Geographical variations in precipitation yields and circulation types in Britain and Ireland

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ABSTRACT

The geographical distribution of daily precipitation with each of the Lamb-classification circulation types is examined for 65 locations in Britain and Ireland. Substantial differences in spatial receipt are related to exposure at the location concerned and length of ocean passage for the air mass involved. Airflow contrasts occurring at regional scales are also instrumental in producing geographical variability in receipt. Cyclonic south westerlies are identified as the most prolific precipitation-producing synoptic type for the area as a whole, while anticyclonic northerlies and north easterlies are the driest. Changes in the frequency of the 27 categories identified by Lamb are then examined over 130 years of record. A significant change in the make-up of the synoptic circulation is seen to have occurred in recent decades. Declining westerlies and increasing cyclonic and anticyclonic airflows are suggested as being primarily responsible for recent changes in precipitation geography. Future precipitation will be determined partly by such changes in airflow types.

KEY WORDS: Precipitation, Synoptic climatology, Lamb-classification circulation types

INTRODUCTION

Many studies have indicated that the broad-scale thermal characteristics of oceanic areas exert significant influences on the magnitude and spatial pattern of precipitation receipt in nearby continental areas. In tropical regions, anomalous sea surface temperatures (SSTs) in the eastern south Atlantic are thought to cause drought conditions in the Sahel area of Africa (Lamb, 1978; Druyan, 1991) while global SST anomaly patterns have been associated with such droughts by Folland *et al.* (1986). Trenberth *et al.* (1988) have shown that recent droughts in North America may be the result of anomalous SSTs over the east central Pacific induced by circulation changes associated with the El Nino-Southern Oscillation.

In temperate regions, precipitation patterns have also been closely associated with the thermal characteristics of adjacent oceanic areas (Mills, 1983) and departures from the oceanic temperature norm have been used to explain concurrent weather patterns in nearby land areas (Perry, 1975). For both temperate and tropical regions, this is largely a consequence of the sea's role in determining the rate of transfer of sensible and latent heat energy into landward-moving circulation systems. In the case of much of western Europe, such disturbances are principally eastward-moving Atlantic depressions, though convective activity over relatively warm sea surfaces in autumn or winter, and its suppression over relatively cool surface waters in spring and summer, is also important.

The amount, intensity, and detailed geographical distribution of precipitation over land adjacent to oceanic areas in both temperate and tropical areas is a function of the interaction between local relief and low level airflows, and of the stability characteristics and moisture content imparted to the lower atmosphere by the air mass's trajectory. Wind direction and exposure are thus the principle controls on the mesoscale variation of precipitation at time scales of about a day. These are often also the spatial and temporal scales appropriate for investigating precipitation-related hazards. The primary purpose of this paper is thus to provide, with reference to Britain and Ireland, information on where significant enhancement (or reduction) of precipitation amounts may occur with a particular synoptic situation. Rudimentary probability forecasting at a sub regional scale also follows from this capability.

As a second objective, the paper examines changes in circulation frequencies. Studying the association between precipitation and circulation types enables the component contributions of a place's annual precipitation regime to be disaggregated according to the circulations producing it. This is important should the frequency of particular circulation types be liable to change. At present there is growing awareness that significant circulation changes have occurred in recent times (Briffa *et al.*, 1990) and that further changes will accompany projected medium term global changes in climate. Indeed it may be argued that short term future climatic changes in the north-western Europe will be determined principally by changes in circulation frequencies. Among other causes, these will result from contrasts in ocean/land responses to global warming (Mikolajewicz *et al.*, 1990) and from differences within the oceans due to spatial contrasts in seasonal mixing depths (Rowntree, 1990). Precipitation changes associated with these circulation changes are thus inevitable and the present paper reviews some of those which may have already occurred and comments on possible future changes in rainfall geography in Britain and Ireland should greenhouse warming proceed as projected in the current generation of general circulation models.

CIRCULATION CATEGORIES AND PRECIPITATION DATA

In relating precipitation yields to synoptic circulation types, the first requirement is for some form of daily categorization of airflow types across Britain and Ireland. A number of approaches have been made to achieving this, ranging from early tabulations of surface wind direction frequencies (Brooks and Hunt, 1933), through more sophisticated air mass analysis (Belasco, 1952) to perhaps the best known catalogue of airflow types devised by Lamb (1972).

The scheme originally devised by Lamb (1950) involved seven primary types: anticyclonic, cyclonic, northwesterly, westerly, northerly, easterly, and southerly. Subsequently, a further nineteen hybrid categories (together with an unclassified category) were added, incorporating more complex circulation types into a daily catalogue extending from 1861 (Lamb, 1972). Updating has enabled a register of over

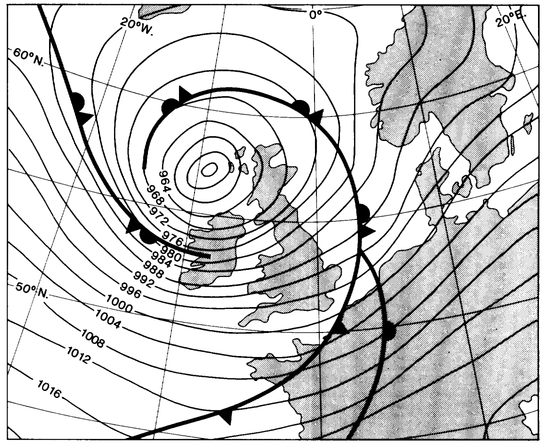

FIGURE 1. A cyclonic westerly synoptic circulation – 12.00 5th January, 1991

130 years of daily circulation types to be compiled. However, although the Lamb Catalogue of Airflow Type has become a popular and widely used system of classifying and describing weather at the synoptic scale, it suffers from a number of limitations, some of which are particularly relevant to the present study.

Limitations of the Lamb-classification of circulation types

Classifying the variety of weather types affecting Britain and Ireland into a small number of categories is not always a straightforward exercise (O'Hare and Sweeney, 1992), a difficulty recognized by Lamb (1972) when he extended his original seven primary types to include the additional nineteen hybrid types referred to above. The criteria used to differentiate some of the hybrid categories from their parent primary circulations can on occasion be somewhat unconvincing. Figure 1 shows a strong westerly circulation extending across Britain and Ireland on 5th January 1991. This shows a particularly deep depression which produced wind gusts up to 90 knots in western Ireland and wave heights over 30 metres offshore at the same location. However, because the central isobar of the depression fails to intercept mainland Scotland the circulation could reasonably be classified as westerly. That this should occur at the critical time of noon (on which the classification is based) is somewhat fortuitous – one hour later the day would have been classified as cyclonic or cyclonic south-westerly. Somewhat ironically, had the depression been slightly less intense, a cyclonic or cyclonic south-westerly designation would also have been appropriate for the day.

