Lamb's Circulation Types and British Weather: An Evaluation

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ABSTRACT: This paper describes H. H. Lamb's synoptic classification of 'airflow types' and shows how this scheme can be utilised to further our understanding of weather patterns in the British Isles. Spatial contrasts in precipitation receipt are related to airflow type as well as to local factors, such as exposure at the location concerned and the length of ocean passage for the airflow involved. Changes in the frequency of the Lamb classification airflow categories are also considered over a 130-year period. Declining frequencies of westerly airflows and increases in cyclonic and anticyclonic airflows are signalled as well as the consequences for climate which these frequency changes bring. Limitations of the Lamb classification system are also highlighted; in particular, the inability of the system to classify complex and transitional synoptic circulations. When more than one airflow type exists over the British Isles simultaneously, the adoption of sub-regional classification schemes may be more appropriate.

Relating weather and climate at local, regional, continental or global scales to an overall frame of reference has been the constant task of the climatologist (Barry and Perry, 1973, p. 7). For small areas, local fluxes of energy and moisture that determine microclimatic conditions are closely related to the physical nature of the ground surface. At the slightly larger sub-regional or meso-scale, investigations have tended to centre on the role of air stability in weather patterns. At the largest dimension, the global scale, work has focussed on the link between the spatial distribution of weather and climate and the general circulation of the atmosphere. For those scales, on the other hand, lying between the local/meso and global scales, ie. regional and continental, many attempts have been made in linking weather and climate to the synoptic circulation.

Baur *et al.* (1944) developed an atmospheric circulation classification scheme for Europe. They described the main circulation types within the area of Europe and the eastern part of the north Atlantic Ocean, taking into account the general circulation pattern of the whole of the northern hemisphere. Using Baur's classification, Hess and

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Brezowsky (1969) produced a register of classified daily European circulation patterns from 1881 to 1966. Since 1948, European circulation patterns and synoptic types have been classified and published monthly by the German Federal Weather Service employing the scheme of Baur, Hess and Brezowsky. This early German work on synoptic climatology is well reviewed by Barry and Perry (1973, pp. 122–31). Bardossy and Caspary (1990), using the Hess and Brezowsky method, have recently examined climate change in Europe by analysing European synoptic patterns from 1881–1989. In the western United States, Hoard and Lee (1986) classified a ten-year sample of weather maps (500 mb) using a synoptic circulation scheme.

The use of synoptic circulations has also been employed to analyse the atmospheric patterns of smaller sub-continental regions. Early schemes devised for the British Isles involved simple tabulations of surface wind-direction frequencies (Brooks and Hunt, 1933) while later systems used more sophisticated airmass analysis (Belasco, 1952). Like Baur, Hess and Brezowsky in Europe, Lamb (1950, 1972) developed a scheme of synoptic types to analyse the weather and climate of the British Isles. Lamb's classification technique of synoptic or airflow types has proved very popular. It has been applied by a number of workers in the British Isles eg. Stone (1983 a, b); Sweeney (1985); Briffa *et al.* (1990); Mayes (1991); Sweeney and O'Hare (1992); and by Maheras (1989) in Greece.

This paper examines the link between British weather and climate and synoptic circulation. An assessment is provided of the ability of Lamb's (1950, 1972) classification of airflow types to describe and analyse the weather of the British Isles. After briefly outlining the chief difficulties of using airmass concepts in weather study, the spatial and structural basis of Lamb's airflow classification is described. A list of the main attributes of Lamb's seven-fold primary scheme (1950) follows, including its ease of application, the close links between airflow category and weather pattern, and the dynamic-spatio-temporal nature of the system. Examples are given of how temperature and precipitation patterns in the British Isles can be linked to Lamb's airflow categories. The annual and seasonal frequency of occurrence of each airflow type over long periods of time is investigated together with important time-based variations in such frequency. A consideration of the principal limitations of the Lamb classification completes the work. These comprise the need to include additional circulation classes, the problem of using a subjective scheme to classify binary and other complex synoptic situations, monitoring difficulties, the need to check distant airflow origins, and the inability of the scheme to depict the finer meso-scale and micro-scale details of the weather.

The airmass approach of Belasco

Since the 1950s, airmass concepts have been widely used in describing weather and climate at the synoptic scale. An example of Belasco's (1952) airmass approach is provided in Table 1. The weather characteristics of the two stations shown can be inferred from the frequency with which they are influenced by different airmass types. The climate of Stornoway in north-west Scotland is dominated by cool, moist airmasses of polar maritime origin (47.5 per cent frequency) and Arctic air is more common than tropical air outside the influence of fronts and high pressure cells. In contrast, polar maritime airmasses at Kew in south-east England are less in evidence (34.7 per cent), and the possibility of a warmer drier climate here is signalled by the enhanced frequency of tropical airmasses and anticyclonic pressure cells. Labelling the climate of a region, and especially a moderate-sized and varied region such as the British Isles, on the basis of its airmass types and frequencies, is not without its problems, however. These difficulties have been summarised by Musk (1988) as follows:

(a) the precise climatological parameters which give each airmass its distinctive identity are not universally agreed upon because airmasses vary so much from one continent to another

(b) most information relates to the surface temperature and humidity conditions of the airmass with little data given on upper air analysis

(c) individual source regions which give an airmass its overall character are seldom uniform

(d) airmasses alter significantly as they move out of their source region often becoming complex and transitional in character

(e) it is difficult to relate precipitation yields to individual airmass types. Airmass analysis tells us little about the smaller meso-scale mechanisms which produce precipitation, for instance in the vicinity of fronts and depressions, in areas of convergence and divergence, in regions where orographic lifting is occurring or where the local air becomes unstable and rises by convective updraft.

Table 1
Air mass description and frequency at 2 stations in the British Isles

Name	Source	Characteristics	Kew	Stornoway
1. Arctic (A)	Arctic Ocean	very cold and very dry	6.5	11.3
2. Polar Maritime (mP)	North Atlantic	cold, moist	24.7	31.5
3. Polar Maritime (returning) (mP. ret)	Atlantic west of British Isles	cool, moist	10.0	16.0
4. Polar Continental (cP)	Russia, Scandinavia	cold, dry	1.4	0.7
5. Tropical Maritime (mT)	Azores High	mild, moist	9.5	8.7
6. Tropical Continental (cT)	Africa	warm, dry	4.7	1.3
7. Anticyclonic		stable, dry and calm	24.3	13.8
8. Air near Fronts		unstable, wet and windy	11.3	11.8

Source: Belasco (1952).

