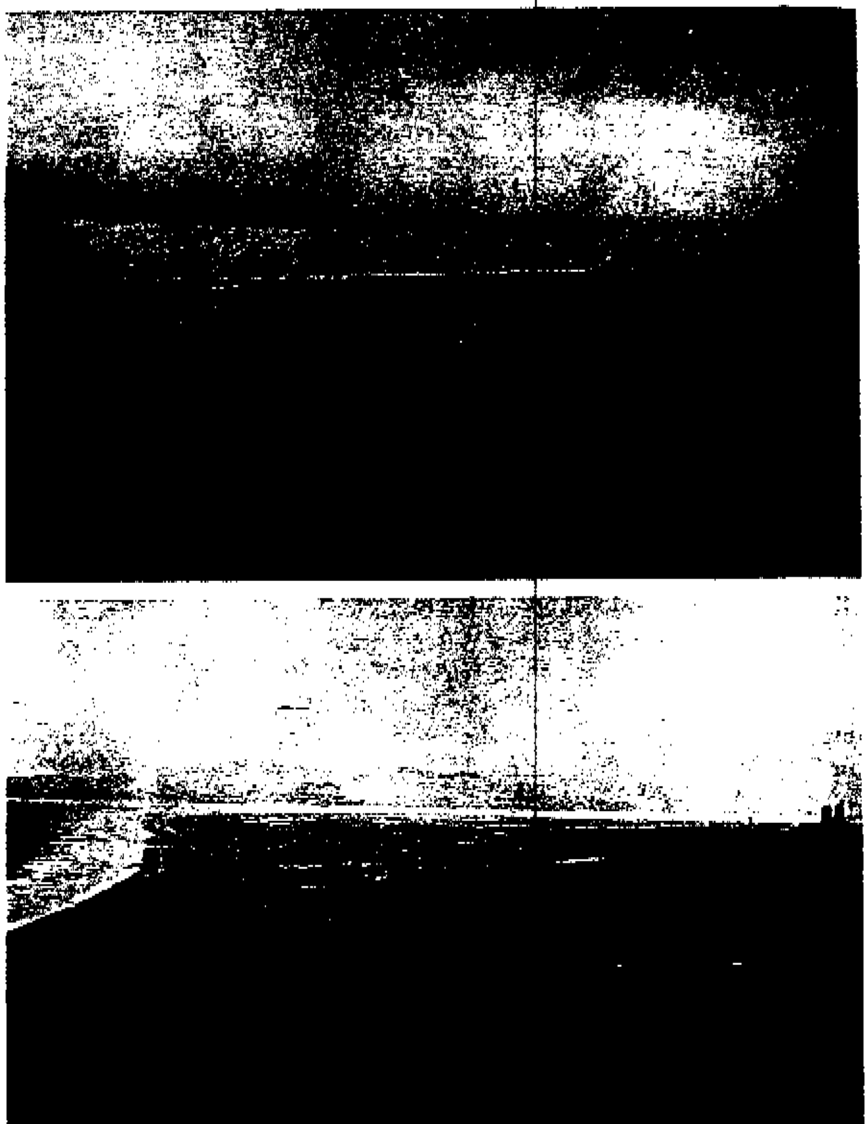

Fig. 71 Some results of the storms of blowing sand in the late Middle Ages: (a) (top) The lagoon at Kenfig on the coast of south Wales, near Port Talbot, formed by sand-dune movements, reputedly around 1316, which closed the medieval port there. Further movements between 1344 and 1480 finally buried the old Roman coast road and with a storm in 1573 carried a line of high sand-dunes 3 km inland. (b) The coast edged with a belt of great sand-dunes protecting the flatland of Morfa Harlech in northwest Wales. These dunes lie more than 1 km seaward of the former port of Harlech, in use until about 1385, which they closed.

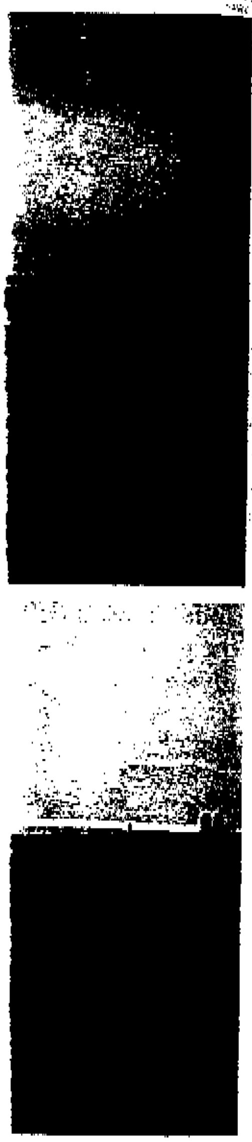

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Fig. 71 (c) The Sands of Forvie: the 30 m high sand-dune which covers the medieval township of Forvie, on the east coast of Aberdeenshire, Scotland, which was obliterated by a great southerly storm in August 1413.

the deaths were estimated at 400,000. And in 1634 there were again great losses of land from the Danish and German coast and the off-lying islands.

Fig. 70 shows the distribution over historical time of known reports of severe sea floods in this part of the world. In the southern North Sea on the Netherlands coast the occurrence of devastating storm surges was greatest in the early 1400s and late 1600s;[5] the late 1500s were remarkable for a few storms of outstanding range and severity, most of all the storm of 1–2 November 1570 when the flooding affected the coasts from France to northwest Germany. In reading the diagram allowance must be made for the reduced chance of reports having been made and surviving from early times, but it seems safe to conclude that there were real maxima of storm flood occurrences for the region as a whole in the eleventh and in the thirteenth centuries AD, and in the southern North Sea at the times mentioned above. There is also a suggestion of more severe floods in, and soon after, late Roman times and again in our own century than at other periods. This distribution suggests that storm floods on the low-lying coasts of the North Sea have been most troublesome: (a) when the sea level may have been somewhat raised after long periods of warm climate and glacier melting; and (b) when a cooling Arctic has produced a strengthened thermal gradient in latitudes between about 50 and 65 °N, leading to increased storm frequency and severity over this zone. In the thirteenth century, and perhaps again in recent decades, both these conditions were present. One must conclude from the much more restricted range and loss of life in modern storms that the dykes which have been built along the coasts of the North Sea, and continually improved, in later centuries are among man's greatest successes in defence against natural disasters.

Another accompaniment of some of the severe storms of the northeast Atlantic and North Sea region in the late Middle Ages and after was the overwhelming of a number of coastal places by blown sand (fig. 71). There was a long epidemic of such disasters on the sandy coasts of northwest Europe from Brittany to the Hebrides and Denmark, starting about the thirteenth century and continuing to about 1800. As examples, the little medieval port of Harlech on the west coast of Wales was permanently obliterated by a line of great sand dunes around 1400, within at most a few decades of the other cases pictured in fig. 71. In the seventeenth century a great storm destroyed the fine natural harbour at Saksun on the northwest side of the Faeroe Islands by filling it with sand, and another overwhelmed an area – now known as the Culbin Sands – of perhaps 60 km^2 of fine farmland, including nine farms and a mansion house, in northeast Scotland. In the sandy terrain of the Breckland in East Anglia and in similar country in the Netherlands even places inland were affected by frequent blowing sand in this period.

It is interesting that the case pictured in fig. 71c on the east coast of northern Scotland took place with a southerly storm, a circumstance which lowers the level of water in the North Sea. Moreover, the date reported was within a few days of a date when the astronomically calculated tide was only 4–7 cm short of the extreme of the nineteen-year cycle, and this was itself only one cycle short of a roughly 2000-year extreme. This coincidence may point to a combination of factors which led to the shifting of so much sand as to destroy a coastal township in a single severe storm. An exceptionally low tide seems likely to have occurred, laying bare a wholly abnormal expanse of sand to be scoured by the wind. It is, of course, possible that previous storms and high tides had played a part in preparing the situation through moving sand towards the shore by wave action and leaving uneven accumulations of it. At all events it is noteworthy that the epochs of widespread sand-dune activity on northwest Europe's coasts both in the last millennium before Christ and in the late Middle Ages were not only times of relatively cold, or cooling, stormy climate in this latitude but were also more or less centred around long-term maxima of the range of the tides.

COOLING AND WETNESS IN EARLY FOURTEENTH-CENTURY EUROPE

The cooling trend, which should be seen as the basic element in the climatic deterioration with which this chapter is concerned, began to affect Europe directly soon after 1300. The generalized temperature curve presented in fig. 30 (p. 84) seems to be verified by the history of the vineyards in England and central Europe and of the upper limit of trees on the hills from the Vosges in the west to the Erzgebirge on the borders of Czechoslovakia, Germany and Poland. This smooth curve, however, masks the real shocks.

The change which broke the medieval warm regime must have appeared devastatingly sudden. It came first in the regions mentioned with the extraordinary run of wet summers, and mostly wet springs and autumns, between 1313 or 1314 and 1317. And it continued with little intermission at least to the early part of 1321. Moreover, this followed closely upon one of the really notable periods in the Middle Ages of mostly warm, dry summers, from 1284 up to 1311. (The first decade of the new century was a time when many had the confidence to start new vineyards in England.) The year 1315 (see fig. 72a), when the grain failed to ripen all across Europe, was probably the worst of the evil sequence which followed. The cumulative effect produced famine in many parts of the continent so dire that there were deaths from hunger and disease on a very great scale, and incidents of cannibalism were reported even in the countries of western Europe. Great numbers of sheep and cattle also died in the 'murrains' or epidemics of disease which swept the sodden and often flooded landscape. Thereafter the fourteenth century seems to have brought wild, and rather long-lasting, variations of weather in western and central Europe, the later 1320s and 1330s and also the 1380s with mostly warm, dry (often seriously droughty) summers and a few other decades, notably the 1360s, predominantly wet. In eastern Europe there seem to have been troubles with heat and drought in the summers throughout the century. The type of variability of the climate in western Europe here described, which affected the winters also, continued in the fifteenth century and spread to eastern Europe as well. The 1430s produced a very remarkable sequence of severe winters, or winters which at least included long severe spells, in central and western Europe, including 1431–2 (fig. 72b) and every winter from 1433–4 to 1437–8. Within the last thousand years only the 1690s seem to have produced so many cold winters or severe spells within the span of one decade. Furthermore, the winters of 1407–8 and 1422–3 had been of historic severity, permitting traffic over the ice across the Baltic and with wolves reported to have passed over the ice on the easternmost part of the North Sea from Norway to Denmark.

A graphical 'history' of the wetness of the Bolton Fell Moss peat-bog on the England–Scotland border near Carlisle, produced by a variety of

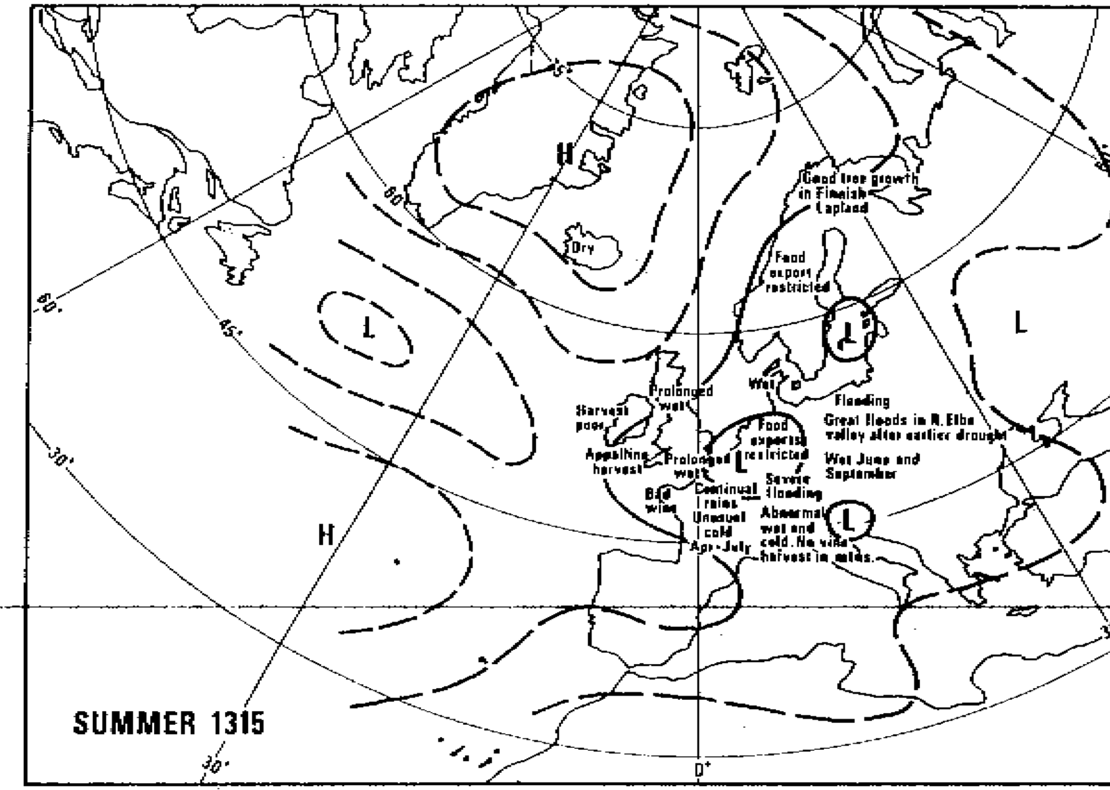

Fig. 72a Reported weather and crop conditions in the summer of 1315 and the proposed pressure and wind pattern which seems to be implied.