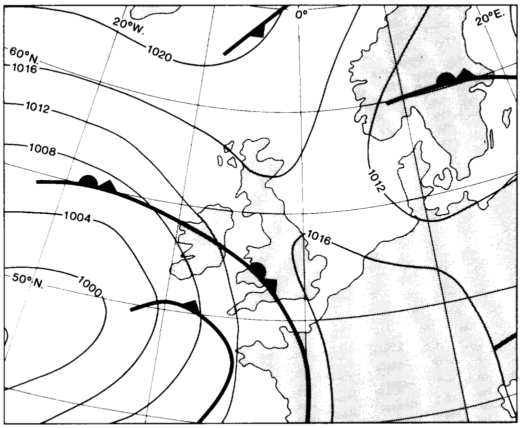

FIGURE 2. An example of a binary circulation – 12.00 14th May, 1990

The most serious limitation, however, relates to the extent of the area to which the classification is validly applied. The categories were originally considered by Lamb to be representative of an area (50°–60°N and 10°W–2°E) which includes the whole of Britain and Ireland. This must be questioned, particularly given the significant regional-scale variations in circulation type recently shown to exist for the period 1959–89 by Mayes (1991).

It is well known that marked contrasts in weather can occur in different parts of Britain and Ireland on a single day as a result of more than one airflow type being present. Figure 2 shows an example of a binary pattern on 14th May 1990. A complex low pressure system with an advancing cold front across the western approaches is shown with a quasi-stationary occluded front over Ireland, Wales and central England. A mild, southerly flow of moist maritime tropical air prevailed to the south of the front, with isolated thunderstorms being reported. By contrast, to the north of the occluded front, a cold north-easterly flow of maritime Arctic air prevailed. Much of eastern Scotland and England experienced their coldest night of the month, with temperatures falling to freezing point in some places. This complex synoptic situation could best be described as a binary airflow over the area with southerly airflow over Ireland, southern England and Wales, and north-easterly airflow over Scotland. Under the Lamb-classification scheme the whole of Britain and Ireland might have been classified as southerly or would have been ascribed to the unclassified category, as was ultimately the case in this instance.

In addressing these problems, Mayes (1991) has suggested that a regional breakdown of circulation types would be appropriate. This would have been desirable for the present study, given the concerns expressed above. However, since regionally specific registers only exist for some parts of the study area, such as Northern Ireland (Betts, 1989), and for periods of time much shorter than Lamb's long register, it was decided to use the Lamb-classification codes in this work.

Precipitation data

Daily rainfall records were assembled for 65 lowland stations in Britain and Ireland for a period of approximately 40 years (Figure 3). In the majority of cases these related to the period from 1941 for the Irish stations and 1952 for the British ones. Some 16 longer records, from both Ireland and Britain, extending as far back as 1875, were also employed (Tables 1–3). Stations were selected on the basis of their length, reliability and location. Some were found to be suspect on individual days and for longer periods of time and their data was discarded where this was observed. A paucity of stations in some areas is nevertheless apparent, and the preparation of maps involved more than might be wished in the way of interpolation, particularly in north-west Scotland where the data net is rather sparse. Interpolation of points from a non-random network runs the risk that some points will exert disproportionate 'leverage' (Unwin and Wrigley, 1987) and so nearest neighbour analysis was carried out to ascertain the degree of clustering which occurred. For the UK network a nearest neighbour statistic of 1·13 was calculated with a corresponding figure of 1·0 for the Irish network. These values indicate that the network could be considered significantly random at the 0·05 level. The data can thus be considered reasonably representative of precipitation conditions in lowland Britain and Ireland.

Matching and within-type temporal consistency

Mean daily rainfall amounts were calculated for each of the Lamb-classification circulation categories for each station. In this respect the exercise was similar to that carried out using 15 years of data for central, eastern and southern England by Stone (1983 (a) and (b)) and one year of data for Ireland by Houghton and O Cinnéide (1976).

Marked differences in rainfall yield are apparent with particular circulation types. An anticyclonic northerly airflow, for example produces only about 0·4 mm on average across Britain and Ireland while a cyclonic southerly flow yields about twelve times

FIGURE 3. Rainfall stations used in the analysis

this amount. The marked rainfall gradients which occur in relation to circulation trajectories are best appreciated, however, when mapped. One of the advantages of using a very long run of data is that such maps are generally based on a very large number of days. In the case of the three most common circulation types: anticyclonic, westerly and cyclonic, the number of days used in the calculations exceeded 2800 at some stations. Accordingly, the rainfall yield may be considered relatively undistorted by particular disturbance trajectories.

Given that the analysis spans a time period of over a century, it might be suspected that significant variations in rainfall yield for the same airflow type might occur over time. This could come about through a slightly changed mean trajectory or as a result of variations in sea surface temperature occurring during the study period. Tables 1–3 show twenty-year breakdowns in yield for the three most common circulations for the stations with the longest records. Though temporal variations are apparent, these are relatively minor. For cyclonic and westerly types it can be seen that approximately 90 per cent of twenty-year average yields fall within ± 10 per cent of the long term mean. Anticyclonic twenty year average yields are less consistent, though rainfall amounts with this airflow are extremely low, magnifying the effect of temporal fluctuations.

TABLE I. *Twenty year average precipitation yields (mm) – Anticyclonic*

Station	*Start*	*Mean*	*pre1880*	*1881–00*	*1901–20*	*1921–40*	*1941–60*	*1961–80*
Workington	1875	0·57	0·45	0·52	0·64	0·69	0·55	0·49
Birmingham	1893	0·40		0·18	0·37	0·56	0·39	0·30
Dover	1894	0·62		0·69	0·52	0·81	0·49	0·64
Cambridge	1898	0·37		0·26	0·29	0·46	0·37	0·33
Cromer	1904	0·47			0·56	0·59	0·39	0·33
Swansea	1910	0·67			0·71	0·87	0·57	0·55
Bude	1912	0·54			0·59	0·58	0·54	0·46
Bournemouth	1913	0·46			0·34	0·54	0·47	0·40
Belfast	1916	0·90			1·22	1·01	0·88	0·70
York	1918	0·40			0·60	0·50	0·34	0·30
Berwick	1901	0·53			0·52	0·70	0·48	0·45
Liverpool	1907	0·67			0·67	0·86	0·61	0·49
Stornoway	1911	2·75			2·97	2·76	2·65	2·55
Aberdeen	1912	0·66			0·59	0·78	0·61	0·60
Prestwick	1913	0·78			0·78	0·90	0·70	0·68
Wick	1941	0·93					0·87	0·97

TABLE II. *Twenty year average precipitation yields (mm) – Westerly*

Station	*Start*	*Mean*	*pre1880*	*1881–00*	*1901–20*	*1921–40*	*1941–60*	*1961–80*
Workington	1875	4·12	3·62	4·59	4·33	3·83	4·00	4·48
Birmingham	1893	2·14		1·64	1·99	2·04	2·40	2·31
Dover	1894	2·04		1·78	2·15	2·15	1·99	1·86
Cambridge	1898	1·53		1·25	1·58	1·39	1·68	1·47
Cromer	1904	2·04			2·10	1·79	2·23	2·10
Swansea	1910	5·06			5·74	4·74	4·94	5·33
Bude	1912	3·36			3·68	3·20	3·34	3·44
Bournemouth	1913	2·63			2·75	2·51	2·67	2·71
Belfast	1916	3·96			4·03	3·79	4·48	3·48
York	1918	1·74			2·17	1·61	1·83	1·76
Berwick	1901	1·74			1·60	1·92	1·77	1·65
Liverpool	1907	5·18			5·37	4·76	5·14	5·58
Stornoway	1911	10·06			10·80	9·32	10·41	10·25
Aberdeen	1912	1·98			1·90	2·07	2·07	1·77
Prestwick	1913	4·36			4·72	4·20	4·38	4·37
Wick	1941	2·74					2·74	2·74

CIRCULATION TYPE AND PRECIPITATION YIELDS

Anticyclonic (Figure 4a)
Pressure is typically high over all of the British Isles with an anticyclonic airflow. Subsiding air inhibits precipitation almost everywhere and generally daily amounts are less than 1·0 mm, with values approximately half of this being the norm over much of England. Only in the extreme north-west of Scotland and Ireland where pressure is lower can north-eastward moving frontal troughs graze the area, producing average falls over 2·0 mm.