The Lamb classification of airflow type

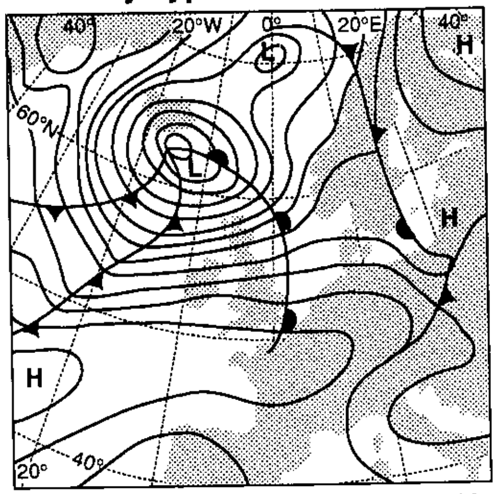
In recognition of these problems, Lamb (1950, 1972) devised a new scheme for classifying the British weather. Lamb studied the daily weather records of the British Isles from 1861 to 1971, and classified them according to a number of "airflow types". In his original (1950) scheme, seven primary *airflow* or *circulation* types were identified (Figs. 1a and 1b). Five of these were based on the compass direction from which the airflows are moving ie. westerly (W), northerly (N), north-westerly (NW), easterly (E) and southerly (S). The other two categories, ie. cyclonic (C) and anticyclonic (A), refer to those occasions when the weather map of the British Isles is dominated by depressions and high pressure systems respectively. The various airflow categories were considered representative of the whole of the British Isles and Ireland, and encompassed an area 50–60°N and 10°W to 2°E.

Benefits of primary classification of airflow types

There are at least five useful features associated with Lamb's primary classification of airflow types when analysing the weather of the British Isles.

(1) Ease of use: Lamb's original scheme of seven primary classes has the merit of being essentially simple and easy to follow. For instance, using Fig. 1 as a guide, A-level students and undergraduates can readily classify the weather of the British Isles from the

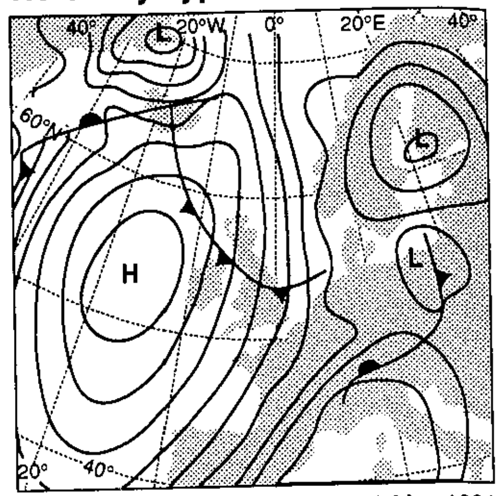
Westerly Type Surface Chart



12 GMT 18 Sept 1990

Low pressure to the north of the British Isles with high pressure to the south. Sequences of depressions and their associated fronts travelling eastward across the region denote this airflow class.

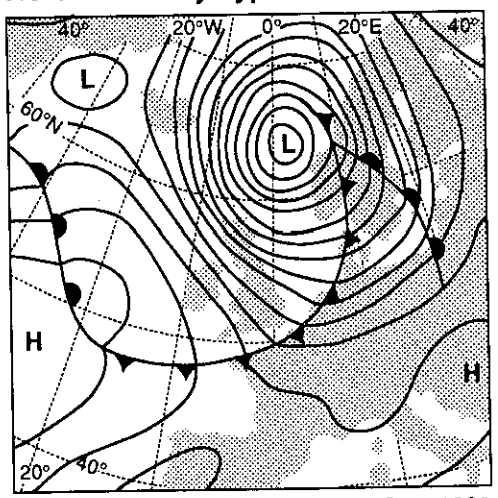
Northerly Type Surface Chart



12 GMT 2 May 1991

High pressure to the west or north west with low pressure over the Baltic, North Sea and Scandinavia. Depressions associated with this synoptic pattern move in a general southwards direction.

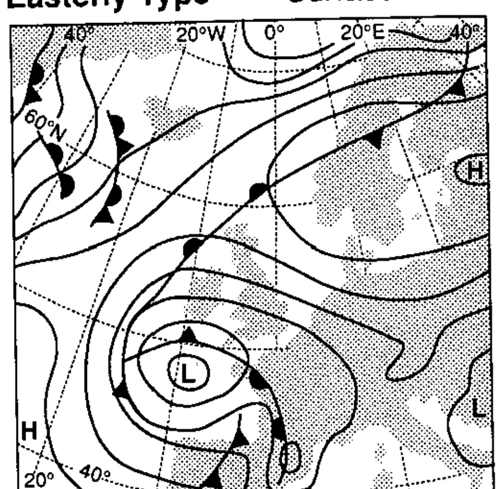
North Westerly Type Surface Chart



12 GMT 19 Sept 1990

Azores high pressure system moves north east towards the British Isles. The dominant clockwise air circulation of the Azores anticyclone transports depressions south eastwards across the region into the North Sea.

Easterly Type Surface Chart

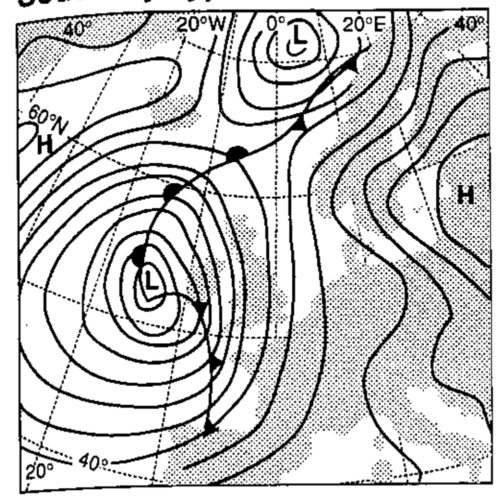


12 GMT 29 July 1991

Anticyclones are stationed over Scandinavia or Iceland with low pressure cells usual off the south west approaches. Air circulations sometimes carrying depressions are driven westwards over the British Isles.

Fig. 1(a). Four recent synoptic situations classified according to Lamb's primary classification of airflow type. Westerly, northerly, north-westerly and easterly circulations shown. Winds at the surface blow anticlockwise and slightly inwards across isobars around low pressure systems; and clockwise and slightly outwards across isobars in high pressure cells.

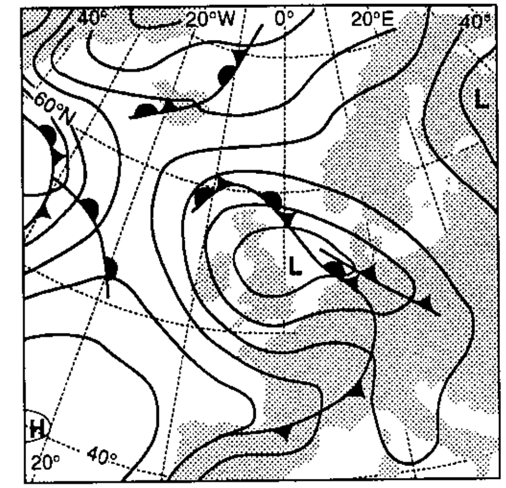
Southerly Type Surface Chart



12 GMT 13 Oct 1990

Atlantic depressions are blocked or sent north or north east along our western coasts because of the existence of high pressure covering central and northern Europe.

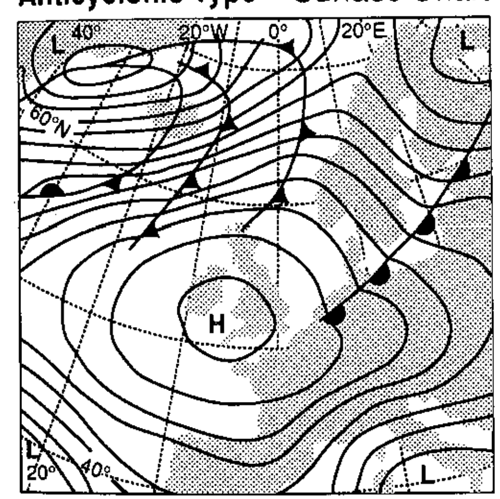
Cyclonic Type Surface Chart



12 GMT 24 July 1991

Depressions, many retaining their cyclonic curvature, centred over some part of Britain and Ireland. Weak fronts, often occluded, are usually associated with such depressions.