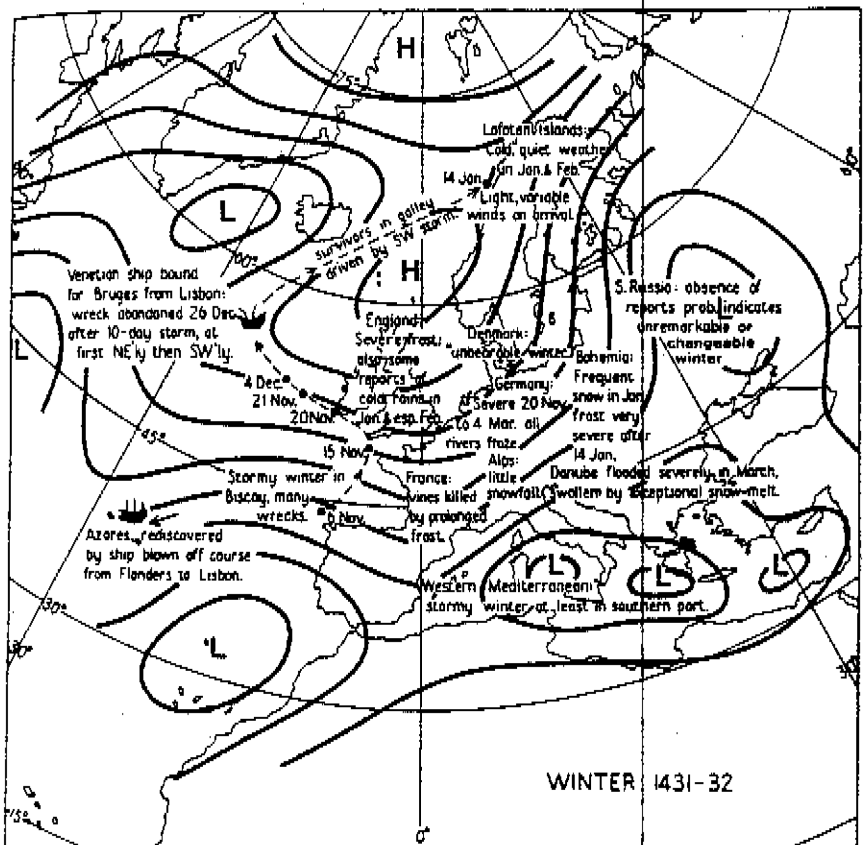

Fig. 72b Reported weather in the winter of 1431–2 and the prevailing pressure and wind pattern which seems to be implied.

researches, is shown in fig. 73. This seems to agree with the temperature and rainfall sequences presented elsewhere in this book and therefore may be regarded as supporting evidence of them. (There is an apparent discrepancy in the wetness indicated in the tenth century, but wetness in the northwest corner of England could be consistent with the pattern we have supposed at that time with westerly winds there and anticyclonic situations producing droughts in the southeastern half of England and in Germany.) The Bolton Moss curve certainly supports Trevelyan's contention[6] that the rivers of England were generally deeper and bigger in the fifteenth century than they are now (and, perhaps, earlier in the high Middle Ages). What is abundantly clear from fig. 73 is that there was a very great change in the prevalence of soil moisture, at least in northwest England, about 1300. The change seems in fact to have occurred much more widely, in view of

Fig. 72a Reported weather and crop conditions in the summer of 1315 and the proposed pressure and wind pattern which seems to be implied.

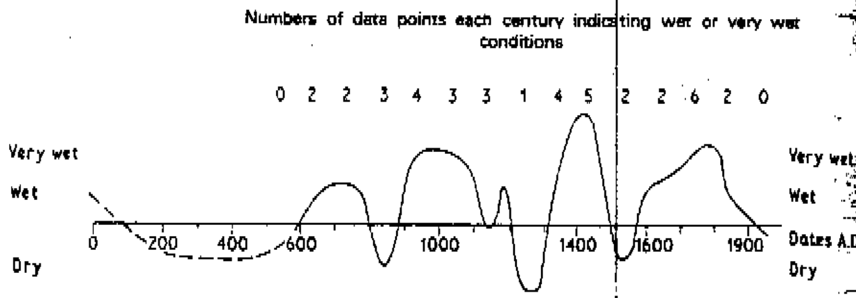

Fig. 73 The record of long-term variations of the surface wetness of Bolton Fell Moss peat-bog northeast of Carlisle, derived by Dr Keith Barber of Southampton University (from pollen and macrofossil analysis, soil chemistry investigations and records of land-use history). (From data kindly supplied by Dr Barber.)

the frequency of regrowth phases reported in the peat-bogs of Sweden and elsewhere in northern and western Europe about this date. Corresponding difficulties, caused by increasing wetness, were noted in the last chapter in the mines in the Harz and other mountains in central Europe.

Perhaps the most remarkable aspect, devastating in all its effects, of European climates in most of the decades studied in the fourteenth and fifteenth centuries AD was the extraordinary frequency of easterly winds which seem to have largely dominated latitudes between about 50–55 ° and 60–65 °N in the summers and winters alike.[7] This we deduce from the weather maps for individual seasons which we have reconstructed in similar manner to the ones here illustrated in figs. 72a and 72b. It certainly applies to the summers in the decades starting in 1310, 1330, 1340, 1420 and 1430, and to the winters in the 1420s and 1430s. The reconstructions were made possible by the availability in the literature of enough reports from around Europe of those seasons of dramatic weather, enough even to supply some support of each other. The decade maps were produced by averaging the maps of the individual years of the decades referred to. Among the most interesting are the maps for the summers of the decade 1310–1319, when there were famines and economic difficulties, and of the 1340s because of the extraordinary wetness of those summers all over western and central Europe followed by the heat of 1348 when the plague, the Black Death, arrived. Equally, the winters of the 1430s, which produced a remarkable number of spells of severe weather, produce an interesting decade map.

The climatic effects which marked those decades can nowhere have been stranger to our ideas of normality than in Norfolk – and probably in eastern England generally – where the usually dry climate owes most to the shelter from the prevailing westerly winds and their moisture provided by the hill ridges of southern and western England and the mountains of Wales and the Pennines. This shelter was replaced in such times by continual supplies of moisture carried by cold north, northeast and east winds from the North Sea and the Baltic. Norfolk particularly, but also much of East Anglia and northeast England, doubtless became much wetter places than we know today. This seems to be confirmed by the frequency of legal disputes in the local courts in those years in pursuit of people who failed to keep their drains running.

Another part of the map seemed also to be supported by a change of the rainfall experienced. In parts of the Alpine region screened from rainfall from the north by the high mountain ridges, notably in northern Italy (Val d'Aosta) and even in the upper Rhône valley and its tributaries (as in Saas), networks of water channels, essentially narrow wooden aqueducts, were built in this period to bring water from the streams that emerged from the glaciers of the high Alps to irrigate the summer pastures on the valley sides. One of these constructions even brought water from high up in the Val d'Ayas 25 km along the high cliffs of Mount Zerbion and over a pass to deliver it on the south side.

Changes in the geographical distribution of rainfall or snowfall, where mountain shelter is involved, can, as in these cases, provide a sensitive detector of changes of the prevailing winds – a distinctive indicator tool in reconstructing climate patterns. The harshness of the climatic effects of these changes in northern Europe, in Scotland and Scandinavia, in the late Middle Ages, brought about by the apparent frequency of northerly and northeasterly winds, is attested by the reports of harvest failures and populations reduced to making bread from the bark of birch trees, and the abandonment of the poorer and more exposed upland farm villages in those countries, and in northern England and Norfolk and the east Midlands besides.

A TIME OF DISEASES

The prevailing wetness during parts of the fourteenth century and, perhaps still more, in the fifteenth century undoubtedly made this an unhealthy time. There were many troubles with the diseases of mankind, animals and crops.

It seems established that in England the average expectation of life decreased by about ten years from the late thirteenth century (when it was apparently about forty-eight) to the period 1376–1400.[8] One of the most horrifying of the diseases of the period – and most clearly associated with the weather – was ergotism, or St Anthony's fire, produced by the ergot blight (*Claviceps purpurea*) which blackened the kernels of the rye in damp harvests. Even a minute proportion of the poisoned grains, baked in bread, would cause the disease. The course of the epidemics was such that the whole population of a village would suffer convulsions, hallucinations, gangrene rotting the extremities of the body, and death. In the chronic stage of the disease, the extremities developed first an icy feeling, then a burning sensation; the limbs then went dark as if burnt, shrivelled, and finally dropped off. Even domestic animals caught it and died. And pregnant women miscarried.

More often mentioned than this disease from the blighted corn in connection with the collapse of confidence and of the economic and cultural structure of Europe's medieval society has been the great bubonic plague, the 'Black Death' which arrived in 1348–50, and its subsequent recurrences. It is estimated that in different districts of Europe from one-eighth to two-thirds of the population died. The consequences in terms of harvests not gathered in, of labour shortage and rising costs, have been much written about. The death rate was heavy in the cities and ports and along much-frequented routes of trade and pilgrimage. Overall probably more than a third of the population of Europe succumbed to the pestilence. Interestingly, the Black Death seems to have originated in China, or in central Asia, in a region where bubonic plague is endemic, during or immediately after exceptional rains and flooding in 1332: this flooding was itself one of the greatest weather disasters ever known, alleged to have taken seven million human lives in the great river valleys of China, and destroying not only the human settlements and their sewage arrangements but also the habitats of wildlife, including of course the rats, over a wide region. Thus, there was a complex of factors in which climate was deeply involved, rather than the Black Death and economic troubles alone or the intellectual questionings of the time, which brought the end of the old medieval era.

DESERTION OF FARMS AND VILLAGE SETTLEMENTS

The fact that the climatic change played a part, independent of the debilitating effects of disease on the population and on the economy, can be seen in the failures of the northern vineyards in England and on the continent, in the retreat of corn-growing too from its former northern limits and of all cultivation from the heights, and in the depopulation of villages and farms. It is recorded in *Nonarium Inquisitiones*, a valuation of agricultural production in the year 1341, a few years before the arrival of the Black Death, that there were large numbers of villages with uncultivated land in every part of England, mostly said to be due to shrinkage of population since the famine years earlier in the century but also to soil exhaustion and shortages of seed corn and ploughing teams.[9]

This abandonment of former settlements was going on all over northern and central Europe and on the higher ground even in the south. The sites of many thousands of deserted medieval hamlets and villages have been

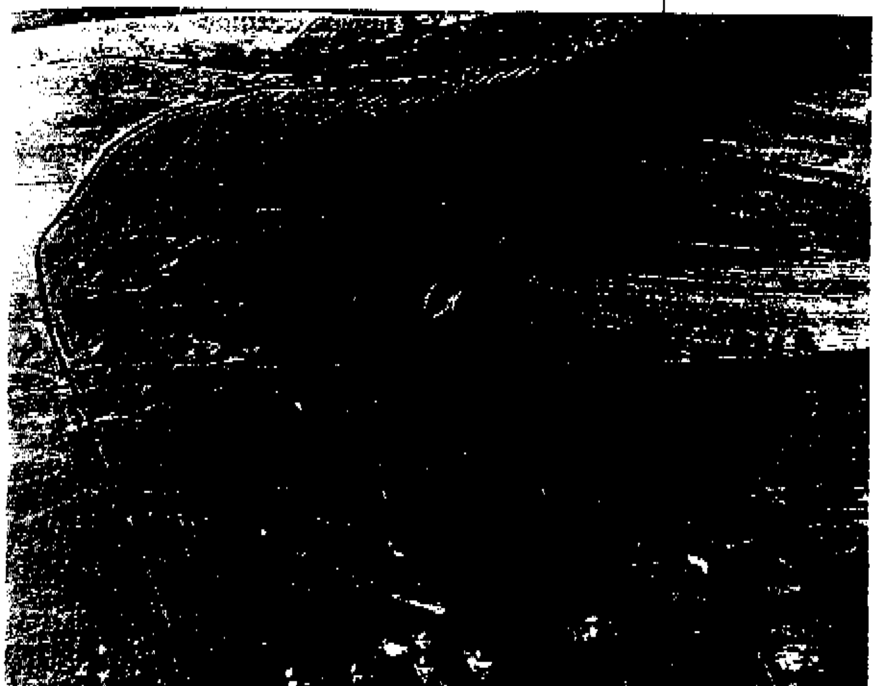

Fig. 74 All that remains of Wharborough, a village on the highest ground in Leicestershire, in the East Midlands of England. It is recorded that Wharborough declined in size between 1430 and 1446 and was deserted by 1495. (Reproduced by kind permission of the photographic air surveys branch of the Ministry of Defence, London.)

identified within the area of pre-war Germany alone.[10] In Germany and England the phenomenon became prominent in connection with the famines of the decade about 1315, but had begun even earlier, and was already reaching its first peak in the twenty years before the Black Death. Of over eighty deserted village sites for which population figures can be deduced from tax records in two counties in central England only about 10 per cent were attributable to the Black Death, but all had suffered severe losses of population in the famine times between 1311 and the 1320s. And those that did disappear around 1350 were generally the same places that had declined most (on average by two-thirds) in the years of famine earlier in the century. The fact that some villages disappeared and others survived in neighbouring positions in various parts of the country has caused many to doubt the climatic explanation, but it seems that these differences of fortune can often be explained by differences of soil and exposure.[11] The coincidence of timing of the waves of desertion over much of Europe points to a widespread, and presumably external, cause such as the behaviour of the climate. Moreover, the period when most desertions took place in England, between about 1430 and 1485, coincides with a fairly well-documented time of frequent cold winters and wretched summers, the latter particularly in the 1450s and later 1460s (fig. 74). But the climatic influence is hinted at most clearly in that it seems to have been Norway that, apart from Iceland and perhaps eastern Europe, was worst hit.