Cyclonic (Figure 4b)
A cyclonic circulation type implies the movement of an Atlantic or Biscay depression across the area. Over a long period of record the actual track taken by such depressions may vary considerably, producing a fairly uniform distribution of precipitation. Only

TABLE III. *Twenty year average precipitation yields (mm) – Cyclonic*

Station	*Start*	*Mean*	*pre1880*	*1881-00*	*1901–20*	*1921–40*	*1941–60*	*1961–80*
Workington	1875	4·40	4·47	4·69	4·54	4·12	4·33	4·36
Birmingham	1893	4·64		5·03	4·72	4·29	5·10	4·55
Dover	1894	4·24		4·12	4·65	4·11	3·87	4·34
Cambridge	1898	3·30		3·54	3·41	3·14	3·51	3·24
Cromer	1904	4·09			4·34	3·78	4·26	4·10
Swansea	1910	5·70			6·05	5·50	5·79	5·65
Bude	1912	4·59			5·11	4·35	4·69	4·55
Bournemouth	1913	4·59			4·93	4·42	4·63	4·69
Belfast	1916	4·64			4·59	4·15	5·61	4·33
York	1918	3·94			5·76	3·71	4·07	3·91
Berwick	1901	5·25			5·37	5·13	5·35	5·26
Liverpool	1907	6·17			5·87	5·79	6·58	6·28
Stornoway	1911	4·59			3·97	4·51	4·75	4·81
Aberdeen	1912	5·20			5·26	5·02	5·61	5·10
Prestwick	1913	3·63			3·52	3·48	3·71	3·65
Wick	1941	3·51					3·56	3·48

in the interiors of Britain and Ireland is there an indication that oceanic water vapour supplies may be diminished somewhat.

The mean situation which the map depicts is that of a depression centred over the Irish Sea. Precipitation amounts are at a maximum in this area, an indication also of available water vapour supplies. South of the depression centre the Bristol Channel is seen to be particularly exposed to cyclonic air masses from the south-west, while to the north the eastern coast of Scotland similarly receives enhanced falls from moist air coming off the North Sea. It is noticeable that much of north-western Scotland is quite sheltered by the Grampians with this airflow. With a generally quite uniform distribution of rainfall by comparison with other major airflows, it could be suggested that should an increase in the frequency of depression tracks across Britain and Ireland occur, the west–east contrast in rainfall receipt which characterizes both Ireland and Britain could be expected to diminish somewhat.

North-westerly (Figures 4c,6b,8b)

A ridge, often extending from the Azores anticyclone, is the most common cause of north-westerly airflow. Depressions move in a north-west to south-east direction north of the study area. Onshore air masses only occur in restricted areas, principally in the north-western quadrant. Falls in excess of 5·0 mm are observed over the north-west Highlands, though outside of this area yields are small. A notable rain shadow area exists along the south coast of Ireland where the driest area with this airflow is located. This area is also relatively close to the area of highest atmospheric pressure. Moisture is picked up wherever this north-westerly airflow has any length of sea passage. This is most apparent in north Wales and north-west England where considerable moisture is obviously picked up over the North Channel and Irish Sea. A smaller effect is apparent also on the exposed northern coast of Cornwall and Devon, and in north Munster.

Anticyclonic north-westerly airflows are significantly drier, especially over southern Britain and Ireland where pressure is highest. A particularly dry area is apparent around Fife, in the lee of the Highlands.

Cyclonic north-westerly airflows, on the other hand, yield over 2·0 mm almost everywhere outside of lowland England. Particularly noteworthy with this airflow is the long tongue of enhanced rainfall stretching down the eastern side of the Irish Sea. Substantially more precipitation is being received in north Wales and north-west England than might be expected with such an airflow and it may be that the North Channel is acting as a trigger for convective activity in such unstable airflows. This is something which forecasters might profitably allow for in regional precipitation forecasts with such synoptic conditions. Satellite imagery might also confirm the North Channel as an area of convective cloud development. This could be expected to be most marked in autumn and winter in unstable north-westerly airflows.

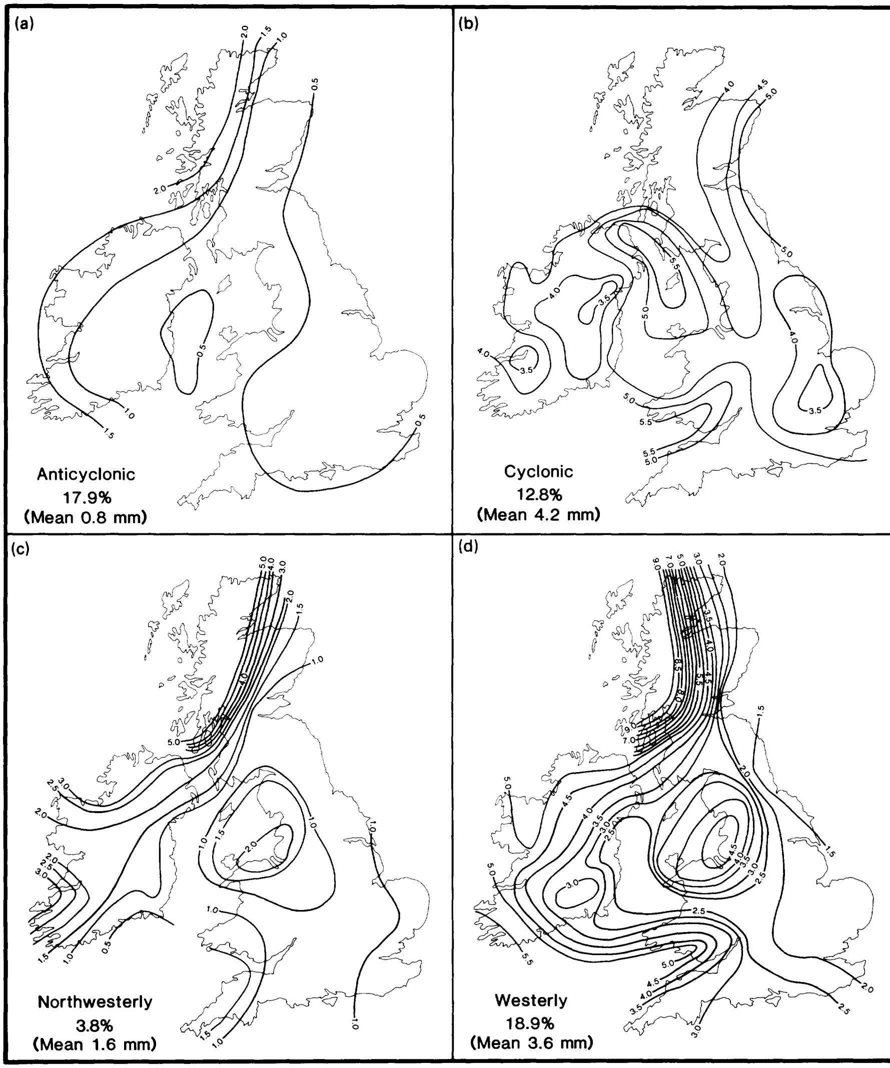

FIGURE 4. Mean daily precipitation with (a) anticyclonic (b) cyclonic (c) north-westerly and (d) westerly types