Anticyclonic Type Surface Chart



12 GMT 7 Dec 1990

High pressure cells centred on or extending over the British Isles. Lower pressure cols between two anticyclones also included.

Fig. 1(b). Three recent synoptic situations classified according to Lamb's primary classification of airflow type. Southerly, cyclonic and anticyclonic circulations shown.

Table 2

General weather characteristics and air masses associated with Lamb's airflow types over the British Isles

Airflow Type	General Weather Characteristics
1. Westerly	Unsettled weather with variable wind directions as depressions cross the country, giving most rain in northern and western districts, with brighter weather in the south and east. Mild in winter with frequent gales; cool and cloudy in summer (associated with mP, mT airmasses)
2. Northerly	In winter the weather is cold with snow and sleet showers especially along the east coast; blizzards may accompany deep polar lows. In summer the weather is cool and showery especially along the east coast (mA)
3. North-westerly	In winter, cool showery changeable conditions with strong winds. The weather in summer is cool with showers on windward coasts; southern Britain may be bright and dry (mP, mA)
4. Easterly	Cold in the winter period, sometimes with severe weather in the south and east with snow and sleet, but fine in the west and north-west. Warm in summer with dry weather especially in the west; occasionally thundery (cA, cP)
5. Southerly	Warm and thundery in summer. In winter it may be associated with a low in the Atlantic giving mild, damp weather especially in the south-west, or with a high over central Europe, in which case the weather is cold and dry (mT or cT in summer; mT or cP in winter)
6. Cyclonic	Rainy, unsettled conditions over most of the country, often accompanied by gales and thunderstorms. Wind direction and strength is variable. Conditions normally mild in autumn and early winter, cool or cold in spring and summer and cool in late winter (mP, mP. ret, mT)
7. Anticyclonic	Mainly dry with light winds; warm in summer with occasional thunderstorms; cold often with frosts and fog in winter especially in the autumn (mT, cT in summer; cP in winter)

Source: Lamb (1972).

daily weather map and produce their own daily weather register over weeks, months or years.

(2) Weather associations: each airflow category is, in theory, linked with a particular type of weather so that the label 'weather type' is often used synonymously with airflow type. Table 2 shows that Lamb provided quite a detailed reference framework on the weather characteristics expected of each airflow type. Taken together the various airflow categories contain seasonal information on wind strength, temperatures, types and extent of precipitation, cloud cover and fog, and humidity conditions. Descriptions of the various air masses likely to be incorporated within each airflow class are also given.

A simple comparison between airflow type assessed from observation of the daily weather map with actual weather conditions allows the link between actual weather and airflow category to be evaluated. A suitable source for this sort of work can be found in the quality daily newspapers. *The Guardian*, for instance, provides daily rainfall, temperature and sunshine values for more than 70 weather stations in the UK in addition to a daily weather chart.

(3) A dynamic system: by giving information on the operation of high pressure cells and low pressure systems (see Table 2), and pressure information covering each circulation type at higher levels (500 mb) in the atmosphere, Lamb was able to add a dynamic element to his classification, something which he felt was lacking in the airmass approach utilised by Belasco (1952).

(4) A spatial system: airflow analysis is essentially spatial in its approach because we are required to focus on contrasting circulation *patterns* between different airflow classes. This is unlike airmass analysis which has a strong aspatial character to it.

(5) A temporal system: Lamb's daily register or catalogue of airflow types for the British Isles spans over 100 years from 1861 to 1971, and is comprehensively documented in *Geophysical Memoir No. 16* (1972). The catalogue was for a number of years updated in the quarterly magazine *Climate Monitor* which was published by the Climatic Research Unit at East Anglia University. Owing to publication difficulties *Climate Monitor* has not

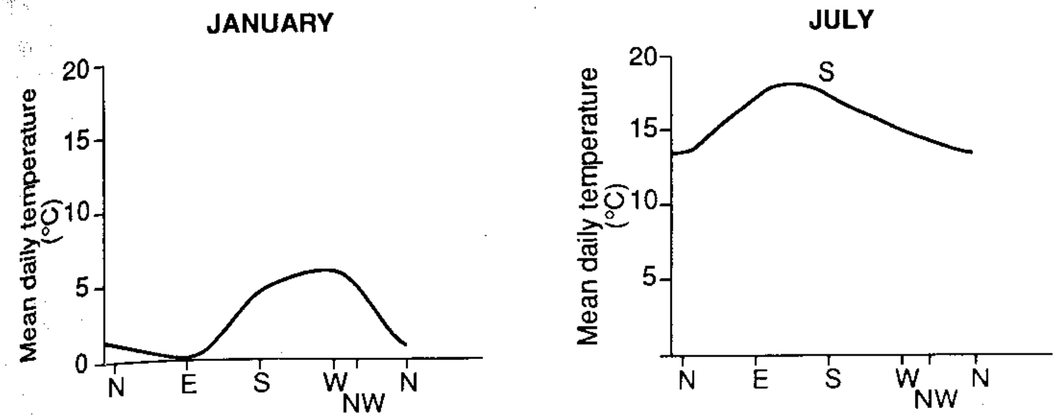


Fig. 2. The relationship between the five directional airflow types of the Lamb primary classification and mean daily temperature for January and July in central England. (Source: Storey, 1982).

been published since early 1989 with the last issue being Volume 17, Number 4. However, Professor Lamb has given permission for *Climate News*, the newsletter of the Association of British Climatologists (ABC), to publish his catalogue. Three years of Lamb's data from December 1988 to December 1991 are provided in the Number 7 (Spring 1992) issue of *Climate News* thus ensuring continuity from the last month of data published by *Climate Monitor*. Future issues of *Climate News* will contain the catalogue updated every six months. The availability of Lamb's 130-year weather record provides scope for statistical analysis, including the establishment of correlations between airflow class and weather conditions, and charting changes in airflow frequency over time.

Examples of use of the scheme

(1) Relationships with temperature: an understanding of the relationship between airflow category and ambient temperature can be encouraged by examining the prevailing temperature field associated with contrasting airflow types. This can be done for single stations in the British Isles or for larger regions and can be expressed over time periods ranging from individual days or seasons to longer periods extending over many years. For instance, Fig. 2 shows that for central England, airflow type exerts a clear control over average temperature. Weather systems moving in from the west or south help to maintain the typical mildness of the British winter, but cold winter spells result from invasions of air from the north or east. Our cool summers, on the other hand, are associated with winds blowing from the west and north, while warm summer episodes are generated by airflow types from the south and east.

(2) Relationships with precipitation: one of the advantages of using airflow rather than airmass type in weather analysis is the ability of the former to be associated with distinctive precipitation patterns. Precipitation yields associated with the Lamb circulation categories can be expressed as with temperature over varying space and time scales. The examples which follow illustrate, for the British Isles, the contrasting distribution patterns in precipitation of westerly and cyclonic airflows. Values are given for both daily and multi-year periods.