THE SEQUENCE IN THE NORTH OF EUROPE: NORWAY, DENMARK, SCOTLAND

We know a good deal about Norway in the Middle Ages and after, thanks to the wealth of information on taxes, occupations and properties in the 'church books' (kirkebøker) and the pioneer researches by Professor Andreas Holmsen of Oslo.[12] These have borne fruit in numerous indications of the interplay between climatic and environmental history and social history in northern Europe, and inspired the Deserted Farms Research Project (Ødegårdsprosjekt)[13] in which all the northern countries, including Finland and Iceland, have collaborated over many years.

The abandonment of farms began first in north Norway already before 1200, accompanied by an expansion of the areas used by Lapp hunters and a drift of the Norwegian population south and towards the coastal fisheries. At the end of the Viking period there must have been about a thousand farms in Hålogaland in north Norway, and they grew barley, oats and rye. By the 1430s, in and near the rich fishery districts in the Lofoten islands up to 95 per cent of the farms had been abandoned, and elsewhere about 60 per cent. At the coast, in fact, the numbers of the population and their economy expanded between 1350 and 1500, and it seems possible that, for so long, the increased cold water outflow from the Arctic near Greenland was compensated by a strengthening of the inflow of the warm Atlantic water with its fish stocks on the Norwegian side. (But later on, in the seventeenth century, the Norwegian fishery too seems to have been affected by the climatic deterioration.)

West Norway was the next to be affected, with some decline of population during the thirteenth century and reduction of the taxes in the 1330s and 1340s on account of lowered farm yields and losses caused by natural disasters such as rock-falls. Owing to the nature of the country there were big variations from district to district and from farm to farm. The decline was on the whole sharpest in the sheltered districts in the inner parts of the fjords and in Trøndelag, the district about Trondheim, which had been richest earlier in the Middle Ages. Wheat had been grown there. Particularly interesting is the case of the marginally situated upland farming village of Hoset (fig. 75), 350 m above sea level, east of Trondheim near the Swedish frontier. The place has been the object of interdisciplinary studies by Professors Sandnes and Hafsten and colleagues, notably Dr Helge Salvesen.

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Archaeological work and pollen analysis show that a small area of the forest was cleared for cultivation, including cereals, about the fourth century AD. The farmers may have been attracted by the possibilities of iron production in the neighbourhood. Twice, or perhaps three times, since then the area has been abandoned and reconquered by the forest, each time in periods of colder climate. This is not surprising because in periods of prevailing southwesterly winds Trøndelag enjoys the shelter of the great mountains of southern Norway (and some additional warming of the south and southwest winds by an effect like that of the Alpine foehn wind[14]), but whenever winds from the northwest and north become prominent the district is directly exposed to these winds from the Arctic seas. Hoset may have been abandoned first for a time about the sixth to ninth centuries AD. There was, however, a climax of cereal cultivation there in the high Middle Ages, and the two later abandonments were precisely in the periods of sharpest climate stress in 1435 and 1698. Full-scale farming was not resumed there until about 1930.

In the most sheltered part of Norway, the central and southeastern part (Østlandet), the medieval expansion continued right up to the Black Death. It would be correspondingly easy to attribute all that followed to the disaster

Fig. 75 Hoset: a farm village at latitude 63° 24′ N 11° 10′ E, east of Trondheim, Norway, 350 m (approximately 1150 ft above sea level). The position is so marginal for agriculture that it was twice abandoned in periods of climatic deterioration in or about 1435 and the 1690s and reconquered by the forest. The first period of cultivation there in earlier times seems also to have gone into decline and possibly been abandoned some time between AD 500 and 900.

of the plague. The incidence of the disease itself was very patchy, the death rate amounted to 90 per cent of the population in the great Hallingdal valley, with its through route, and about two-thirds along the pilgrim route to Trondheim through southern Sweden, while blood group research suggests that the more remote parts of Telemark in central south Norway were never touched. But it is noteworthy that there was no real recovery in Norway for about two hundred years. The farms on the higher ground stood empty for that long, partly because any surviving occupants had been able to take up vacant farms on richer land in the valleys. But by 1387 production and tax yields were only from (in some districts) as little as 12 per cent to barely 70 per cent of what they had been around 1300. Even on the bishop's land near Oslo only oats were grown. And in the 1460s it was becoming recognized that the change seemed permanent. As late as the year 1665 the total Norwegian grain harvest is reported to have been only 67–70 per cent of what it had been about the year 1300, and in west Norway the medieval production was not exceeded until around the middle of the eighteenth century.[15]

In parts of Denmark, particularly Jutland, near the North Sea, the situation seems to have been not much better, with many farms deserted, corn growing given up and those farmhouses that were still maintained were shared by several families.[16] English visitors to a Danish royal wedding in 1406 reported seeing much sodden uncultivated ground and that wheat was grown nowhere. There was, in fact, a gradation across the country with much less stress in the more sheltered districts of the islands of Fyn and Sjaelland farther east.[17]

It is clear that the changes registered in agriculture and husbandry in various parts of Europe in the late Middle Ages were influenced by impact of the climate as well as by the disastrous depopulation brought by the Black Death. The growing season everywhere shortened, perhaps typically by three weeks or more, its accumulated warmth decreased and the frequency of harvest failures increased – the dreaded 'green years' when the crops fail to ripen – in the north. Wheat has a rather higher requirement of summer warmth than barley or oats and thrives best in regions where the yearly rainfall is less than 90 cm; but it can be successfully carted wet for drying indoors, whereas the other cereals soon overheat. Rye withstands severe winters better than other cereals and is the most productive grain on poor soils. As the climate deteriorated, barley, oats and rye were therefore to be preferred to wheat except in the warmer parts of Europe. On the other hand, there were many places where cereal growing ceased to be profitable and was given up in favour of sheep rearing to meet the increasing demand for wool.

In the Highlands of Scotland, it seems, the long history of clan warfare and of the Highlanders raiding cattle from the Lowlands, as also in this period the cattle raids from the Southern Uplands across the border into

England, may be explained by the stress of a deteriorating climate upon the settlements which had been established far up the glens in the 'golden age' of the twelfth and thirteenth centuries. As early as the 1070s and 1080s, when King Malcolm III and his queen (who became St Margaret) held their court in Dunfermline, Scotland was a haven for innumerable English exiles from Norman rule. But as in Iceland and in north and west Norway, much of the country is exposed to a drastic change whenever northwest and north winds become more frequent at the expense of the benign southwesterlies. Internal troubles of various kinds, not all connected with the incursions of the English king and his forces, began about 1300. The fifteenth century historian Boece wrote that in 1396 all the north of Scotland was engulfed in clan warfare. There was more of it in 1411 and fairly clearly the fifteenth century was the peak period for such troubles. It was in 1433 that the estate of the Earls of Mar who had ruled the central area of the Highlands collapsed, and poverty rapidly worsened in the region. In that decade of the 1430s in the Scottish Highlands, as in Sweden, bread had to be made from the bark of trees for want of grain. And in the accompanying unrest, in 1436, King James I of Scotland was murdered when hunting on the edge of the Highland region near Perth. It was then that it was decided that at no place north of Edinburgh Castle could the king's safety be guaranteed, and so Edinburgh became the capital of the country. In the same decade, the severity of which in other parts of Europe we have already noted, dearth and famine were recorded for the first time in the annals of Dunfermline. And W. G. Hoskins estimates that the famine in England in 1437–9[18] was second only to that in 1315–17.

The physical background to these developments in the history of Scotland shows itself in the fact that the upper limit of cultivation on the Lammermuir Hills[19] southeast of Edinburgh, which had been as high as 425 m (nearly 1400 ft) above sea level at one point in the mid-thirteenth century, fell in stages until by 1600 it was 200 m lower. Over the period from 1300 to 1500 on the hills of continental Europe, from the Vosges in the west, through middle and southern Germany to Czechoslovakia, the upper tree line fell by 100–200 m. And after 1300–1430 the upper limit of vineyard cultivation in Baden in southwest Germany was brought down by 220 m. These height changes tend to verify the approximate magnitude of the change of summer temperatures as derived in fig. 30 (p. 84). We also have a register of the climate of this whole period in the yearly growth rings of larches near the upper tree line near Berchtesgaden in the German Alps:[20] between 1330 and 1490 the rings were of unusually variable width, but from 1490 to 1560 there was a period of good growth. Decline followed and from 1590 the growth rings have on the overall average only had half the width of the 1490–1560 period, though 1770–1810 and 1850–1950 appear as relatively good growth periods.

CENTRAL, SOUTHERN AND EASTERN EUROPE

The changing climate with its enhanced short-term fluctuations, including some runs of three to five years, or even more, of wet, flood-ridden seasons, of droughts and either severe or very mild winters, made itself felt also farther south in Europe after 1300. The wheatlands and the vineyards of northern France shared in the harvest failures and the resulting famine and deaths by the million in the decade beginning in 1310. Ladurie[21] has shown how the dates of the southern French wine harvests beginning in 1349 (but only forming a continuous series from about 1550) can be used as an index[22] of the climate. And K. Müller[23] derived a similarly informative index, from the early Middle Ages to our own times, from the percentage of the wine harvests in south Germany which were reported as good in different periods. Although the early records are fragmentary, the German record shows a decline from figures ranging between 30 and 70 per cent before 1300 to figures never above 53 per cent and at times under 20 per cent between 1400 and 1700.

In the widespread famines of the 1420s and 1430s there were reports of cannibalism in eastern Europe, as there had been also in the west in the 1310s. The repeated famines gave rise to an emigration from Russia westwards into Germany, (It would be useful to have an estimate of the size of this population movement.) And in the severe winters in the 1430s the wolves were active in many parts of Europe, from Smolensk in the east to England in the west. (In England, but not in Scotland or Ireland, this may have been the last time that wolves were reported.)

It was not only in the Highlands of Scotland that there was turmoil in the fifteenth century period of climatic stress. In Denmark and in what is now the southern province of Sweden (Skåne) the deepening crisis in agriculture led to a drift to the towns and by the end of the century apparently to a more general emigration affecting the towns as well. In Bohemia the 1420s and 1430s saw the Hussite risings; and, although these were basically concerned with religious and political ideas of democracy and independence, we may suppose that the times of bad weather and harvest failures made many people rootless and more readily persuaded to join the conflict. Something of the same influences may have applied in England, where the Wars of the Roses dragged on from 1455 to 1485: Trevelyan[24] mentions that, although the common people were probably little concerned about the dynastic causes of these campaigns, the effect of starvation and the run-down state of the country on soldiers returned from France and the Hundred Years War probably encouraged them to enlist. In many, perhaps most, parts of Europe – in England, Sweden and south Germany, for example – it was in the fifteenth century that the main abandonment of the small, unsuccessful settlements occurred. In England John Rous of Warwick, writing in 1485, listed fifty-eight sites, mostly in that one county, which had become depopulated in his life-time.[25] There was much agitation about the conversion of previously tilled land to other use, usually sheep rearing (with the shepherds using any abandoned houses, which had not fallen or been pulled down, for shelter). And the landlords who organized the conversion and enclosed the land became a focus of hostility. In Germany the rising civic pride and splendour in the merchant cities in the fifteenth century seems to have been linked to some extent with the drift to the towns and the protection which they offered against the lawless state of the countryside, in which peasant revolts grew worse until the general rebellion in 1525.