Westerly (Figures 4d,7d,9d)
Westerly circulations are the most frequent synoptic type in the Lamb-classification register, occurring 18·9 per cent of the time over the century from 1880. With low pressure to the north and high pressure to the south, there is obviously going to be a decline from north to south in precipitation yield. As troughs and ridges pass across the area from west to east, there is also obviously going to be a marked west-east contrast in precipitation receipt. This is dramatically illustrated in Scotland where the west coast receives over five times as much precipitation as the east coast. Indeed only in the western Highlands are very large yields recorded with a westerly airflow, a reflection of the combination of orographic influences and a long sea passage. Very prominent rain shadows can be seen to the lee of the Wicklow mountains, affecting much of the eastern Irish coast, and to the east of the Pennines. Again, significant enhancement of amounts is apparent along the western coasts of England and Wales and the south Wales coast.

Anticyclonic westerlies show yields typically less than half their westerly counterparts, though the airflow is noticeably drier in north-west England and

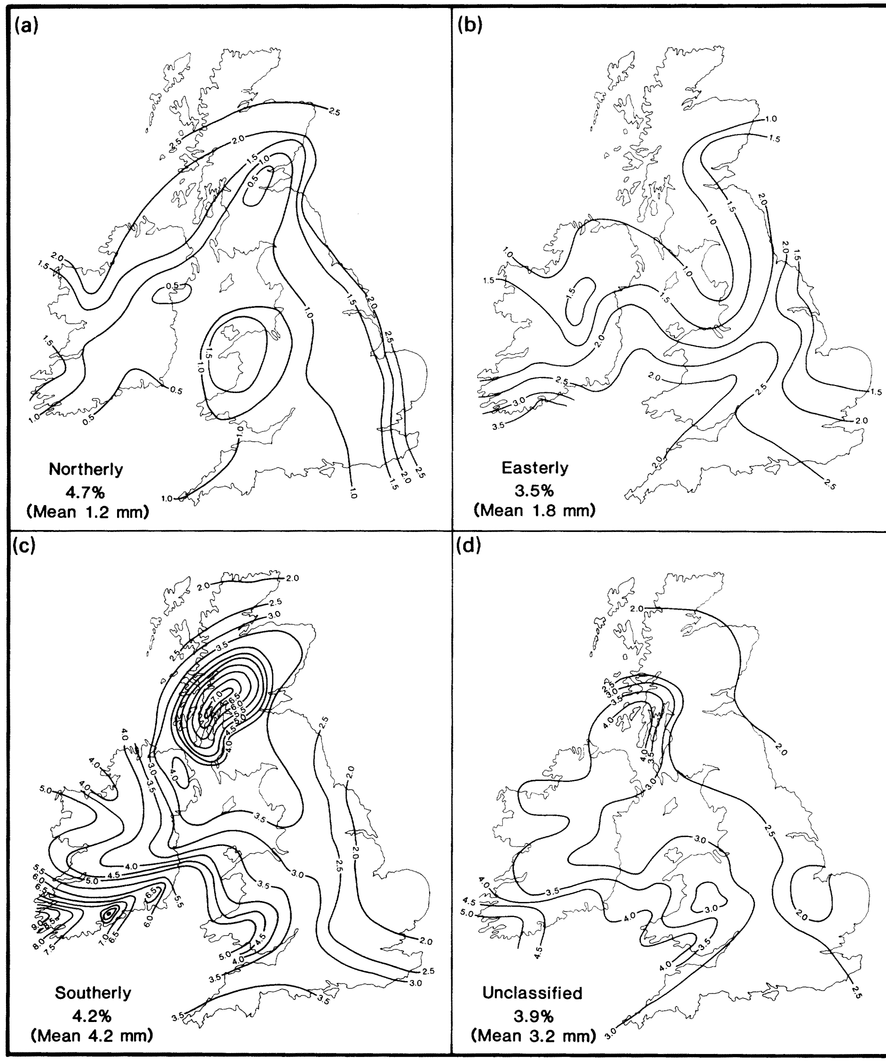

FIGURE 5. Mean daily precipitation with (a) northerly (b) easterly (c) southerly and (d) unclassified types

south Wales. Cyclonic westerlies on the other hand show increased yields everywhere and a lessening of geographical contrasts with all areas outside the western Highlands receiving between 3 and 6·0 mm.

Again the effects of a continued decline in the frequency of westerly circulations could be expected to ultimately diminish west–east contrasts apparent in the annual rainfall map, particularly if the replacement of such flows by cyclonic airflows occurred.

Northerly (Figures 5a,6a,8a)

High pressure to the west of Ireland means that Ireland is generally drier than Britain with this airflow which occurs about 4·7 per cent of the time. The orographic scouring of water vapour by the Scottish Highlands is clearly displayed and eastern central Scotland is the driest place in Britain, receiving less than 0·5 mm of rainfall on average. Other areas of significantly reduced yield are around Dundalk (south of the Mournes) and in south Leinster (south of the Wicklows). Enhanced yields are apparent in north Wales due to moisture being picked up in passage over the Irish Sea. Away from the west coast of Britain, pressure is lower and uplift more likely. Along the east coast of England a band of higher than average precipitation exists, most prominently along