(i) Westerly Airflow Type

Westerly, southerly and cyclonic circulations are responsible for the highest precipitation loadings of the seven primary Lamb Circulation Types. Westerly circulations laden with moist maritime airmasses originating over the Atlantic (mP, mT), yield copious amounts of cloud and precipitation when forced to rise and cool by air ascent either at fronts or in the vicinity of mountain barriers. Over the mountains of southern Ireland, north and south Wales and the Highlands of Scotland this orographic influence can be expected to be very marked. As westerly circulations pass across the British Isles from west to east, there is going to be a marked west-east contrast in precipitation receipt.

The 24-hour precipitation yield from the westerly circulation of 9 February, 1988 (Fig. 3) bears out this essential idea. Very strong winds, reaching storm force at times, brought quite heavy falls of precipitation (with rain, hail and sleet) to districts along the west coast approaches, with 16 mm being shed over the Western Isles and at stations in north and south Wales. The maximum precipitation values were recorded further inland however at Glasgow (20 mm) and in the central Southern Uplands (30 mm), where presumably the westerly airflow continued to rise and deposit its moisture. In contrast, a definite rain shadow effect was experienced in eastern Britain; most stations here received generally less than 5 mm and often only trace amounts of precipitation in the 24-hour period.

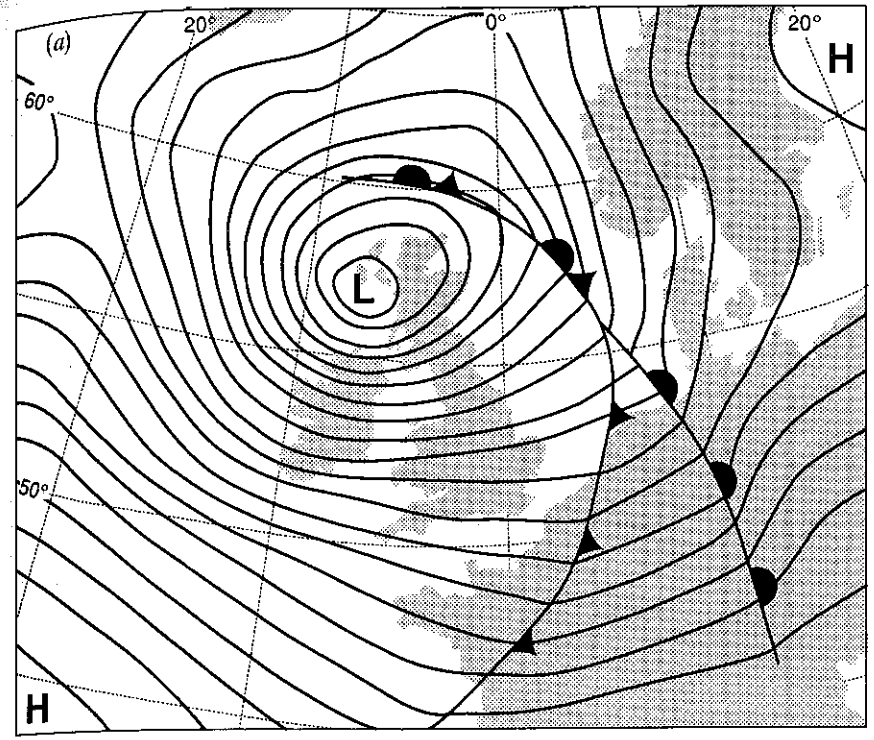
When precipitation yields are averaged and linked to airflow type over long periods of time (eg. for 30 to 40 years or more) there is a tendency for irregular or extreme values to be smoothed out. Nevertheless, a strong west-east gradient in precipitation is still dramatically illustrated with reference to the long-term average loadings (Fig. 3b). In Scotland, the west coast receives between 4 and 5 times as much precipitation as the east coast (over 9 mm as opposed to less than 2 mm). Significant enhancement of amounts can also be demonstrated along the eastern Irish Sea basin and the south Wales coast, with marked rain shadow domains east of the Pennines and over south-east England.

(ii) Cyclonic Airflow Type

The absence of marked west-east precipitation gradients across Britain is a particular feature of cyclonic circulation types. Figure 4 shows a cyclonic circulation over the British Isles and Ireland on 3 May, 1988. The highest precipitation yields associated with this synoptic circulation occurred where air was forced to rise over hills east of the Irish Sea in north Wales (20 mm) and along the Bristol Channel in south Wales (16 mm). But moderate to high precipitation levels fell over an extensive area, for example at Nairn in north-east Scotland (12 mm), and at Cromer in eastern England (6 mm). Some particularly heavy showers developed over the midlands (9 mm) around the middle of the day and then moved north into northern England, the Borders and northern Ireland.

Over a long period of time the actual track taken by cyclonic circulations across the British Isles may vary considerably (Davies *et al.*, 1991), producing a fairly uniform distribution of precipitation as shown in Fig. 4b. In common with the synoptic situation of 3 May 1988, average amounts are at a maximum in the vicinity of sea areas which provide water vapour supplies, for instance, around the Irish Sea, along the English Channel and off the North Sea along the east coast of Scotland. It is noticeable that much of north-west Scotland which is exposed to westerly airflows is quite sheltered by the Grampian Mountains from cyclonic airflow types.

(3) Circulation frequency: the daily categorisation of airflow types across Great Britain and Ireland over the last 130 years allows us to calculate the average number of days when each primary airflow class, including various sub-types (see section on user limitations) prevailed. Table 3 indicates that pure westerly circulations are the most frequent synoptic type in the Lamb register, occurring 18.9 per cent of the time from 1861 to 1991. This is followed closely by pure anticyclonic (17.9 per cent) and cyclonic circulations (12.8 per cent). All the remaining pure directional flows show a frequency level of less than 5 per cent. Airflows from other minor directions ie. from north-easterly, south-easterly and south-westerly points of the compass, together with the anticyclonic and cyclonic variants