In European Russia a greater proportion of the apparently increasing climatic troubles after 1300 seem to have been due to summer droughts than farther west. This trend seems to be confirmed by the general decline of ring widths shown by the timbers used in the successive surfacings of the streets of medieval Novgorod. There seems also to have been an increasing incidence of severe winters. And the impression given by the chronicles of the monasteries[26] is that the results were of a severity in terms of famine and loss of life, and indeed of the frequency of such events, unmatched in western Europe except in a few decades such as the 1310s, 1430s and 1690s.

In southern Europe, although we have so far disappointingly little direct evidence of the climate in the fifteenth century, grain prices and vintage dates alike suggest that there were no severe effects in the 1430s nor from other parts of the period between about 1420 and 1480 which produced so many harsh seasons farther north. (Fig. 33a, p. 88, suggests that the southwest peninsula of England escaped similarly.) Preliminary meteorological analysis of the 1430s indicates an extraordinary predominance of blocking anticyclones over northern Europe. The southerly winds at the western limit of the anticyclones could well explain the impression that this period was one of some recovery in Iceland. If this analysis is right, the fifteenth century probably saw an abnormal amount of cyclonic activity in parts of the Mediterranean, giving more rainfall than is now normal there but few extremes of temperature. It is greatly to be hoped that the documentary archives of the Spanish and Italian cathedrals will some day be systematically studied for what they may contain in the way of direct information on the climatic history of the Mediterranean region.

DEVELOPMENTS IN AFRICA AND INDIA

Farther south again, in the desert regions of north Africa the writings of the great Arab geographers indicate that there was more moisture than now all through the high Middle Ages and after, from the eleventh to the fourteenth centuries. This probably applied to Arabia too. There are descriptions of journeys across the Saharan region[27] from the north African fringe to Ghana and Mali and to the Kufra oasis (24–25 °N 22 °E), in the eastern desert. The desert did not extend north of latitude 27 °N. Crossing of the uninhabited region took two months, but even there, on a journey in 1352, it was reported that a large number of wild cattle often approached the caravan. By that date it seems, however, that a drying tendency had set in, since it was also remarked that the rearing of beef cattle had been given up in the Kufra region. Formerly, great herds had found pasture there in regions which had become desert. From the thirteenth century until the fifteenth there was a Mali empire, which at its height between 1307 and 1332 is said to have covered most of west Africa. In 1325 the Mali sultan built a royal palace in Timbuktu and a tower for the mosque. After the temporary loss of Timbuktu, Mali power was restored there in 1353 and continued until it was abandoned to the Tuareg nomads in 1433. Although it can never be safe to deduce climatic changes from human political history, in this extreme region the events described most probably confirm that drying out of the desert region was proceeding and causing increasing difficulty. In the meantime, we do know from the pollen analysis researches of J. Maley of the Université des Sciences et Techniques du Languedoc at Montpellier in France that in the Lake Chad Basin there was a maximum occurrence of the pollens of the plants of the Sudan-Guinean monsoon zone flora between about AD 700 and 1200 and that these and other water-demanding plants declined rapidly over the period 1300–1500. A curious feature of the period between the moisture optimum around AD 700–1200 and the greater difficulties experienced in this area in the Little Ice Age is that there were successive waves of human migration southwards at two-hundred year intervals, in the thirteenth, fifteenth and seventeenth centuries. In these regions we may hope for further and more direct information from the Arabic libraries, which are reported to contain records of at least the more important years of drought, and from the continuing studies and dating of the former levels of Lake Chad and other African lakes.

The position is rather similar regarding the climatic sequence in the Indian subcontinent. K. S. Lal[28] has described the sources of information on famines and population in India during the Middle Ages and after. Although the data on famines and behaviour of the monsoon in this early period have not been analysed yet, the population estimates are interesting, since they once again produce a sequence which (apart from the underlying long-term increase) roughly parallels our estimates of the temperature trend in higher latitudes. According to Lal, the best estimates of the total population of the subcontinent rise to a maximum, around 200 to 300 millions, about AD 1000, already fall slightly to 190 to 200 millions about AD 1200 and to 170 millions in 1388, followed by a sharper fall to a minimum, around 120 millions, between about 1525 and 1550. Around 1600 a population of about 130 to 140 millions is suggested. When all allowance is made for the effects of wars and massacres, it seems likely that famines and disease must be the main explanation for the fall of population on such a scale as is indicated in the late Middle Ages.

THE SEQUENCE IN NORTH AMERICA: HOW THE PRE-EUROPEAN CULTURES WERE AFFECTED

When we turn our attention to North America, the researches carried out by the Institute for Environmental Studies in the University of Wisconsin at Madison under Professor R. A. Bryson indicate drastic population shifts, the timing and the nature of which point strongly to a meteorological explanation. About AD 1000 the Amero-Indian people had been growing corn all across the high plains from the base of the Rockies, through eastern Colorado and western Nebraska; and farther east there were substantial settlements in the river valleys, where oaks and cottonwoods grew. One of these places, now known as Cahokia, in southern Illinois just east of St Louis, is estimated to have had a population of 40,000 people. From pollen analysis studies, and from counting the bones of different animals found in the refuse dumps (or kitchen middens) of these farming and hunting communities. Bryson and Baerreis have found that the scene underwent a rapid change after AD 1200. There was least change in the valleys close to the watercourses, but the oaks disappeared in most of the places where they had grown, and the overall numbers of trees declined in favour of the plants of the prairie. And among these the shorter grasses gained at the expense of the bigger, more moisture-demanding types. At one site investigated in northwestern Iowa the increase of grass pollen from a negligible proportion to about 70 per cent of the not-tree pollens took only forty-five years or less. Correspondingly, the forest animals, the deer, gave way to bison in the people's diet. These are signs of a significant decrease of rainfall. Moreover, this suggestion accords with the idea of increased dominance of the west winds, generated by the increased north to south gradient of temperature at a time of cooling of the Arctic. This would extend the rain-shadow effect of the Rocky Mountains farther east than before and intensify the dryness within it. The picture is completed by wholesale abandonment of the settlements after about AD 1200. At first, it seems the smaller villages in the driest areas were deserted and people tended to congregate in the bigger places in the river valleys. But ultimately even the biggest of them, Cahokia, was abandoned, seemingly about 1300; and when the first European (French) traders arrived in the area in the eighteenth century they found only scattered, small Indian settlements. As Bryson and his collaborators have demonstrated,[29] the rainfall pattern over the United States in one of those summer months in modern times that have more than usual development of the westerly winds typically produces a long eastward-pointing 'finger' of severe rainfall deficiency, exceeding 50 per cent, an extension of the rain-shadow of the Rocky Mountains. And this feature is so placed that the main concentration of the village sites of the Mill Creek culture in the northern Middle West and Cahokia itself lay close to its axis. In the always drier parts of the plains nearer the Rockies the change in the thirteenth century was plainly catastrophic: all the small village sites there were soon abandoned.

Bryson estimates that the period of extreme dryness lasted two hundred years and coincided with the strong development of the circumpolar vortex which carried the westerlies mostly far to the north in the European sector, accounting for the warm periods of the thirteenth and fourteenth centuries there but also for the vigorous development of the cyclonic rains in Europe around 1315 when the westerlies came farther south. Much farther south, over the southern plains in northwestern Texas and adjacent parts of Oklahoma, the same investigation indicates that there would be an increase of rainfall – as appears to have occurred in the Mediterranean in the high Middle Ages – and it may have been substantial. It is presumed that it was towards these regions that the former population of the northern plains went. Certainly, archaeology indicates that the numbers inhabiting the so-called Panhandle region of Texas rapidly increased around AD 1200. Karlstrom and his associates in the US Geological Survey and in the University of Northern Arizona at Flagstaff have found that the Indian populations on the Colorado plateaux and neighbouring parts of northern Arizona and New Mexico experienced changes corresponding to those over the northern plains.[30] The economy was based on maize, squashes (i.e. plants of the pumpkin family) and beans, and some wild plants, supplemented by hunted game. The population had been increasing and spreading over the area from AD 550 or thereabouts, until between 800 and 1150 almost every habitable part of the plateaux was occupied. It was these people who created the great cliff dwellings of the Mesa Verde and built the many-storeyed stone villages and towns of Pueblo Bonito and the Chaco Canyon in the tenth to thirteenth centuries. They also built water control channels, roads and signalling stations. But after 1150 many areas, especially in the higher parts, were deserted in favour of positions along the bigger stream courses and more control channels for water for irrigation and domestic use were provided. After 1300 the former homelands were almost entirely deserted and the population had moved south and southwest, along the Rio Grande and to the Hopi Mesas area in central Arizona. The associated environmental changes, particularly in terms of moisture availability and water table, were demonstrated by pollen studies and tree ring work, which was also used for the dating.

12

THE LITTLE ICE AGE

Background to the history of the sixteenth and seventeenth centuries

THE SIXTEENTH CENTURY

During the sixteenth century we reach the period from which a great many more documentary reports of the weather survive. This is particularly true for Europe, where the reports are increasingly specific, verifiable and often precisely dated. But also around this time documentary reports begin to be available for other parts of the world. And the middle and later seventeenth century provides the earliest instrument observation records. These, like the evidence of the glaciers in many parts of the world and of the Arctic sea ice, introduce us to a colder climate than that of the twentieth century. In England the late seventeenth-century thermometer record indicates annual mean temperatures about 0.9 °C (1.6 °F) lower than in the period 1920–60. Over the years 1690–9 the deficit was 1.5 °C (2.7 °F).

The temperatures which we derive from the sixteenth-century material available for England (fig. 30, p. 84) and other parts of Europe, like the indications of tree ring width in California (fig. 52, p. 141) and the palaeotemperatures indicated by isotopic studies of the calcite in a cave in New Zealand,[1] point to generally rather warmer conditions between about 1500 and 1550 than in the previous century. We cannot yet say whether this was (in terms of the wind circulation patterns) any sort of counterpart to the temporary recovery in part of the fifteenth century registered by isotope measurements on the north Greenland ice (fig. 36, p. 93) and which seems to have affected Iceland too. The warmth of the early sixteenth century in Europe was probably produced by rather frequent anticyclones affecting the zone near latitudes 45–50 °N and westerly winds over northern Europe, whereas the previous century – like the period from 1550 to after 1700 – was characterized by a remarkable frequency of anticyclones north of 60 °N and winds from between northeast and southeast over Europe south of that latitude.

Despite the mostly genial character of the period 1500–50, there were at least three winters in England with enough severe weather to freeze over the Thames in London – it froze more easily in the days before the tributary streams were put into pipes and the new bridges allowed the tides to reach so far up the river – and the summers of the 1530s on the continent alternated in quality so strongly that graphs of the tree ring record from the oaks in Germany and the vintage dates recorded in France and Switzerland produce a regular saw-tooth zig-zag appearance.[2] (This *Sägesignatur* is a prime example of the more or less biennial, or alternate years, cycle which is present and at times prominent in many series of climatic data.) These observations suggest that the warmth of the 1500–50 period in Europe did not quite match that of 1900 to the 1950s, though the difference was probably not great. From examination of weather diaries covering the years 1508–31 from two places in Bavaria (Eichstatt and Ingolstadt) Professor Flohn found no significant difference of the winter temperatures from the level of 1880–1930, but the summers were on average slightly (7–8 per cent) wetter and by implication less warm.

In the middle of the sixteenth century a remarkably sharp change occurred. And over the next hundred and fifty years or more the evidence points to the coldest regime – though accompanied by notably great variations from year to year and from one group of a few years to the next – at any time since the last major ice age ended ten thousand years or so ago. It is the only time for which evidence from all parts of the world indicates a colder regime than now. This may reasonably be regarded as the broad climax of the Little Ice Age, though we can distinguish some severer years and decades within it and others that were less so. From another point of view it would be reasonable to regard the whole period between about 1420, or even 1190, up to 1850 or 1900 as belonging to the Little Ice Age development.