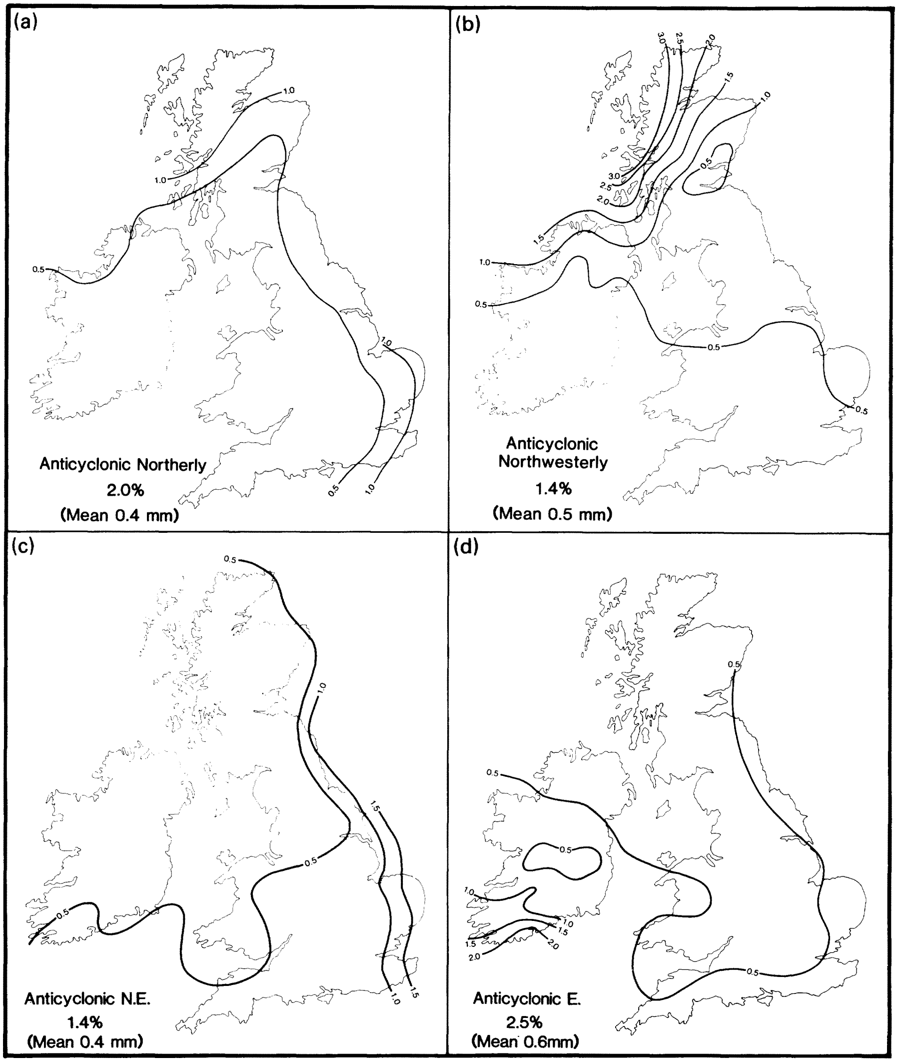

FIGURE 6. Mean daily precipitation with (a) anticyclonic northerly (b) anticyclonic north-westerly (c) anticyclonic north-easterly and (d) anticyclonic easterly types

the coast of East Anglia, as showers develop in unstable polar maritime (sometimes Arctic) air coming off the North Sea. In winter a significant proportion of these precipitation events may occur as snowfall.

Anticyclonic northerlies are much drier everywhere and replicate weakly the pattern for northerlies. Cyclonic northerlies, by contrast, show particularly well developed enhancement of receipt along the east coast of England as depressions track southwards in the North Sea. South-eastern Scotland typically receives almost five times as much rain as the Firth of Clyde with such airflows.

Easterly (Figures 5b,6d,8d)

Low pressure over France or the Bay of Biscay and high pressure to the north of Britain and Ireland is the most common cause of an easterly airflow. Fronts may move from east to west across southern parts, often becoming slow moving. Precipitation is thus highest in southern England and especially on the south coast of Ireland where a passage across the Celtic Sea enables moisture collection and encourages convective overturning in winter and autumn. Indeed, perhaps somewhat surprisingly, much of the Irish south coast receives greater yields from an

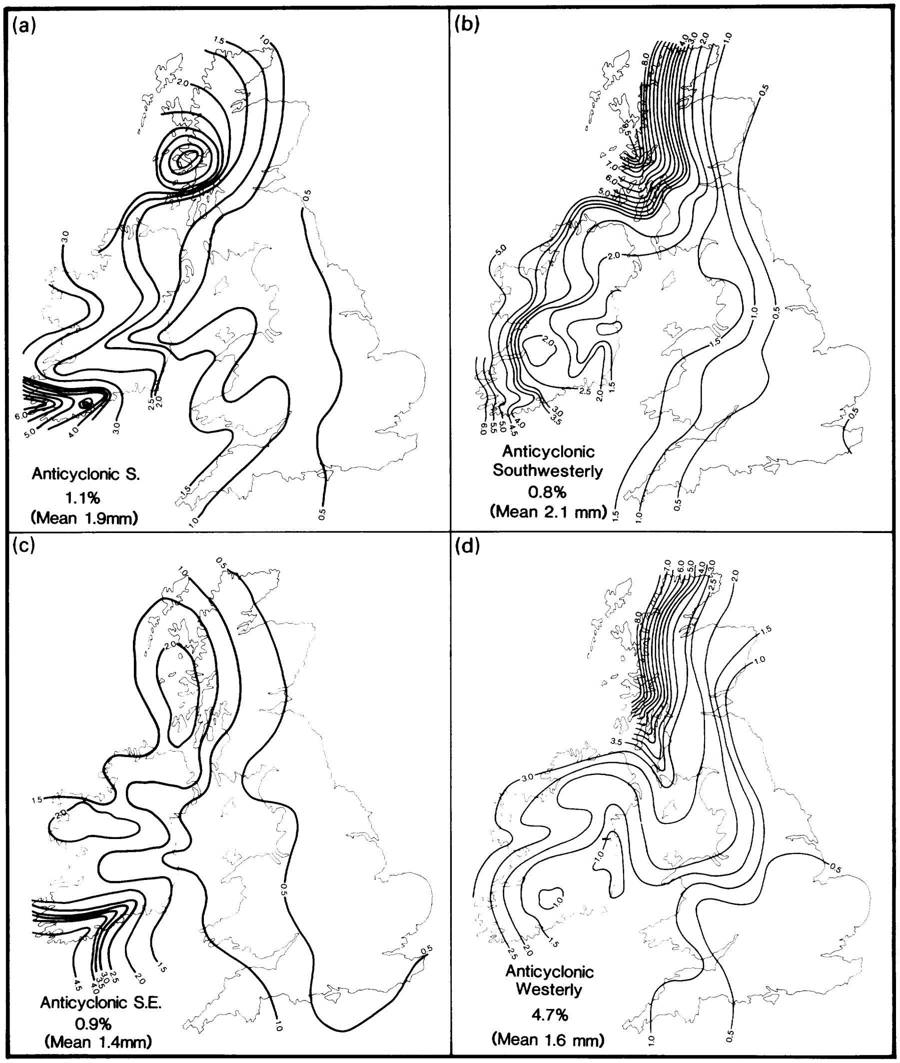

FIGURE 7. Mean daily precipitation with (a) anticyclonic southerly (b) anticyclonic south-westerly (c) anticyclonic south-easterly and (d) anticyclonic westerly types

easterly flow than from a westerly airstream. Further west the airflow is quite dry, reflecting its continental origins. It is also noteworthy that the eastern coastal area of England receives less rainfall than further inland. In summer this may relate to a tendency for increasing convective activity as already unstable flows are directed across warm land surfaces. Distinct rain shadows west of the Pennines and west of the Wicklows are apparent.

Anticyclonic easterlies are one of the driest airflows over Britain with amounts of 0·5 mm typical. Cyclonic easterlies, by contrast are one of the wettest, especially over southern England. More active fronts and a greater proximity to the centre of low pressure are probable causes of this.