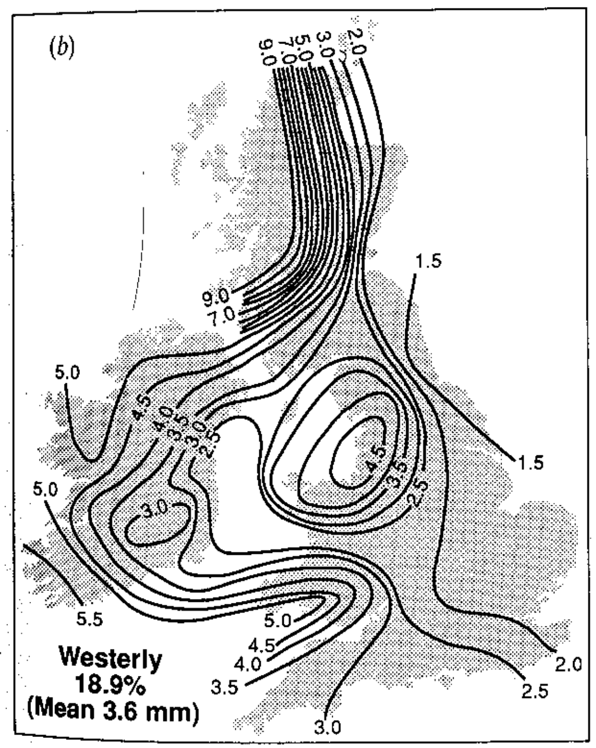
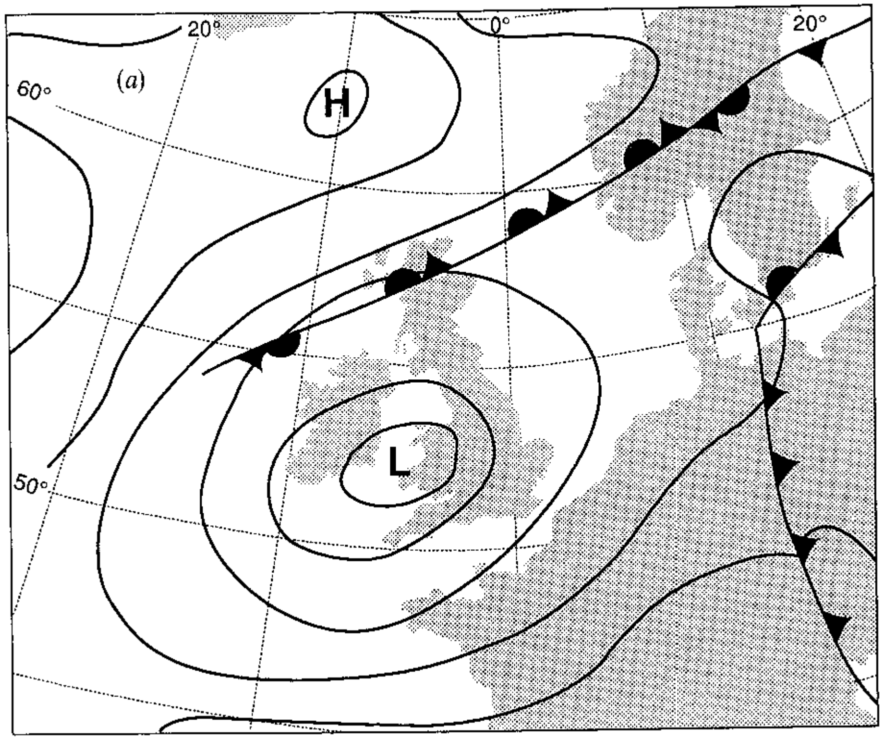


Fig. 3(a). A westerly circulation over the British Isles on 9 February, 1988 at 12.00, using the Lamb primary scheme. This airflow type should be classified as cyclonic westerly using Lamb's later extended system. (b) Long-term average daily precipitation yields over the British Isles from westerly airflows. Compiled from daily precipitation values at 65 lowland stations in Britain and Ireland, some records extending back 40 years or more. (Source: Sweeney and O'Hare, 1992).



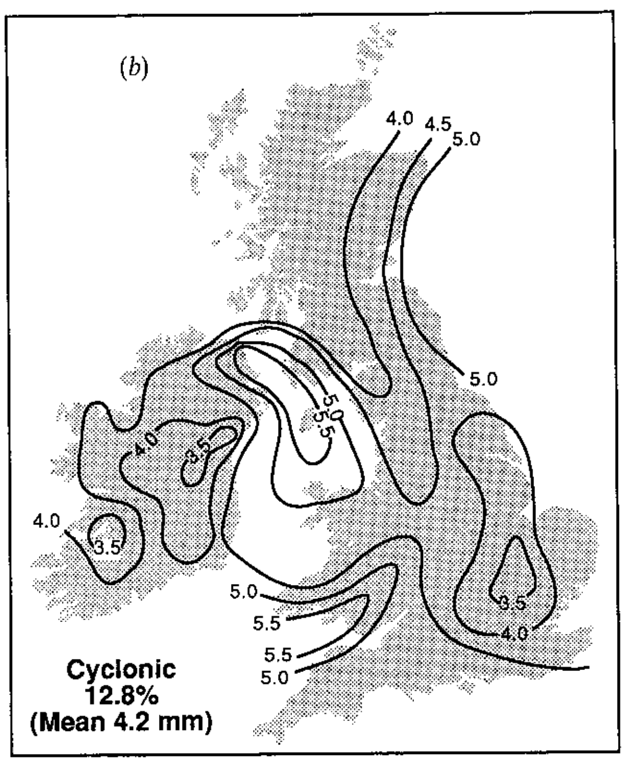


Fig. 4(a). A cyclonic circulation over the British Isles on 3 May, 1988 at 12.00 classified using the Lamb primary scheme (b) Long-term average daily precipitation yields over the British Isles from cyclonic airflows. Compiled as Fig. 3b. (Source Sweeney and O'Hare, 1992).

Table 3
Average frequencies of Lamb's Primary Airflow Types, including directional sub-types and minor categories, 1861–1991.

Airflow Category	% Frequency	
	pure airflow types	*with sub-types*
1. Westerly Type (including anticyclonic and cyclonic sub-types)	18.9	(27.6)
2. Northerly Type (including anticyclonic and cyclonic sub-types)	4.7	(8.1)
3. North-westerly Type (including anticyclonic and cyclonic sub-types)	3.8	(6.1)
4. Easterly Type (including anticyclonic and cyclonic sub-types)	3.5	(7.1)
5. Southerly Type (including anticyclonic and cyclonic sub-types)	4.2	(6.6)
6. Cyclonic Type (pure circulations)	12.8	(12.8)
7. Anticyclonic Type (pure circulations)	17.9	(17.9)
8. (a) Other minor categories eg. north-easterly, south-easterly and south-westerly types (including anticyclonic and cyclonic sub-types)	5.2	(9.8)
(b) unclassified class		(4.0)
Total	71.0	(100)

Source: Sweeney and O'Hare (1992).

Table 4
Seasonal frequency of Lamb's Primary Circulation Types in the UK, 1861–1991

Primary Airflow Category	Season			
	Winter (Dec–Feb)	Spring (Mar–May)	Summer (Jun–Aug)	Autumn (Sep–Nov)
1. Westerly	22.9	13.3	18.0	19.7
2. Northerly	3.6	5.6	4.8	4.6
3. North-westerly	3.7	3.4	4.6	3.4
4. Easterly	3.3	5.9	1.9	2.9
5. Southerly	5.4	4.4	2.5	4.7
6. Anticyclonic	16.1	18.9	18.8	18.9
7. Cyclonic	10.7	13.1	16.1	12.1

occur on 9.8 per cent of the time, while 4 per cent of synoptic situations remain unclassified.

A breakdown of frequency variation according to season or month for the period 1861–1991 can also be made. For example, Table 4 shows that pure westerly circulations exhibit a high frequency of 18 per cent and over throughout the year except in spring (March–May) when their ratings fall to about 13 per cent as other circulations eg. northerly and easterly types reach their highest frequencies. Pure anticyclonic circulations have almost a 19 per cent frequency in all seasons except winter (Dec–Feb) when they fall to 16 per cent. True cyclonic systems show a 10 per cent or greater frequency in all seasons but reach a maximum of 16 per cent in summer (June–Aug).