THE CHANGES IN CENTRAL EUROPE: 1500s TO 1800s

In a weather diary kept at Zurich from 1546 to 1576 the relative frequency of snow among the snowy and rainy days of winter was 44 per cent up to 1563 and 63 per cent from 1564 onwards. From this and similar statistical studies of other data Flohn has concluded that the mean winter temperature from 1560 to 1599 in central Europe was about 1.3 °C lower than in 1880–1930 or the first half of the sixteenth century, while Tycho Brahe's observations in Denmark from 1582 to 1597 seem to imply winter temperatures 1.5 °C lower there than in about the same modern period used for comparison. We also know from the Danish observations, as well as from a survey of ships' experience on the seas between the Netherlands and southern Europe, that easterly winds became prominent. In Tycho Brahe's observation series in Denmark southeast was the commonest single direction over the year as a whole, and northwest winds were as common as southwest. No equally reliable assessment of the summer temperatures

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has been possible yet in the absence of instrument measurements, although work on the stable isotopes of the chemical elements present in tree rings may lead to such a result when the problems of interpretation are better understood. Meanwhile, we note that the proportion of good wine years between 1550 and 1620 in Baden in southwest Germany was rather under half the frequency between 1480 and 1550. In fig. 30 (p. 84) we showed that the summer temperatures derived for England in the late sixteenth and seventeenth centuries averaged 0.6 to 0.8 °C below those of 1900–50 or the earlier sixteenth century, and it is likely that the difference would be a little greater on the continent. It seems reasonable therefore to attribute much, if not all, of the sharp increases of grain prices seen in figs. 33a and b (p. 88) to the climatic change.

We can follow the course of the changes over three centuries in central Europe in some detail in fig. 76, and I am greatly indebted to the Swiss historian Dr Christian Pfister of Bern for allowing me to reproduce these results of his close analysis of the wealth of documentary reports from Switzerland. The graphs show a progressive cooling of the winters from the 1540s to the end of that century, which was repeated after the recovery to the 1620s and culminated in the very cold 1690s. Another recovery followed, but the winters of the 1750s to 1780s were again on average cold. The springs and summers largely pursue parallel courses, but some of the changes from decade to decade appear sharper than those that affected the winters. The springs of the 1690s and the summers of the 1570s and 1810–19 appear as outstandingly cold. The warm summers of the 1550s were dry in Switzerland, but there followed more than half a century of predominance of wet summers, notably so from the 1570s to the 1620s inclusive. There were recurrences of the wet character of the summers in Switzerland in the 1690s, in the 1720s and 1730s and from about 1760 to the 1780s. None of the other seasons of the year showed long periods of wetness during the Little Ice Age, except the autumns between about 1760 and the first decade of the nineteenth century and to a lesser extent the autumns of the 1550s, 1570s and 1590s and the period 1690 to the 1720s. The most noteworthy feature of the autumns is that they continued warm – in fact it was the Augusts, Septembers and Octobers which continued warm – until the 1560s, even rising to a maximum of warmth in that decade. There were other peaks of autumn warmth in the 1630s, 1660s and 1680s and in the 1770s, in all cases followed by swings to a much colder climate which usually included a sharp change to colder autumns as well. The coldness of the autumns in the 1690s, as with the other seasons, stands out.

It is not surprising that the generally cold wet years that predominated from about 1570 to 1600, and from 1690 to 1740, produced great advances of the glaciers in the Alps (fig. 77). (The report of a traveller, Sebastian Münster, in 1546 tells us that the Rhone Glacier in Switzerland was already

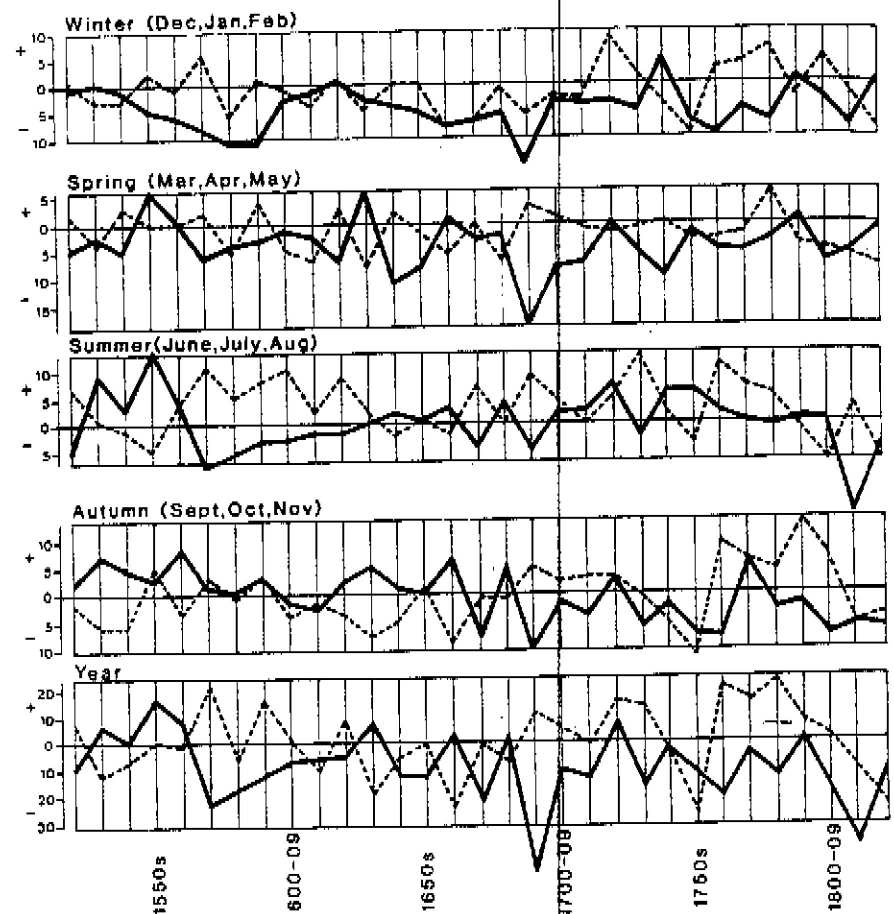
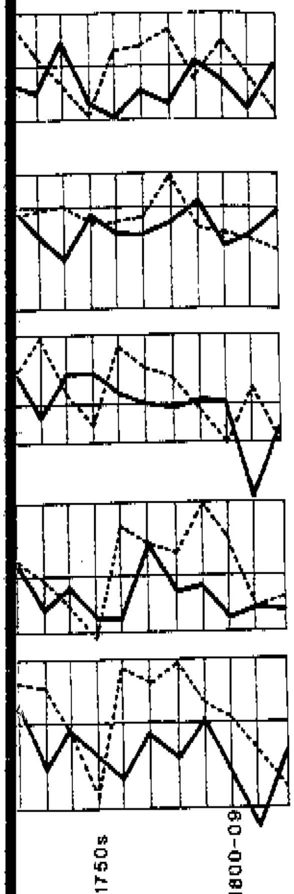


Fig. 76 Thermal index (bold line) and wetness index (broken line) for each season of the year near Bern and Zurich, Switzerland, averaged by decades from 1525–9 and 1530–9 to 1820–9. The indices are defined by the numbers of unmistakably warm (or wet) months minus the numbers of unmistakably cold (or dry) months (respectively) indicated by available documentary records. (Kindly supplied by Dr Christian Pfister of the Geographical Institute, University of Bern, Switzerland and reproduced by permission.)

as far forward as it was around 1900, reaching the broad valley bottom at the foot of the steep ascent to the Furka pass, though by no means reaching the size it had in the eighteenth century.) Pfister has examined the later eighteenth century recurrences of cold wet years in more detail, using the instrument readings of the climatic observation network set up in 1759 by the Economic Society of Bern.[3] There were strong short-term fluctuations: the years 1759–63 and 1778–84 had a warm tendency; but the period



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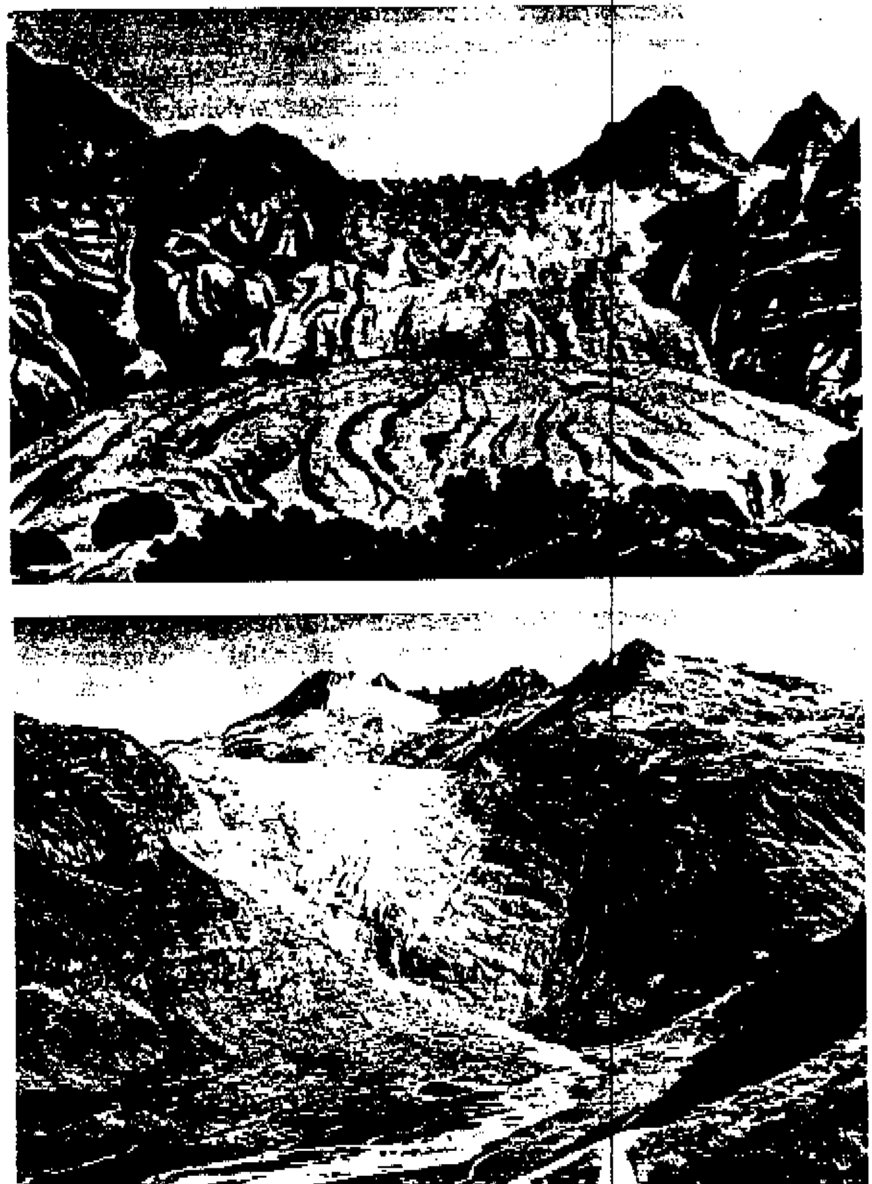

Fig. 77 The Rhone glacier viewed from the same viewpoint:
(a) (top) in 1750; (b) in 1950.

1764–77 was notably cold, the summers being rainy on the Swiss lowlands and snowy in the Alps, the winters long and snowy, especially around 1770. The summers were too short to melt the snows on the alpine pastures, and the glaciers advanced strongly; and in 1769–71 the dearth of wheat, potatoes and milk produced famine. There was a brief repetition of conditions similar to these in 1812–17, with famine in 1816 and 1817.

Pfister has also been able to study weather diaries from the areas around Bern and Zurich from the year 1683 onwards and finds that the average number of days a year with snow covering the ground was about 70 in the first twenty years, 75 in the 1690s, though in the ten years 1705–14 it was as low (42 days) as in the decade (the 1920s) of mildest winters in the present century. More remarkably, the winters of 1684–5, 1730–1, 1769–70 and 1788–9 produced totals of about 110–112 days around Zurich and in 1784–5 over 150 days in Bern. It is thought that 1613–14 also had about 150 days. These figures are to be compared with the total of 86 days recorded in 1962–3, the longest winter in Switzerland of the last hundred years. By statistical methods Pfister has been able to derive temperatures from the weather observations in these diaries and finds that the mean winter temperatures in Zurich in 1683–1700 were 1.5 °C below the 1900–60 average (which agrees well with the departure derived for central England, from the data used in fig. 30, p. 84). The greatest deviation from modern times was, however, in the months of March, which averaged 2.2–2.7 °C (4.9 °F) colder than in the present century. March was a full winter month and in all the extreme winters mentioned in this paragraph had a complete snow cover throughout. In 1687 at Einsiedeln (882 m above sea level) this applied to April also, and in the three years 1699–1701 the snow cover lasted until 15 May, implying mean temperatures 4–5 °C below the modern average. The effects of these years on the Swiss farms were drastic. It seems that the grain crops suffered from attacks of a parasite, *Fusarium nivale*, which is active under snow cover in spring in Scandinavia and northern Germany but is not known in Switzerland today. And the stocks of hay for the animals ran out when the snow still lay in March and April, so that the cattle had to be fed on straw and pine branches and many cows were slaughtered.

Having gauged the situation in Europe where we have these details, let us now survey the situation around the world as we have done for earlier periods in the preceding chapters.