Southerly (Figures 5c,7a,9a)

Maritime tropical air masses come heavily laden with moisture and southerly circulation types share with cyclonic the distinction of producing the greatest precipitation yield of the Lamb-classification primary categories. Stratiform cloud produced by air passing over the progressively cooler waters of the North Atlantic Drift yield copious amounts of precipitation

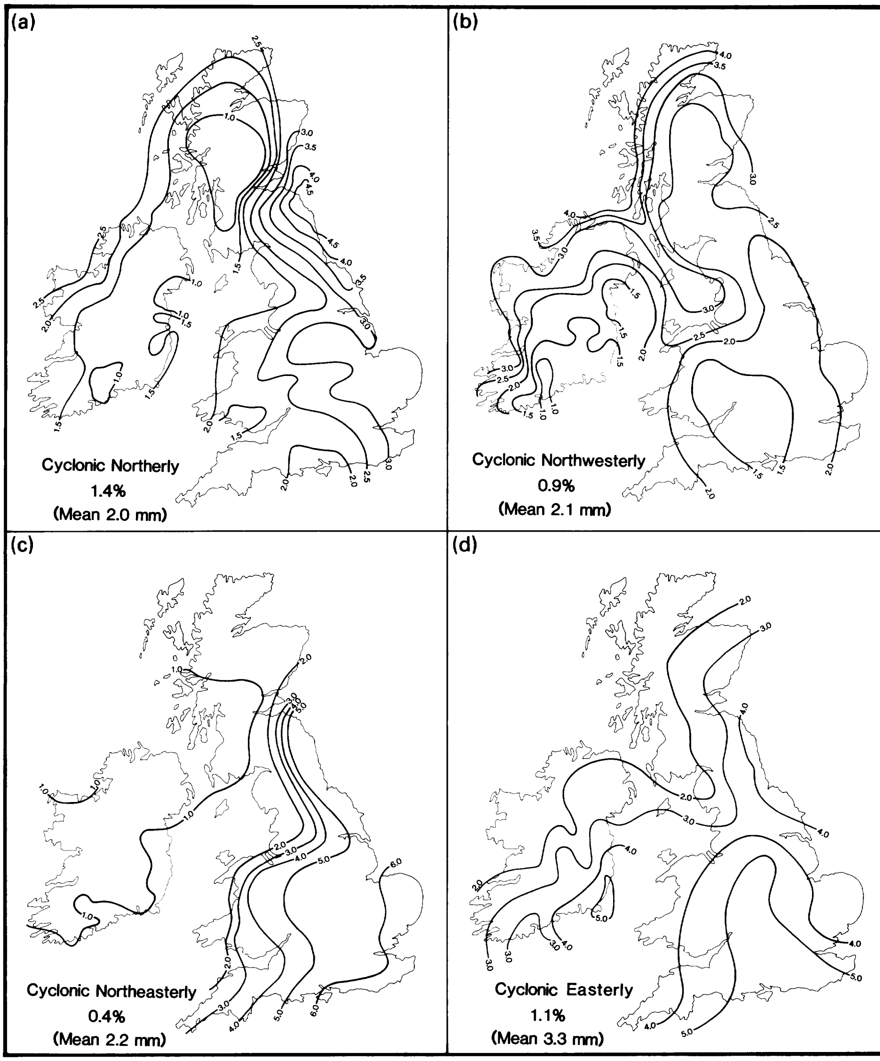

FIGURE 8. Mean daily precipitation with (a) cyclonic northerly (b) cyclonic north-westerly (c) cyclonic north-easterly and (d) cyclonic easterly types

when any lifting occurs. Over the mountains of Cork/Kerry, south Wales, and the Highlands this orographic influence is very striking. Further east the back trajectory of the air is predominantly over continental Europe and so a marked reduction in yields is apparent. Even with anticyclonic southerlies the orographic influence is almost as pronounced in Ireland and Scotland though higher pressure further east causes a more rapid decay of the enhancement in this case. Cyclonic southerlies are associated with a depression located west of the Hebrides and, with the exception of western parts of Scotland, a more even spread of precipitation receipt is apparent. It is perhaps surprising that a greater tongue of enhanced precipitation does not extend northwards through the Irish Sea, as was the case with cyclonic north-westerlies above. This would seem to merit further investigation and possibly relates to sea surface temperatures. Increased stability can be expected to result from a passage over cooler waters as this airstream proceeded northwards.

Other circulation types

Though not considered as primary circulation types, the Lamb-classification catalogue also identifies north-easterly, south-westerly and south-easterly

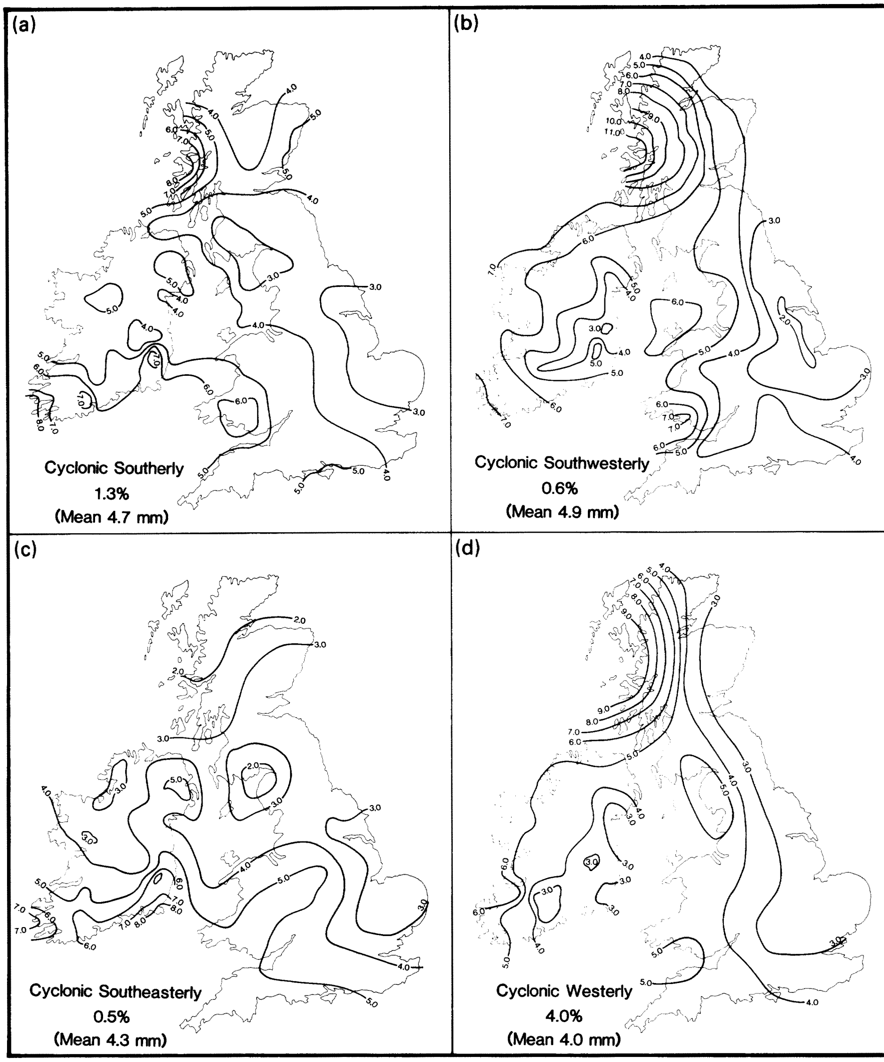

FIGURE 9. Mean daily precipitation with (a) cyclonic southerly (b) cyclonic south-westerly (c) cyclonic south-easterly and (d) cyclonic westerly types

categories. Together with their cyclonic and anticyclonic hybrids these occur approximately 10 per cent of the time.