(4) Changes in circulation frequency: an examination of the Lamb Catalogue of Daily Weather Types during the period 1861–1991 allows us to monitor some important changes in circulation frequency. Figure 5 shows the number of days per year during which westerly, cyclonic, anticyclonic and north-westerly airflows prevailed. The time series of annual frequencies for each circulation type has been analysed using a low pass filter (in this case an 11-year moving average) to filter out general tendencies. In addition, error bars at one standard deviation have been calculated for each time series. Results are presented in this manner because the moving average is a simple filter and often used in meteorological studies.

The most notable feature of circulation frequency change shown in Fig. 5, is the major

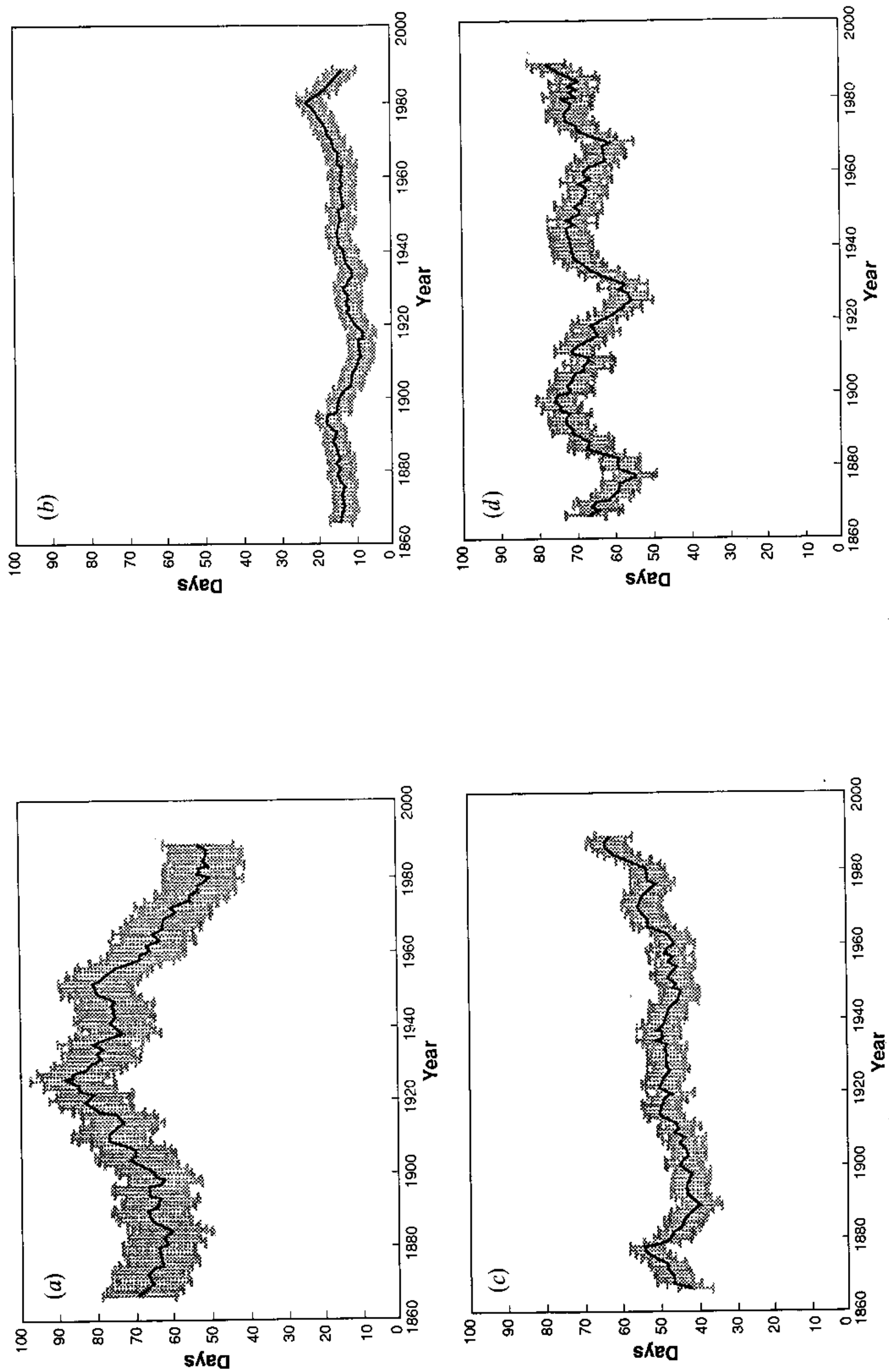


Fig. 5. Changes in circulation frequency of (a) westerly, (b) north-westerly, (c) cyclonic and (d) anticyclonic airflows over the British Isles. Annual frequencies have been [illegible] moving averages and error bars are added at one standard deviation. The number of climate stations used in the compilation of this [illegible]

decline in the number of westerly days from around their peak average of 85 days in the 1920s to 50 days at the present time. In contrast, cyclonic and anticyclonic categories have shown corresponding increases over the same period, especially during the 1980s, and some directional types have also shown enhanced frequencies (Briffa *et al.*, 1990). This latter point is confirmed for north-westerly circulations in Fig. 5, though frequencies which began to rise sharply in the 1970s have subsequently declined steeply during the 1980s. A reduction in the frequency of westerly airflows which bring unstable windy weather (see Table 2) suggests that our climate may be becoming generally less stormy, notwithstanding the great storm of October 1987, and the severe gales of January 1990, over southern parts of Britain. Enhanced frequencies of cyclonic and anticyclonic circulations on the other hand, may indicate a more varied climate (Briffa *et al.*, 1990).

It is interesting in this context that Bardossy and Caspary (1990) found little change in the annual frequencies of all zonal (west-east) circulations across Europe between 1881–1989. They report that zonal frequencies have increased in December and January since about 1973, while all 'East' circulations have declined from about 1980. These two effects have been implicated by Bardossy and Caspary in causing a recent run of relatively warm and humid winters in central Europe. The apparent increase in the frequency of zonal west-east circulations, and the decrease of airflow types (blocking anticyclones) from the 'East' found by Bardossy and Caspary for Europe, appear to contradict the British case where the frequency of westerlies has declined. It is difficult to relate Bardossy and Caspary's results to those obtained for the British Isles, however, and direct comparisons may be misleading. Circulation patterns which influence the British Isles are often very different from those in Central Europe – a half Rossby wavelength away. Moreover, the airflow categories used by Bardossy and Caspary do not closely match the Lamb categories. The European zonal and 'East' airflow classes for instance mentioned above are in effect aggregate groupings of up to 4 synoptic types and incorporate several Lamb-designated hybrid categories.

The frequency trends for the British Isles identified in this paper have been linked to changes in the general circulation of the atmosphere. One factor which may alter the planetary circulation is global warming by greenhouse gases. As most models of global warming predict greater warming in the higher latitudes than in the lower latitudes over the coming decades (Houghton *et al.*, 1990), a decrease in the equator-pole thermal gradient can be expected. A reduction in the hemispherical thermal gradient will induce a (further?) decline in the energy and frequency of westerly airflows in the higher middle latitudes. On the other hand, it may take several decades for northern latitudes to warm sufficiently because of the cooling effect of large reflective ice sheets. During this interval when the equator-pole temperature gradient may actually increase, enhanced westerliness and storminess may occur. There may already be symptoms of this effect. Mayes (1991) using a regional (ie. sub-synoptic) classification of airflow type, has shown that during the 1980s, westerliness has increased in Scotland, while anticyclonic activity has increased in south-east England.