ICELAND AND THE ARCTIC FRINGE

Greenland, as we have reported (see also fig. 23, p. 60), was already cut off by the spreading of the Arctic sea ice. And by the 1580s the broad Denmark Strait between Iceland and Greenland was in several summers found entirely blocked by the pack-ice. In Iceland the effects were most severely felt in all the northern districts and in the east and southeast of the island. Later, around the end of the seventeenth century, there are documentary records of the advancing glaciers overrunning farms. And from about 1480 onwards there had been disasters, entailing losses of farmland, through glacier bursts connected with volcanic activity under the ice and consequential river floods bringing torrents of sand and gravel with them. These *jökulhlaupar* characteristically lasted about one week, and are estimated to have brought a maximum river flow a thousand times that of the Thames.[4] During these times, therefore, there was a general drift from the farms towards the coast, and an increasing activity in the fishing, in the more sheltered southwest of the country. The overall decline of the population, which we have noted in the last chapter, suggests that there may also have been at least some emigration out of the country altogether. The sea ice was tending (albeit with many shorter-term fluctuations) to increase further and in the worst year, 1695, surrounded the country entirely so that no ships could come in for many months. We have referred in chapter 4 to the still greater spread of the Arctic cold water. In these circumstances the cod fishery, which had been the island's relief, ultimately also failed, even in the southwest of the country, for twenty years, from 1685 to 1704. The primitive equipment used by the Icelanders for their fishery in those times played a part in the failure, for foreign vessels operating 20 km off the south coast were able to obtain cod.[5] At the Faeroe Islands the fishery failed for thirty years, and it seems that the cold water was extensive in that direction. As late as 1756 the Arctic sea ice was again at the coasts of Iceland for thirty weeks.

During the period of these manifestations of strong cooling of the Arctic, and its spread to middle latitudes, there were two sectors of the far north, in Alaska and Lapland (northernmost Finland), where the tree ring records show that a more genial climate allowing good growth continued until 1580 or somewhat after. This can reasonably be attributed meteorologically to frequent anticyclones, with sunshine and some southerly winds, in those sectors (which are still particularly prone to blocking anticyclones today). These were doubtless the same anticyclones that were responsible for the frequent northerly and easterly winds over much of Europe and North America at that time.

GREAT STORMS AND COASTAL FLOODS IN EUROPE

As we have remarked in connection with fig. 23, the spread of the Arctic ice to Iceland and of the polar water to the region of the Faeroes meant that the surface of the North Atlantic between there and southeast Iceland became 5 °C colder than is usual today. Consequently, there was a greatly strengthened thermal gradient between latitudes 50 and 61 to 65 °N. This

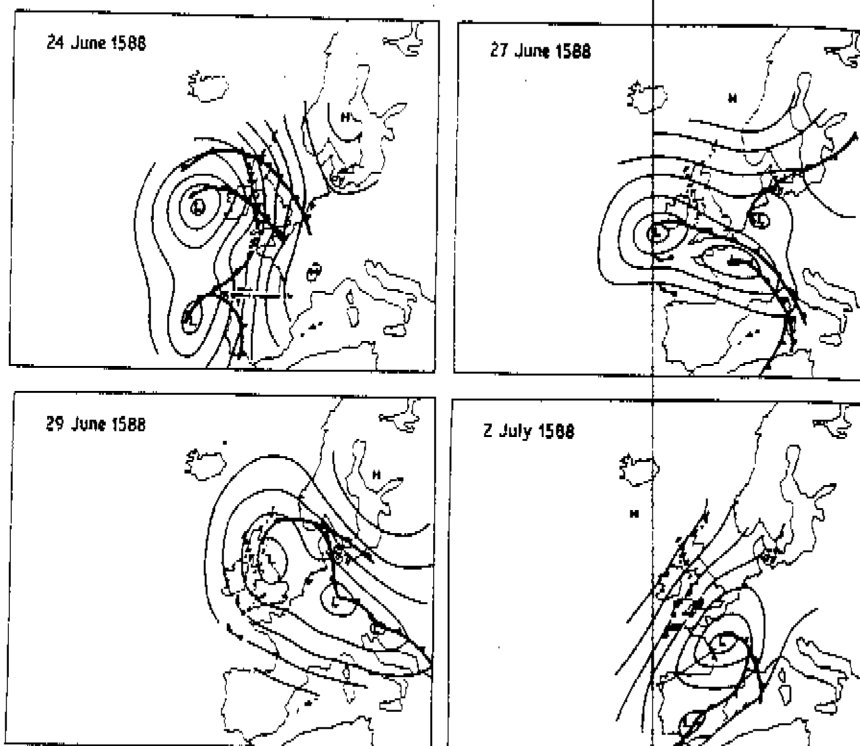

Fig. 78 A series of four daily weather maps from the summer of 1588, analysed with observations from ships of the Spanish Armada and the Danish astronomer Tycho Brahe.

seems to have been the basis for the development of occasional cyclonic wind storms over this part of the North Atlantic exceeding the severity of most of the worst storms of modern times. This is suggested by the many coastal disasters from sea floods – even at a time of slightly lowered sea level (as indicated by the first tide gauge, installed at Amsterdam in 1682) – and erosion and blowing sand. It is most clearly indicated by meteorological analysis of the weather reports available from the Spanish Armada in 1588 (fig. 78). The analysis of the weather situations on sixty days during the Armada's expedition fixes the positions of the depression centres with sufficient accuracy to indicate that their rates of travel on at least six occasions during that one summer corresponded to jet stream winds at the limit of, or beyond, the maximum speeds expected from modern experience.

The development of great storms in this zone continued: from the vast North Sea floods and loss of life on the continental coasts in 1570, mentioned in the last chapter, to the permanent losses of land from the

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Danish, German and Dutch coasts (and demolishing of the island of Nordstrand) in the storm of 21 October 1634; to the formation of the Culbin Sands in northeast Scotland in 1694, and the overwhelming of a four-thousand-year-old settlement site in the Hebrides with sand in 1697; to the great storm which passed across southern England on 7–8 December (New Style calendar) 1703 and was described in careful detail by Defoe.[6] The Eddystone lighthouse near Plymouth was blown down, as were houses in towns and countryside all across England to the east coast; the damage in London alone was estimated at £2 million; enormous numbers of trees were blown down; and many ships were blown up-river, or lifted beyond the usual reach of the tides, or wrecked on the coast and at sea; 8000 lives are said to have been lost. Despite the severity of these floods on the continental side in 1634, 1671, 1682 and 1686 and again at Christmas 1717, in each of which some thousands of people were drowned, and losses of land on many other occasions besides, it is unlikely – in a cold epoch of apparently more or less world-wide extent with glaciers generally in a state of growth – that the general sea level was as high as it had been in the Middle Ages around AD 1000 and between 1200 and 1400, though the difference may have been only of the order of 50 cm. The frequency of such floods between 1570 and about 1720 must be attributed to greater storminess.

EFFECTS IN SCOTLAND

A bizarre occurrence – serious for the individuals concerned – presumably resulting from the great southward spread of the polar water and ice was the arrival about the Orkney Islands a number of times between about 1690 and 1728, and once in the river Don near Aberdeen, of an Eskimo in his kayak. The situation in Scotland itself became serious. The recognition, based on the reports of sea ice and the fisheries, particularly the cod fishery, that the ocean surface between Iceland and the Faeroe Islands – only a few hundred kilometres to the north of Scotland – was probably 5 °C colder than it usually is today at last makes sense of the numerous reports by learned travellers of the time of permanent snow on the tops of the Cairngorms and elsewhere on the Scottish mountains. The cod, which thrives best in rather cold waters at between 4 and 7 °C, serves as a valuable indicator in this connection, because its kidneys fail at temperatures below 2 °C and it therefore cannot venture into colder seas. The cod fishery at the Faeroe Islands began to fail about 1615, and did so increasingly until, as we have noticed, there were no cod thereabouts for thirty years between 1675 and 1704. In the worst year, the same year 1695 in which the ice surrounded Iceland, cod became scarce also in Shetland waters and disappeared from the entire coast of Norway (except for a colony apparently surviving in the inner part of Trondheim fjord). It seems safe to infer that the Arctic cold water had spread across the surface of the whole Norwegian Sea. And although there was some immediate improvement the next year, the sea conditions seem to have been significantly colder than today until well after 1800.

The course of the development in Scotland and the periods of most severe climatic stress can be identified in the records of famines brought together in fig. 79. The information used in this diagram was mainly compiled from the economic records, annals and chronicles surveyed by Lythe and Smout.[7] Although most of the data relate to eastern Scotland, there are indications that the situation was worse in the north and in the poorer Highland districts in the west. The experience of recurrent famines in the later decades of the sixteenth century was at work in the movement of emigration from Scotland, then beginning, which was destined to became a well-known theme in the following centuries. Smout writes that 'the stimulus to leave Scotland was compounded of many factors, of which the general poverty and discomfort of the native land was the most obvious . . . Ulster and (later) America offered empty territory; Holland and England offered mercantile fleshpots; Russia, Sweden, Denmark, France and all the petty princedoms of Germany offered military opportunity' (p. 90). The Scottish mercenary soldier who figures in the writings of Sir Walter Scott was a familiar figure in the wars which troubled Europe in the seventeenth century, particularly in the service of the Swedish king in central Europe in the Thirty Years War: 'by 1660 the stream of military migration had fallen off. . . . Nevertheless even in 1700 there was hardly an army north of the Mediterranean without Scottish officers of some sort' (Smout, p. 92). But the most serious legacy of this time survives to our own day in the 'plantation' in 1612 of Scots farmers in the richer lands and more sheltered climate of Ulster in northeast Ireland after first evicting the native Irish. This seems to have been a device of King James VI at one stroke to stabilize the Irish political and religious situation in his favour and to relieve the impact of harvest failures in Scotland, by taking advantage of the power over Ireland that fell to him on his accession to the throne of England. In modern terms, it would surely be regarded as a model of how not to conduct international relations and a characteristic abuse of (near-)absolute power. It is estimated that by 1691 there were 100,000 Scots in Ulster, already about a tenth of the population of Scotland, and their numbers were soon to be swollen again by emigrants abandoning their Scottish homes in the disasters of the 1690s. Unlike the protégés from elsewhere who were introduced into Ireland in the seventeenth century, these were mostly humble folk who tilled the soil themselves.

If the Ulster plantation of 1612 was related in any way to the dearth in Scotland in that year, which doubtless awakened unhappy memories of the 1590s, it seems to have been an over-reaction. For more than sixty years dearths and famines were less frequent in Scotland than they had

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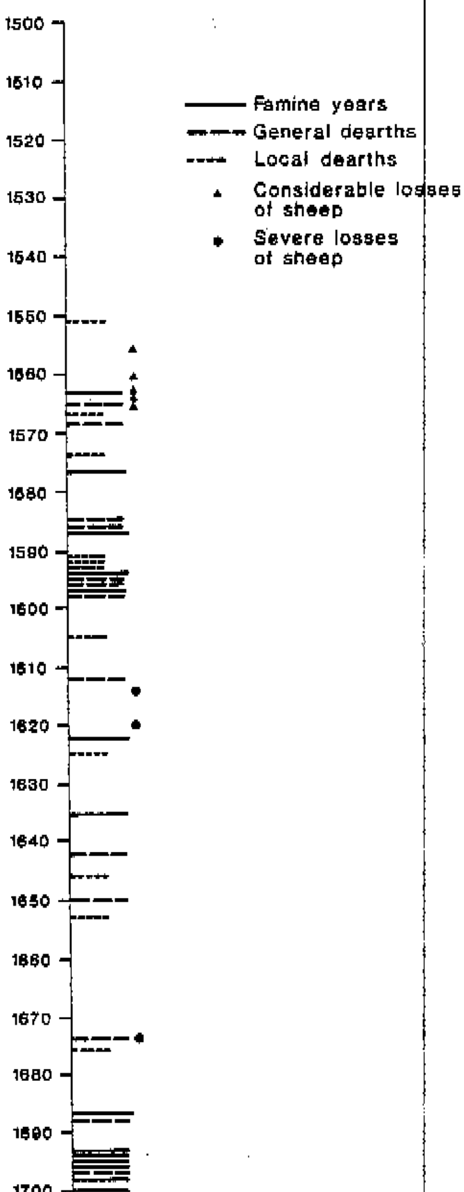

Fig. 79 Years of reported dearth (broken lines) and famine (full lines) in Scotland between 1550 and 1700. The information is mainly from eastern Scotland. Years with severe losses of stock (sheep and cattle), usually because of snow, are marked by dots.

been in the last forty years of the previous century. But from about 1670 the situation deteriorated again, with tremendous snows and frosts in that year and huge losses of sheep in the thirteen days of continously drifting snow in early March (by the modern calendar) 1674. Worse was to come in the last years of the century, when between 1693 and 1700 the harvests (largely oats) failed in seven years out of eight in all the upland parishes of Scotland. There are many accounts of those years parish by parish in the volumes of the *Statistical Account of Scotland* compiled by Sir John Sinclair a hundred years later. 'The poorer sort of people frequented the churchyard to pull a mass of nettles, and frequently fought over it . . . which they greedily fed upon . . .' (parish record of Duthil and Rothiemurchus in north central Scotland). Some were reported to have sold their children into slavery. In parishes all over the country from one-third to two-thirds of the population died – a greater disaster in many places than the Black Death – and great was the fear of being buried in a mass grave. Some whole villages and wide tracts of the countryside were depopulated at this time (fig. 80). And Andrew Fletcher of Saltoun in Midlothian appealed in the Scots parliament in Edinburgh in 1698 that the well-to-do should 'grudge themselves their luxuries' and recognize the nation's need, mentioning that 'from unwholesome food diseases are multiplied among the poor people' and that perhaps 20 per cent of the population of the country were reduced to begging from door to door. To the Jacobites these were the 'ill years of King William's reign', but to the rest of the population they probably made the union with England in 1707 seem inevitable.