North-easterly (Figures 6c,8c,10a)

North-easterlies are commonly associated with blocking over the eastern Atlantic. Often a bifurcation of the jet stream is involved, producing a cut-off low to the south of the British Isles with a blocking anticyclone to the north. Precipitation yield clearly is dependent on the precise location of these features. As might be expected, eastern England bears the brunt of such airflows with southern parts noticeably wetter with cyclonic north-easterlies than with any other category. Even with anticyclonic north-easterlies exposed parts of East Anglia and the North Downs receive over 1·5 mm. With this airflow a considerable amount of precipitation in winter would be in the form of snow. Rain shadows downwind of the Pennines and especially the Scottish highlands are prominent. The effects of a more lengthy sea passage can just be detected with cyclonic north-easterlies along the Leinster and Munster coasts and in the increase in precipitation along the north Connaught coast.

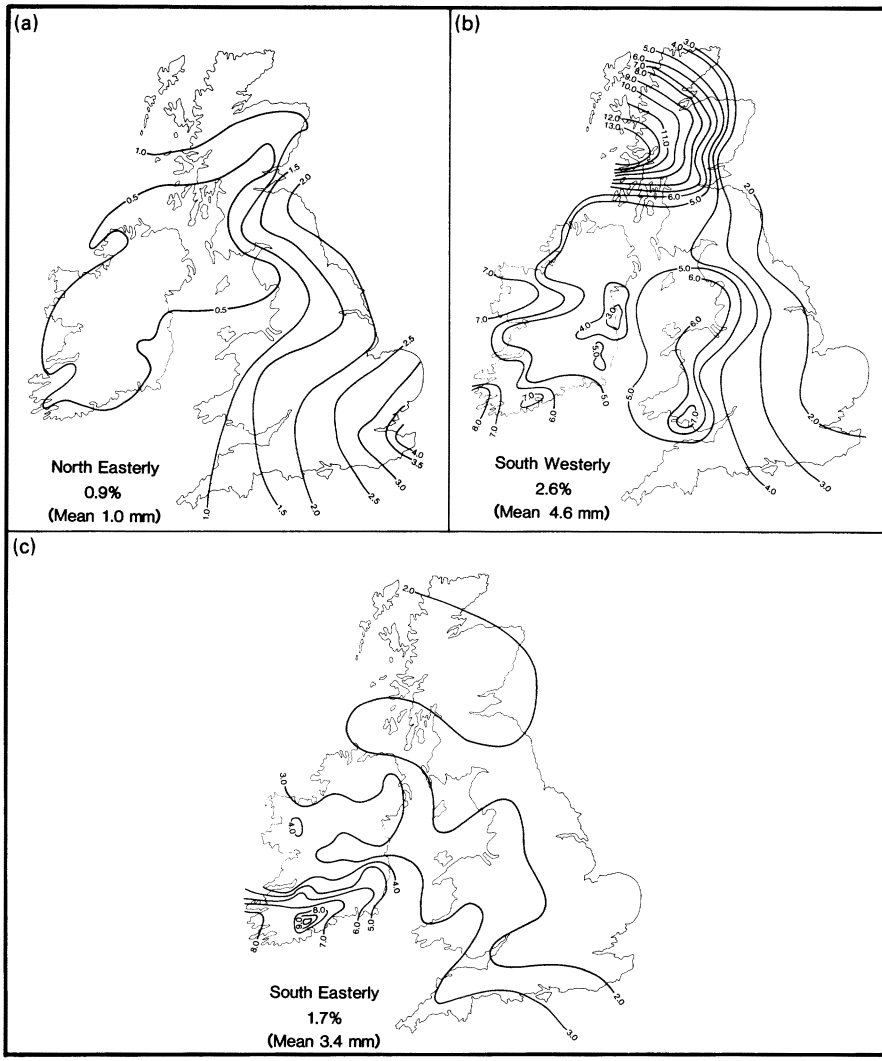

FIGURE 10. Mean daily precipitation with (a) north-easterly (b) south-westerly and (c) south-easterly types

South-westerly (Figures 7b,9b,10b)

As might be expected with such airflows, a marked gradient in receipt is apparent from west to east. Orographic influences due to lifting of maritime tropical air are also very clear. North western Scotland is more than six times wetter in south-westerly airflows than eastern England and overall many similarities exist with the maps of westerly distributions. Cyclonic south-westerly is the highest yielding airflow in precipitation terms of all of the Lamb-classification categories. This is true of almost all areas with the exception of south-east England and is undoubtedly due to the existence both of a moist tropical air mass and a delivery system in the form of a depression off the north-west coast.

South-easterly (Figures 7c,9c,10c)

An anticyclone in the North Sea or Low Countries means south-easterlies reaching eastern Britain will normally be stable airflows with a short sea passage. Further west more instability will exist, and air reaching Ireland for example will have passed also over the Celtic Sea, picking up moisture as it proceeds. With all forms of south-easterly, it is therefore the Cork-Kerry mountains which receive the greatest falls. Surprisingly, receipts for these areas exceed those for the westerly categories, probably a function of proximity to lower pressure. Amounts also increase away from exposed coasts in England in a similar fashion to that observed with easterlies, and again is possibly related to increased convective activity in summer as overturning of the continental air mass occurs.

CHANGES IN CIRCULATION FREQUENCY

The number of days per year during which each principal synoptic type prevailed is plotted in Figure 11. The most notable feature is the well known major decline in the number of westerly days to 60–70 per cent of their frequency of the 1930s and 1940s. Recent work by Briffa *et al.* (1990) has confirmed that this decline has been most marked in winter, though it exists for all seasons. Examination of the data for other categories, including the hybrid types, suggested that a similar decline has also taken place in cyclonic westerlies. In contrast, anticyclonic and cyclonic categories have shown corresponding increases, particularly during the 1980s. The only other significant changes have occurred in south-westerlies which appear to have doubled in frequency since 1960 (from approximately 10 days per annum to 20), northerlies which have steadily declined since mid-century, and north-westerlies which have sharply declined during the 1980s following a few years of higher than average frequencies in the 1970s. Such changes have also been identified using principal components analysis by Briffa *et al.* (1990) who suggested that causal mechanisms may be possible to identify in terms of larger scale aspects of the atmospheric circulation.

In essence, a marked decline in westerliness has been partially compensated for by increases in cyclonic and anticyclonic airflows. Such frequency changes can be expected to have implications for precipitation geography and it is to this aspect that attention now turns.