Changes in circulation frequency can be expected to produce alterations in the precipitation geography of the British Isles. Westerly circulation frequency increases during the first half of the twentieth century (Fig. 5) have been implicated in an increase of 5–10 per cent in average annual precipitation in western districts of Britain between the reference periods of 1881–1915 and 1916–1950 (Glasspoole, 1954). Conversely, a decline in the incidence of westerlies may produce a lessening of the marked west–east contrast in precipitation yields across the British Isles shown in Fig. 3b. The precipitation geography of the 1951–1980 period, for instance, shows the effects of diminished westerlies and increased blocking. This is particularly marked in summer. Summer rainfall totals in parts of north-western Scotland and Wales, for example, were less than 90 per cent of their 1916–1950 average. In contrast, parts of central and southern England received values in excess of 100 per cent of the earlier long-term average. It would appear that decreased westerliness and enhanced cyclonicity diminishes the spatial contrast in precipitation from west to east across the study area. Moreover, the enhanced anticyclonic activity over south-east England identified by Mayes (1991) during the 1980s may be related to the extended period of drought (1988–1992) now affecting this region. It would be incorrect to attribute current regional drought in Britain to global warming, however, since major droughts are part of the natural climate cycle, occurring regularly once or twice each century.

Limitations of Lamb's classification

Although the Lamb Catalogue of Airflow Type is a popular and widely used system of classifying and describing weather at the synoptic scale, it nevertheless suffers from a number of limitations. The source of these limitations lies in the fact that a fairly simple and practical system is being used to analyse and describe a very complex, ever-changing atmosphere. The major problems with Lamb's classification system will now be outlined.

(a) Additional classes: it is not always easy to classify the sheer variety of the British weather with its many different synoptic situations into 7 primary airflow types. Lamb (1972) recognised this by identifying a further 19 sub-categories as well as an unclassified class making 27 categories in all. Three sub-categories are determined by other compass bearings not initially used ie. south-east (SE), south-west (SW) and north-east (NE). The other 16 are hybrid classes created by the combination of pure anticyclonic or cyclonic circulations and the other directional flows eg. anticyclonic westerly, cyclonic northerly, anticyclonic south-easterly (see Table 3). Figure 3(a) gives an example of one of these hybrid classes. The synoptic situation of 9 February, 1988, shows a strong westerly airflow across the British Isles. Using Lamb's 7 primary classes this circulation is classed as a westerly flow similar to that shown in Fig. 1; but the close presence of a deep low over west Scotland places the circulation, under the 27-class scheme, into the hybrid category of cyclonic westerly. Though it may be argued that the 27-category system of classification can better identify weather variation over the British Isles, the new larger scheme is much more complex and less easy to use than the original primary scheme.

(b) Unclassified category: when regionally varied synoptic situations exist over the British Isles ie. when more than one airflow type determines the weather on a single day (next section), it may not be possible to assign them to a single airflow type, whether 7 primary classes or an additional 19 sub-classes are selected. Lamb (1972) therefore devised an unclassified category to accommodate such complex airflow types (see Table 3).

(c) Regional variation: it is well known that marked contrasts in weather can occur in different parts of the British Isles on a single day. Such contrasts can result from the presence of several airflow types over the British Isles at any one time, rather than the modification of the influence of a single airflow, say by rain-shadow effects or exposure at particular locations. Figure 6 shows an example of a binary airflow pattern over the British Isles on 29 March, 1985. The surface pressure chart for the day reveals a complex low pressure system with an advancing warm front across the Irish Channel and northern England, and a more stationary, occluded front over central Scotland. A well-developed southerly airflow associated with maritime tropical air (mT) is situated to the south of the advancing warm front and is linked with maximum temperatures of 8–11°C over most of England and as much as 14°C in Northern Ireland. Maritime tropical airmasses come heavily laden with moisture, and southerly circulation types share with cyclonic the distinction of producing the greatest precipitation yield of Lamb's primary categories.

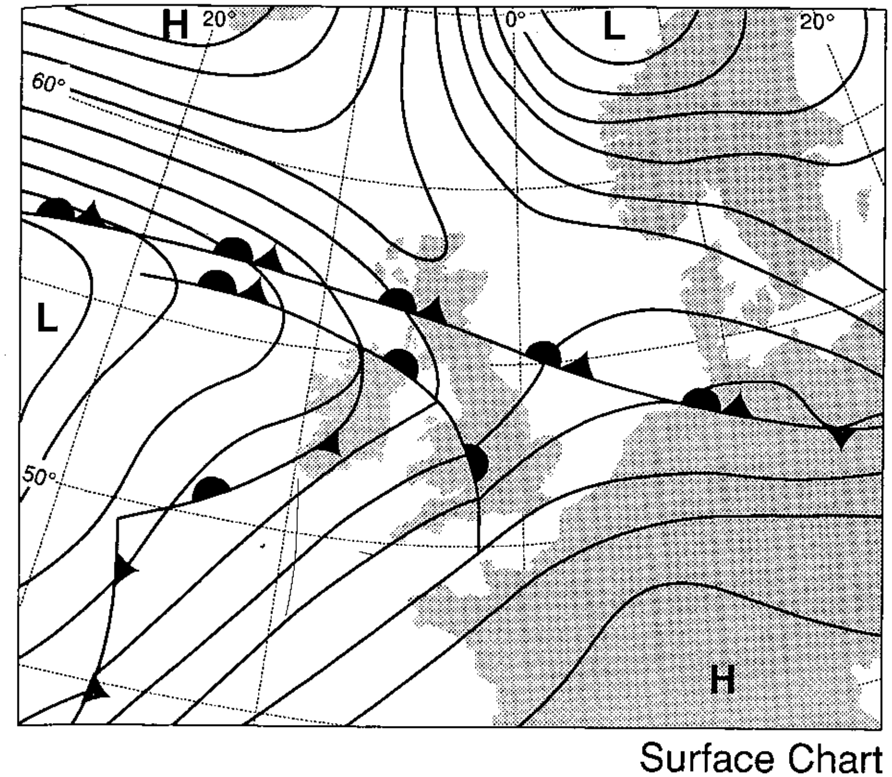


Fig. 6. A southerly circulation classified using the Lamb primary scheme over the British Isles on 29 March, 1985 at 12.00. A north-easterly airflow present over Scotland, however, makes the synoptic situation difficult to classify.

Stratiform cloud produced by air passing over the progressively cooler waters of the North Atlantic Drift yield large amounts of precipitation when any lifting occurs. The heaviest 24-hour rainfall on 29 March, 1985, consequently was recorded in northern and western regions with 21 mm falling over south Wales, 28 mm over north Wales and 14 mm in the vicinity of the hills around the Solway Firth. Much of south and east England remained cloudy but dry, being in the rain shadow of the dominant southerly circulation.