A measure of the lowering of the general level of the temperatures prevailing in the northern and eastern Highlands of Scotland in those times is indicated by one or two reports of high-level tarns, or lochans, which had ice on them all the year round. Thus, there is a report in the Philosophical Transactions of the Royal Society dated 1675 of 'a little lake in Straglash [Strathglass] at Glencannich on land belonging to one Chisholm . . . in a bottom between the tops of a very high hill. . . . This lake never wants [lacks] ice on it in the middle, even in the hottest summer'. We also have the travellers' reports of permanent snow on the tops of the Cairngorms. These observations seem to require temperatures 1.5–2.0 °C below twentieth century values averaged over the year, a lowering twice to three times as great as that which has been substantiated in central England from actual thermometer readings, though not unreasonable in view of the apparent advance of the polar ocean water southeast of Iceland (see ch. 4, pp. 61, 205, and fig. 23).

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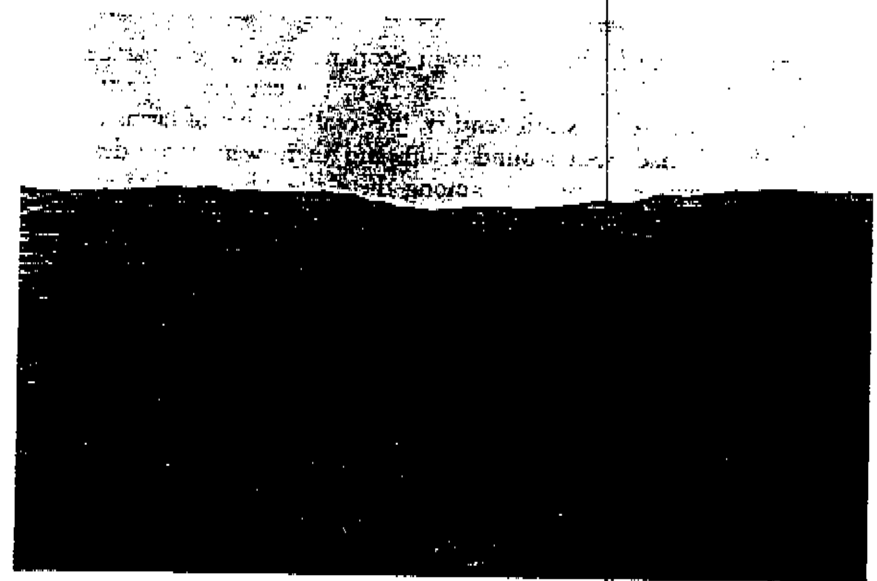

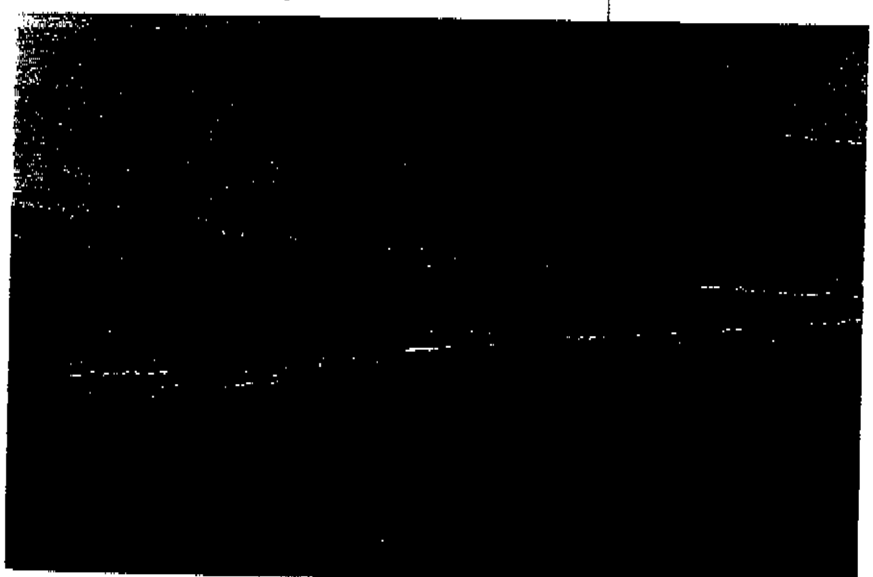

Fig. 80 The site of a village, Daintoun or Upper Davidstown, in the southern uplands of Scotland, which was abandoned in the 1690s. The slope faces north and is 275 m (900 ft) above sea level. (a) (top) General view from the north, (b) at the site, looking northeast. The rectangular shapes of the footings of house-walls can be seen in the pictures. (Photographs kindly supplied by I. J. W. Pothecary.)

SCANDINAVIA AND FINLAND

As might be expected, the situation in Scotland was largely paralleled in Norway. In spite of the degree of recovery in the country in parts of the sixteenth and early seventeenth century, the total number of farms in 1665 was less than it had been around 1300, and there were more desertions later in the seventeenth century, among them the whole village at Hoset (as noticed in the last chapter). Over the next hundred years farms were in some cases overrun by the advancing glaciers and their land partly destroyed by avalanches, floods, rock-falls and landslides. On the Hardanger Vidda plateau small new glaciers were formed, one or two of which survive as dead ice today. Between 1936 and 1951 two sections of a rope fence, which had been erected on a mountainside near Olden in Nordfjord in west Norway by the farmer who owned the land from 1602 to 1624 to protect his sheep from wolves, were found to have been released from the snow and ice which had covered it in the intervening time. It seems that the climatic deterioration did not strike Norway as soon as Scotland and Iceland, although there were some harvest failures at the end of the sixteenth century. The country probably benefited from the influence of the

Fig. 81 Three nineteenth-century pictures showing the types of boat and the methods of drying cod used in the Norwegian coast fisheries over some hundreds of years: (a) A vessel with cargo in rough water on the west coast making for Bergen (picture published in *Norsk Penning Magazin* in 1836, but which apart from the flag could be in the sixteenth century).

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Fig. 81 – continued (b) A rowing boat and fishing station with cod hanging up to dry (from *Norsk Skilling Magazin* 1868). (c) Split cod drying on the rocks near Kristiansund. (Photograph 1935 by Wilse, in Norsk Folkemuseum.) (The pictures at (a) and (b) were republished in Kari Lindbekk, *Lofoten og Vesterålens Historie 1500–1700*, Kommunene i Lofoten og Vesterålen 1978; copies of the pictures were kindly obtained and supplied for this book by Ivar Toflen and Øystein Bottolfsen of Stokmarknes in Vesterålen. The picture at (c) was similarly obtained and supplied by Professor Trygve Solhaug of Bergen.)

anticyclones and southerly winds of which we have noticed evidence in the tree rings in Lapland. The taking up again of long-abandoned farms on the higher ground in south Norway continued until about 1640. A reassessment of farm and land values carried out with great care in 1667 put up the taxes and land-rents, which were paid in kind, above what they had been in the previous century. But troubles and difficulties imposed by nature began soon after that. Reports of rock-falls, avalanches, landslides and flood damage led to pleas for reduction of taxes which were meticulously investigated and generally granted. By the late 1680s and 1690s these incidents had multiplied manifold, and the glaciers themselves were overrunning farmland.[8] There was a great frequency of disasters in these categories in Norway between about 1690 and 1710, which continued with little abatement until the middle of the eighteenth century and then tailed off to reach a negligible level in the middle decades of the present century.

The worst years for the harvest in the Trondheim district of Norway often came three in a row, according to an eighteenth-century Norwegian historian, G. Schøning, writing in the first volume of the Trondheim Society's *Skrifter* (1761). He lists 1600–2, 1632–4, 1685–7, 1695–7 and 1740–2 as examples. In many of those years, however, the herring fishery was better than usual. Schøning wrote: 'the natural cause of this is without doubt that the self-same conditions which produce harvest failures with us, namely long-lasting harsh and stormy westerly and northerly winds . . . drive the great fish stocks of the Arctic Ocean [Barents Sea] in greater than usual numbers to our coasts'. This explanation was no doubt broadly right except in relation to the extreme situation in the 1690s when the fish seem to have been driven altogether farther south.

In north Norway the population fluctuated remarkably during the sixteenth and seventeenth centuries with the variations of the fisheries, as can be established from the taxation documents.[9] In Lofoten and Vesterålen there was a maximum of population about 1618, followed by a 20–30 per cent fall over the next thirty years, then an even greater maximum in the 1650s followed again by a nearly 30 per cent fall to the end of the century. It seems that these changes must have involved migration of fisherfolk in and out of the region from the south. The climate connection is partly obscured here by the effect of changes, controlled by war and peace in central Europe, in the amount of trading of fish – notably dried cod – for corn from the eastern Baltic lands (fig. 81). But it is clear that the fisheries were in poor shape in the latter part of the seventeenth century and that farms were once again being abandoned on a considerable scale in north Norway especially in the later decades of the seventeenth century.[10]

In Sweden most of the same pressures are registered as elsewhere in northern Europe, though less severely than in Norway or Russia. (There seems no mistaking that northerly storms in the Norwegian Sea and the

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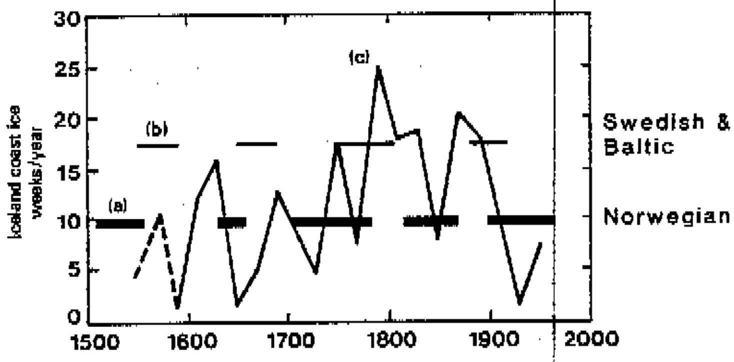

Fig. 82 Periods of herring fishery; (a) Norwegian coast; (b) Swedish coast (Baltic); (c) the incidence of Arctic sea ice at the coasts of Iceland. (Adapted from R. J. H. Beverton and A. J. Lee, 'Hydrographic fluctuations in the North Atlantic Ocean . . .', in C. G. Johnson and L. P. Smith (eds), *The Biological Significance of Climatic Changes in Britain*, pp. 79–107, London and New York, Academic Press for Institute of Biology, 1965.)

severity of the winters in Russia were prime aspects of the climatic deterioration.) In north Sweden there is little sign of the retreat of settlement and agriculture that was so widespread in other parts of Europe, probably because only the best land and the best sites for habitation had ever been occupied. And in Finland desertions hardly begin before the seventeenth century, although there was some migration of Finns to settle farther south in Sweden and Norway already in the sixteenth century.[11]

FISHERIES AND THE SEAFARING NATIONS OF NORTHERN EUROPE

The Baltic and North Sea–Norwegian Sea herring fisheries underwent sharp changes, largely alternating with each other in a way that had obvious climatic as well as historical significance. The variations are outlined in fig. 82. How far they represent migrations of the same fish stocks is not known, of course. All five of the Norwegian herring fishery periods, however, corresponded to minima in the occurrence of ice at the coasts of Iceland. In the sixteenth and seventeenth century cases the fish seem to have preferred the North Sea rather than the Norwegian coast. (The herring normally inhabit waters with temperatures between 3 and 13 °C.) Trevelyan wrote of the impact on English history:[12] 'The increase of deep-sea fishing was a feature of early Tudor times and helped to build up the maritime population and strength of the country. . . . The herring had recently moved from the Baltic into the North Sea' and in the words of the late-sixteenth-century English historian, Camden: 'These herrings, which in the times of our grandfathers swarmed only about Norway, now in our times

. . . swim in great shoals round our coasts every year.' Thus, in at least this aspect and perhaps in others, the Little Ice Age caused England to gain at the expense of her northern neighbours.