CIRCULATION CHANGES AND RECENT PRECIPITATION CHANGES

As the westerly circulation has declined, those areas very dependent on westerly-borne precipitation have seen their annual totals fall. In most other cases, however, precipitation receipt from other synoptic types has compensated for the shortfall from westerly sources, meaning that the annual totals are often little changed. Only in a few places sheltered from all but westerly trajectories have significant declines been apparent. One such area, approximating to Co. Limerick has already been identified as falling into such a category (Sweeney, 1985). Sheltered by the mountains of Cork-Kerry (to the south) the mountains of the Burren and Connemara (north) and the main land mass of Ireland (east), a high dependency on westerly-borne precipitation exists for such areas. Even here though, on the western fringes of Ireland, it is the cyclonic category which now contributes the largest segment of the annual precipitation total, a phenomenon shared by probably all locations with the possible exception of north-western Scotland. Half a century ago westerly-borne rainfall contributions would have been the dominant providers of the annual precipitation amount throughout most of Britain and Ireland.

Average annual rainfall in western parts of Britain increased by 5–10 per cent or more during the 1916–50 reference period compared to the 1881–1915 period (Glasspoole, 1954). This reflects the westerly circulation frequency increases of the 1920s and 1930s. The contrast between western and eastern parts increased over this interval. In contrast the precipitation geography of the 1951–80 period shows the effects of diminished westerlies and increased blocking. This was particularly marked in summer when summer rainfall totals in parts of north-western Scotland and Wales were less than 90 per cent of their 1916–50 average, while parts of central and southern England enjoyed values in excess of 110 per cent of the earlier average. As seen above, increased cyclonicity and decreased westerliness diminishes spatial contrasts in receipt across the study area.

The 1980s have seen an increase in westerliness in Scotland, while anticyclonic activity has increased in south-east England (Mayes, 1991). These regional contrasts have not been reflected fully in the Lamb-classification codings for the period and provide additional justification for the use of regionally specific circulation indices. Clearly further work is necessary to establish the precipitation implications of such regional contrasts and also to identify the seasonal geographical variations in receipt which occur with particular synoptic types. The latter are likely to be significant in view of the varying thermal control exerted by land and sea at different times of the year on precipitation-producing mechanisms.

At a larger scale, a decreased equator-pole thermal gradient is likely to be a consequence of greenhouse

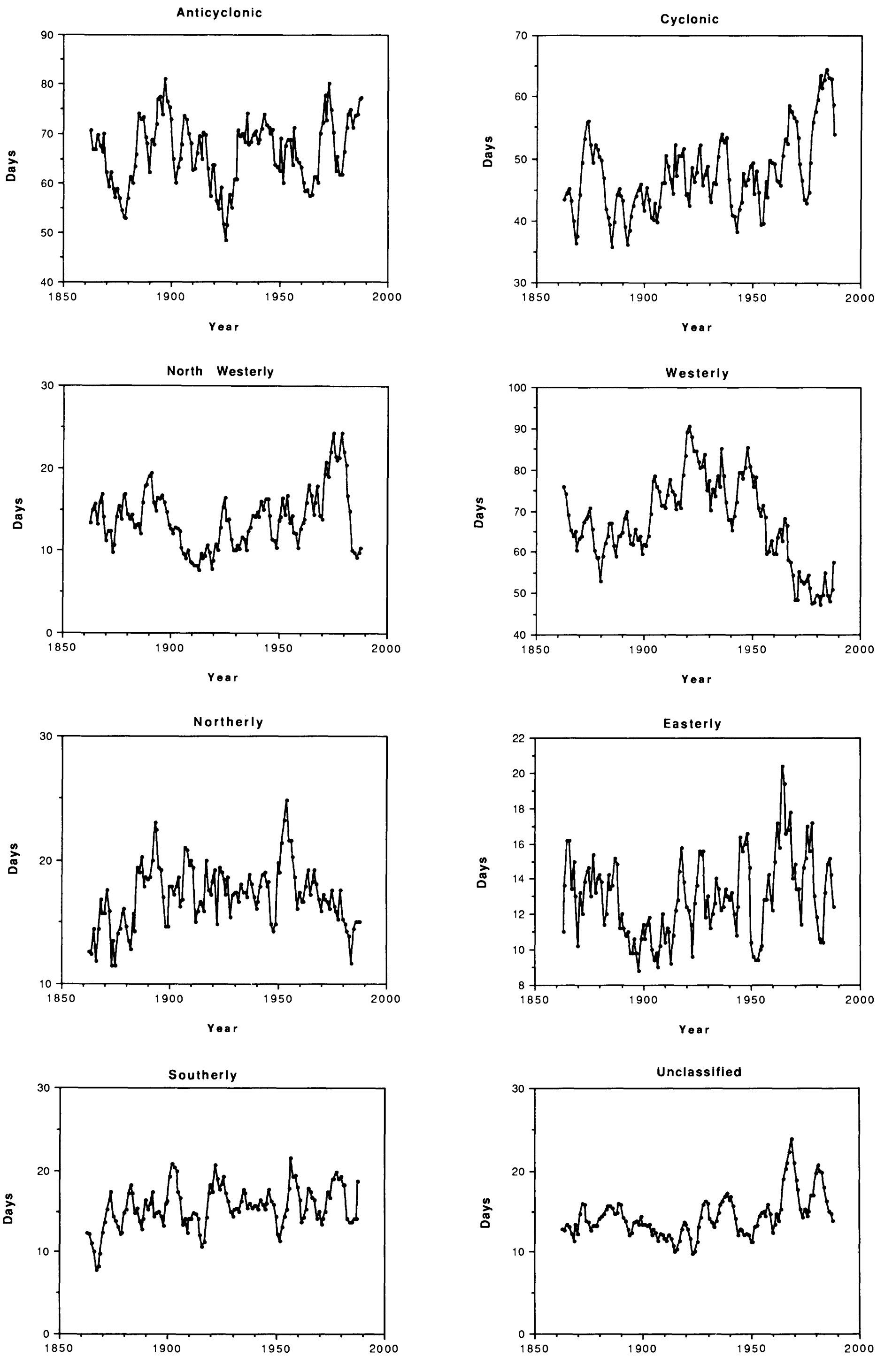

FIGURE 11. Annual frequency of principal Lamb types

warming as higher latitudes warm more quickly due to the ice-albedo feedback effect. This should result in further decreases in the westerly circulation in the long term with possible implications for water supply in western Britain. Should significant warming occur in this region such water supply problems would be exacerbated by increased evaporation demands. Considerable uncertainties remain however in projections of regional scale greenhouse-related changes in climate. In the case of north-western Europe these centre primarily on the effects which slow melting Arctic ice may have on circulation climatology. In the medium term the lag in response of the ice edge to global warming may actually increase the regional thermal gradient for a number of decades in higher middle latitudes. Increased westerliness and storminess may occur during this interval. Indeed the recent divergence in circulation trends between northern and southern Britain noted above may even be a symptom of this phenomenon which may also therefore be a factor to consider when assessing the influence of future circulation changes on precipitation in Britain and Ireland.

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