Very different airflow and thus weather conditions are found a short distance north of the warm front. A cold north-easterly airflow associated with maritime Arctic (mA) air beneath the occluded front brought frost over the preceding night to much of Scotland. In the Scottish glens, maximum daytime temperatures stayed close to zero and in the Central Valley of Scotland peak temperatures remained below the freezing level (−1°C). From southern Scotland to Aberdeen, rising conveyor belt of air in advance of the surface warm front gave cloud and precipitation which fell as sleet and snow in many areas as surface air temperatures remained close to zero. The regional contrast in weather over the UK on 29 March, 1985, was therefore dramatic and the result of a complex airflow system. This complex circulation can be best described as a binary airflow over the area with south-westerly airflow over Northern Ireland, England and Wales and north-easterly airflow over Scotland. Using Lamb's scheme the whole of the British Isles is classified (at best) as southerly or south-westerly; (at worst) the synoptic situation would remain unclassified.

Significant regional scale variations in temperature and precipitation as a result of the operation of multiple airflow types have recently been shown to exist for the period 1959–1989 by Mayes (1991). He claims that by adopting a regional or meso-scale approach to airflow analysis some of the problems imposed by complex circulations can be overcome. There is a good case for a regional breakdown in the register of weather types so that separate districts such as south-east England or western Scotland can be more successfully described. Mayes (1991) has recently shown, using a regional airflow approach, that westerly circulations in north Scotland could be increasing, a trend quite at variance with westerly airflow over the British Isles as a whole. However, regionally specific registers exist only for some parts of the area such Northern Ireland (Betts, 1989) and for periods of time much less than Lamb's long register.

(d) Lack of objectivity: the Lamb classification of airflow type remains a subjective system. With subjective schemes the investigator manually groups the circulation types after visually examining the data. The process is acknowledged to be time-consuming and replication of the classification results by any two analysts is unlikely. Despite Lamb applying fairly rigorous guidelines to facilitate airflow category identification, the possibility exists that various long-term (low frequency) biases in Lamb's data are present. This is important to emphasise when nowadays several different objective synoptic classification schemes are available (Perry, 1983; Todhunter, 1989). Objective classification schemes utilise statistical techniques to group days into meteorologically homogeneous categories based on 'objective' criteria. The statistical techniques most frequently used include grouping of correlation coefficients obtained from multiple regression analyses, discriminant analysis of surface and upper-level meteorological data, and cluster analysis of principal component scores. With the advent of high-speed computers the so-called 'objective' techniques in which the machines are employed to classify the data were seen as more objective than manual methods of classification, producing replicable results and saving a great deal of time. Davis and Kalkstein (1990) for instance have developed an objective, automated, classification scheme to quickly categorise the daily synoptic circulation pattern of a large country such as the USA. Nevertheless, objective synoptic classification schemes are not without their own problems. Yarnal and White (1987) suggest that classification results are altered by the way in which the data are used in a correlation-based analysis. Ironically, they point to the inherent subjectivity of many objective schemes.

(e) Synchronisation: there are problems in assigning airflow types and their weather to individual days because of time-phased monitoring irregularities. Any particular day in the Lamb register is classified according to the airflow type prevailing on each calendar day ie. from midnight (00.00 hours) to midnight (24.00 hours) with the noon (12.00 hours) synoptic situation often used as the keystone for classification (see Fig. 1). It is obviously unrealistic to expect that a circulation pattern sampled at noon will always adequately summarise the 24-hour weather, especially with regard to fast-moving weather systems. Accordingly, it is possible for one airflow type to be replaced or at least substantially modified by another over the 24-hour day. Moreover, a particular day's rainfall is measured at 09.00 hours on the following day. This lack of synchronisation or time-lag between the calendar day and the monitoring day may cause additional airflow types, their weather and precipitation loadings, to be incorrectly related to the previous day.

(f) 'Within-type' variation: the relationship between precipitation yield and each of Lamb's airflow categories may not be constant over long periods of time. For instance, the precipitation yield of cyclonic or westerly circulations may not be the same for the 1920s and 1930s as it is for the 1950s and 1970s. When precipitation yields are calculated for long periods as shown in Figs. 3b and 4b, such 'within type' variations may be masked. However, recent work by Sweeney and O'Hare (1992) indicates that though such long-

term variations in precipitation yield for the same airflow over time are apparent, they are relatively minor.

(g) Distant origins: it may be important to identify the origin of an airflow well before it reaches the British Isles. For example, southerly airflow types as shown in Table 2 can give contrasting winter weather. When southerly circulations are associated with Atlantic lows at this time, they incorporate tropical maritime air and give mild and damp weather. On the other hand, cold dry weather is associated with southerly airflows when they originate from central European high-pressure cells bearing polar continental air. Davies *et al.* (1991) found considerable variation in the back-trajectories from Eskdalemuir, Scotland, of Lamb-classified westerly, cyclonic, and anticyclonic airflows from 1981 to 1984. Though most westerly circulation trajectories, for instance, were found to originate as expected over the Atlantic to the west of the UK, several westerly airflows displayed some unusual and very diverse source points including the North Sea, an area to the west of Portugal, coastal Norway and even north of Spitsbergen.

(h) Meso-scale and micro-scale processes: it is useful to bear in mind that Lamb's circulation categories are synoptic in scale, and can present rather a gross picture for the study of certain meso-scale and micro-scale processes. For instance, a single synoptic airflow type (eg. westerly) may be relatively wet or dry depending on the degree to which meso-scale features such as frontal systems develop within it. Whether fogs develop or not under anticyclonic airflow in winter, may depend as much on micro-scale features such as plant transpiration, dew-point temperature and katabatic airflow, as on general air subsidence with clear skies, low-level inversions and gentle winds.

Conclusions

Using the concept of airflow type, Lamb has produced a spatial and dynamic approach to British weather classification. His primary scheme of 7 circulation categories and an unclassified class is simple, uncluttered and practicable. A-level students and undergraduates who become familiar with the scheme can develop their own daily weather register of airflow type. By examining the daily weather map they can develop correlations between actual weather events over the British Isles and the prevailing airflow pattern. Moreover, the availability of a very long daily register of airflow types, enables statistically reliable correlations between weather and circulation type, or the changing frequency of airflow types over time, to be calculated.

The Lamb method of airflow analysis does have its difficulties, however. Firstly, the techniques used to monitor airflow types and their associated weather are poorly synchronised and significant mismatches between the two can occur. Secondly, there are always synoptic situations which remain difficult to classify whether Lamb's original 7, or subsequent 26 categories, are employed, so that a final resort may have to be made to the unclassified class. Some difficulty lies in the subjective nature of Lamb's scheme itself where complex or transitional synoptic situations can prove troublesome. Classification may also be a difficult task because of the wide regional variation in airflow patterns which can exist across the British Isles on a single day. Large contrasts in airflow and hence weather condition across the British Isles can result not only from the modification of a single airflow type; but also from the presence of more than one airflow category during a 24-hour period. However, the difficulties introduced by binary airflow patterns may be overcome to an extent by adopting a more regional approach to airflow analysis. Thirdly, the use of airflow analysis alone, whether at the national or regional scale, may not be sufficient to paint the finer details of the weather of individual areas. The detailed weather characteristics of individual local areas are often shaped by meso-scale and micro-scale processes working within the overall synoptic situation.

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