Similarly, the centuries we have reviewed witnessed the decline of Trondheim as a northern capital, the shift of the Norwegian court first to Oslo and the Akershus fortress and later to Copenhagen after the union of the northern kingdoms: finally in 1536 Norway ceased to exist as a separate country (until 1815). A parallel (but shorter distance) southward movement took place in Scotland and culminated in the union with England in 1707.

The prosperity of Holland in the first half of the seventeenth century also owed a good deal to the transference of the fisheries to the North Sea and Atlantic waters, as well as to an industrial revolution based on the exploitation of the windmill. The rise of Dutch sea power also had something to do with the chaos produced by the Thirty Years War in central Europe and the need to protect Dutch trading interests in troublous times. Later in the seventeenth century the prosperity declined somewhat, owing partly to the incidence of great storms and sea floods which broke the dykes as well as to poorer yields from both farming and fishing.

HARVESTS AND HEALTH IN ENGLAND

England did not altogether escape direct impacts from the development of the Little Ice Age climate, however. Hoskins's survey of English wheat harvests, mainly in the west, from 1480 to 1760[13] shows a few runs of terrible years, among which some in the 1550s and 1560s, 1594–7, 1692–8, as well as the years 1709, 1740 and 1756, stand out. There were notable runs of good harvests in the 1490s, 1537–48, 1685–90 and 1700–7, and a much greater proportion of good harvests from 1717 to the end of the survey.

For England the summers of 1555 and 1556 and the harvests they produced certainly came as a severe shock after the easier times that preceded them. Already in 1550, 1551 and 1554 the harvests had been mediocre or worse. Whether the outcome should be described as famine is debatable, but presumably malnutrition aggravated the influenza epidemic of 1557–8 in which whole families died.[14] A close study of the registers of births, marriages and deaths in a sample parish, Colyton (near Exeter) in southwest England, provides a survey of its population from about 1550 onwards.[15] There was a decline in the 1550s, when deaths exceeded the number of births for several years. Thereafter, there was fairly steady growth until the last plague epidemic in the area in the 1640s reduced the population by about 20 per cent in a single year. But afterwards, apart from a spurt of marriages in the 1650s, there was no real recovery for a long time. The yearly number of burials exceeded the births from the 1660s until

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about 1730. Only after the 1780s were the births substantially in excess. Delay of the marriage age and a general loss of fertility seem to have been the order of the day. From 1560 to 1645 the average age of the women of the parish at marriage had been 27, then until after 1700 it was 30 years. After 1720 it began to fall: the long-term average around 1800 was 25 and in the 1830s it had fallen to 23 years. Whatever the exact causes of these changes in this agricultural parish, with its small market town and involvement in the woollen industry, the numbers of the population and the expectation of life show an obvious and direct association with what we believe to have been the variations of prevailing temperature, apart from the plague of the 1640s.

THE VARIABILITY OF WEATHER IN THE LITTLE ICE AGE

The difficulties imposed by the climate in the Little Ice Age time were not only due to the lower temperatures, to which any generation could no doubt adapt, even if with some effects on health, fertility, length of life, etc. But, as the harvest results mentioned in the last two paragraphs have implied, there was an enhanced variability of the temperature level, which must have badly upset harvest expectations and posed a need for storage of reserves of foodstuffs beyond the resources of the community at that time. This was not just an occasionally very wide variability from year to year but, doubtless with more distressing effects, the wide differences between one group of up to six or eight years and the next. This is a characteristic which seems to have recurred in recent years. The well-known occurrence of very hot summer weather in the two summers of 1665 and 1666, when London experienced its last great epidemic of the plague which ended with the great fire that burnt the city in September 1666, occurred in the middle of the coldest century of the last millennium; this inevitably now arouses memories of the summers of 1975 and 1976. Similarly, the two winters with least Baltic ice as shown by the over four hundred years long record of ice closing the port of Riga occurred in 1651–2 and 1652–3; the winter of 1658–9 produced the opposite extreme – much as the great Baltic ice winters of 1962–3 and 1965–6 occurred only a few years before the ice-free winter of 1974–5. This tendency can be illustrated also by the listing of the most extreme winters and summers shown by the temperatures measured in England since 1659, in tables 2 and 3 below. Notice particularly the occurrences of opposite extremes within a few years of each other in the Little Ice Age, in the winters of the 1680s, 1690s and the 1790s, and in the summers of the 1670s and around 1720.

The temperature values quoted in tables 2 and 3 are from the series painstakingly homogenized by the late Professor Gordon Manley.[16]

Table 2 Average temperatures over December, January and February in the seven coldest and seven mildest winters in central England between 1659 and 1979 (long-term average for winter 1850–1950 4.0 °C)

Winter	1683–4	1739–40	1962–3	1813–14	1794–5	1694–5	1878–9
°C	–1.2	–0.4	–0.3	+0.4	+0.5	+0.7	+0.7
Winter	1868–9	1833–4	1974–5	1685–6	1795–6	1733–4	1934–5
°C	6.8	6.5	6.3	6.3	6.2	6.1	6.1

Some of the gentry who had taken over the former monastic estates in England after the Reformation were encouraged by some of the warmer summers of the late sixteenth to eighteenth centuries to try once more establishing vineyards, as the monks had done in the high Middle Ages, though protected by specially built walled gardens and not in the open field as of old. However, when Samuel Pepys went in July–August 1661 to see one of the grandest of them, the vineyard which the Cecils had established fifty years earlier at Hatfield House, he remarked only on the coldness of the day and the size of the gooseberries.

Table 3 Average temperatures over June, July and August in the fourteen hottest and fifteen coldest summers in central England between 1659 and 1979 (long-term average for summer 1850–1950 15.2 °C)

Summer	1826	1976	1846	1781	1911	1933	1947	
°C	17.6	17.5	17.1	17.0	17.0	17.0	17.0	
Summer	1868	1899	1676	1975	1666	1719	1762	
°C	16.9	16.9	16.8	16.8	16.7	16.7	16.7	
Summer	1725	1695	1816	1860	1823	1674	1675	
°C	13.1	13.2	13.4	13.5	13.6	13.7	13.7	
Summer	1694	1888	1922	1812	1862	1698	1890	1920
°C	13.7	13.7	13.7	13.8	13.8	14.0	14.0	14.0

NOTABLE WINTERS AND SUMMERS IN EUROPE

The period of history with which this chapter deals was, of course, the time of the great frosts which froze the rivers of Europe (fig. 83). The River Thames was frozen over in London at least 11 times in the seventeenth century, 20–22 times between 1564–5 and 1813–14. This phenomenon in itself was probably not of very great economic importance, particularly as it

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.0 °C)

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	+0.7	+0.7
-6	1733–4	1934–5
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1719	1762	
16.7	16.7	
1674	1675	
13.7	13.7	
1698	1890	1920
14.0	14.0	14.0

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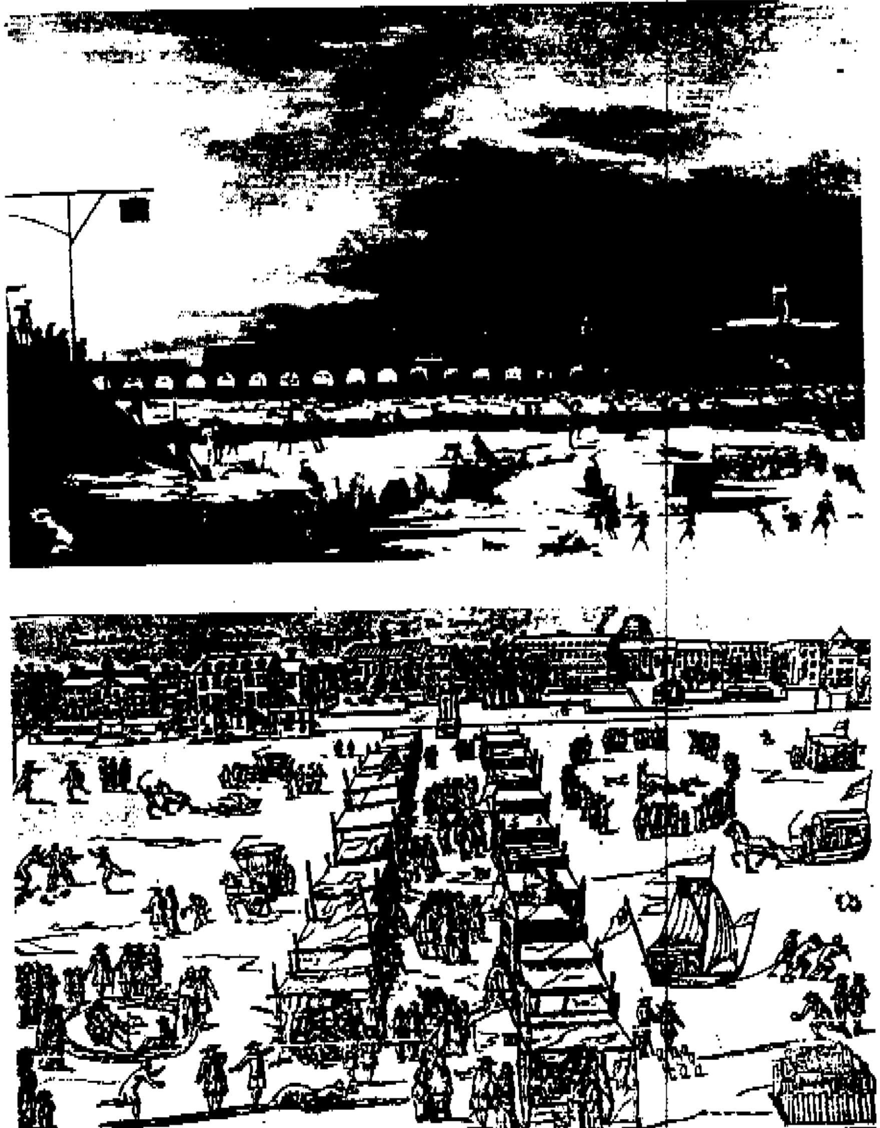

Fig. 83 The frozen River Thames in London: (a) (top) in December 1676; (b) in February 1684. (The painting by Abraham Hondius in (a) is reproduced by courtesy of the Museum of London.)

came to be an expected norm and society was adjusted to it. Nevertheless, the careful records that were kept of when the Dutch canals were closed to traffic because of ice have made it possible to reconstruct the prevailing winter temperatures in the Netherlands back to 1634.[17] The series confirms the very low winter temperatures between 1670 and 1700, but suggests that in the Netherlands – more than in England – the coldness of the seventeenth century winters was fully matched for some decades around 1800. The long-term average winter temperatures for central England between 1670 and 1700 suggest that the normal yearly number of days with snow lying must have been 20–30 as against the 2–10 days which has characterized much of the present century. In the extreme cases of the seventeenth century we have a few reports of much greater totals: 60–70 days at Aldenham in 1662–3, about 80 days at Buckland (also in Hertfordshire) in 1783–4 and 102 days at another point in southern England in 1657–8. These may be compared with the general experience of between 50 and 65 days in 1962–3 and about 40 days in 1978–9. The great winter of 1683–4 was also remarkable for the recorded fact that the ground was frozen to a depth of nearly 4 ft (more than 1 m) where it was snow-free in southwest England (Somerset). In 1683–4 also belts of sea ice 5 km broad appeared along the Channel coasts of south-east England and France; at the North Sea coast of the Netherlands the ice belt is believed to have been 30–40 km broad (see also pp. 238–40). Shipping was halted, as in the Baltic. Similar conditions probably occurred in the winter of 1607–8.

The lowered summer temperatures in and around the 1690s were probably more important economically than the severity of the winters. We have reported the failures of the harvest in Scotland in those years and the similar difficulties in Norway and Switzerland. In England the growing season was presumably shortened on the long-term (30–50 years) average by about 5 weeks in comparison with the warmest decades of the twentieth century, and the yearly total accumulation of summer warmth for the crops correspondingly reduced. In the coldest individual years such as 1695, 1725, 1740 and 1816, when spring, summer and autumn temperatures were low and the summer months mostly about 2.0 °C (3.6 °F) or more below the modern normal, the growing season was probably shortened by two months or even rather more. The effects on crops in the lowland countries of Europe, particularly the continent's main 'breadbaskets' on the eastern part of the great plain in Poland and Russia, and in France, seem not to have been by any means as serious as in the uplands, but in 1695 the harvest failure was more general and from 1695 to 1697 there was famine in eastern Europe, e.g. Estonia.

There is an apparent anomaly in that the years between 1680 and 1720 saw the first great growth of merchant shipping in Norway, the first steps to that country's later possession of one of the biggest merchant fleets in the world. It seems from the local histories recorded around the coasts of

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