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The future of upland Britain

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35 The climate of upland Britain

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INTRODUCTION

The climate of upland Britain cannot be considered in isolation from that of the British Isles as a whole. The maximum east-west extent of Britain is about 300 miles, across Wales and East Anglia, and most upland areas lie within 50 miles of the West coast. A consequence of this western location is that upland Britain experiences the predominantly maritime climate dictated by the geographical location of the British Isles at the eastern extremity of the Atlantic Ocean. The principal features of a maritime climate are:

(i) Relatively small annual variation in mean air temperature
(ii) Relatively high mean wind speeds at sea-level
(iii) A plentiful supply of moist air to give relatively high rainfall amounts, fairly evenly spread throughout the year.

The other geographical factor which greatly affects the climate of Britian is latitude. The range of latitude of the British Isles is roughly 50°N to 60°N, an extent which lies within the belt of low level westerly winds that dominate the weather of the North Atlantic. As a consequence of lying in mid-latitudes, there is a large annual variation in solar radiation receipts over Britain and hence in associated sunshine amounts. The latitudinal difference of 10° is enough to give Cornwall 2 hours per day more possible sunshine than Shetland in winter and 2 hours less in summer.

In what follows the effect of altitude as a modifying influence on British climate will be discussed. A much more detailed description of British upland climate can be found in Taylor (1976) and an interesting illustrative account in Manley (1952).

RADIATION AND SUNSHINE

Measurements of total solar radiation in Britain are not plentiful, the network of recording instruments being very sparse. The position for sunshine records is much better but gaps in the network exist, mainly in sparsely inhabited upland areas. Various empirical methods have been devised to estimate total radiation from sunshine records (eg Glover & McCulloch, 1958) but it is best to treat the results as being a guide to geographical distribution rather than of absolute numerical value.

Maps of the geographical distribution of bright sunshine are found in Meteorological Office (1974) for each month of the year and also as mean values for the year as a whole. The general picture is one of decreasing sunshine amounts from south to north, and also with altitude. The decrease with height is a result of increasing cloud amounts over high ground; the difference can average an hour a day in summer between upland areas and adjacent coasts. For the year as a whole the average daily duration of bright sunshine ranges from 5.0 hours on the south coast of England down to 2.8 hours in the Shetland Islands. Upland Wales receives about 3.5 hours, as do much of the Pennines and inland areas of Scotland, but parts of North West England, the Southern Uplands of Scotland and North West Scotland receive less than 3.0 hours a day.

Table 1 shows the average daily totals of bright sunshine for several stations in Britain, the data are taken from Meteorological Office (1976a).

A marked annual variation, characteristic of mid-latitudes, is seen at all the stations listed in Table 1. The effect of latitude range is seen in the difference between the values at Scilly and Lerwick. The two Welsh stations are at the same latitude, but the height difference of 286 m is enough to substantially reduce sunshine amounts, by about 0.7 hours a day in summer and 0.2 hours in winter (Smith 1950). MAFF (1976) lists estimated sunshine/height gradients from data in the Northern Pennines which range from 0.10 hours a day per 100 m in winter to just over 0.20 hours a day per 100 m in summer.

Information on radiation amounts, as said earlier, is not readily available owing to the shortage of measuring instruments. The long term records that do exist are discussed by Collingbourne (1976). Yearly average daily totals of global radiation vary from about 11 mega joules per square metre (MJm^{-2}) in the south west of England to less than 8 MJm^{-2} in the north of Scotland. The annual variation of mean daily totals is from about 2 MJm^{-2} in winter to 16 MJm^{-2} in summer at Eskdalemuir (55°19'N, 03°42'W, 249 m AMSL). On clear cloudless days radiation amounts increase with height (Barry & Chorley, 1968) but in cloudy conditions the reverse is generally true, and total radiation receipts decrease with altitude due to increasing cloud amounts. MAFF (1976) give values for radiation/height gradients but do not quote sources. An important

Table 1

AVERAGE DAILY TOTALS OF BRIGHT SUNSHINE (HOURS) AT VARIOUS LOCATIONS IN BRITAIN

Place	Location	Height (m)	J	F	M	A	M	J	J	A	S	O	N	D	Year
Lerwick	60°08'N 01°11'W	84	0.79	1.91	2.79	4.55	5.08	5.08	4.23	3.73	3.30	1.99	1.08	0.50	2.92
Aberystwyth	52°25'N 04°03'W	5	1.71	2.78	4.06	5.36	6.43	6.61	5.26	5.28	4.17	3.25	1.90	1.56	4.03
Llety-Evan-Hen	52°27'N 03°56'W	291	1.48	2.39	3.72	4.76	5.77	6.01	4.56	4.49	3.56	2.85	1.76	1.40	3.56
Scilly (St Mary's)	49°56'N 06°18'W	63	1.93	2.85	4.26	6.34	7.58	7.45	6.72	6.53	5.14	3.73	2.50	1.86	4.74

modifying factor on radiation receipts is the slope of the ground surface. In general south-facing slopes are better favoured than north-facing (Geiger, 1965; Jones, 1976). The partitioning of incoming radiation greatly determines ambient temperature. The three way split into unequal parts due to albedo (reflected directly), latent heat (evaporation) and heating of air and soil varies with terrain features, and hence with height. For example, air over a cover of snow will not receive the same heating as air over a green crop since the amount of radiation reflected is much higher (by a factor of 4 or 5).

WIND

Mean sea-surface wind speeds over the North Atlantic are among the highest in the world (Lauscher, 1951). Mean values of 20 knots in winter and over 10 knots in summer are only exceeded in the unconfined latitudes of the Antarctic Ocean. The western coast of Britain, especially that of Scotland, experiences the full force of North Atlantic winds, making the off-shore islands of Scotland one of the windiest inhabited areas of the world.

The surface of the earth exerts a drag on the circulation of the atmosphere, the drag being least over the sea. The effects of surface drag diminish with altitude through the first kilometre or so of the free atmosphere until a level is reached at which no drag is felt. The characteristics of wind over Britain are in agreement with these facts. Near surface wind speeds are generally higher in the west, in most cases diminish with increasing distance from the coast, and increase with height of the ground. The narrow east-west extent of most British upland areas is probably insufficient to modify a large scale atmospheric weather system passing over them, however local climates are established due to topographic features, in which wind is a major element.

Table 2 lists wind speeds for five stations in North Britain, averaged over the period 1961-1975. Only Tiree has a complete record for this period, all other stations lack data, some for a couple of years.

Table 2
AVERAGE WIND SPEEDS (KNOTS) FOR ANEMOGRAPH STATIONS AT VARIOUS ELEVATIONS IN NORTH BRITAIN

Place	Location	Height (m)	Winter	Spring	Summer	Autumn	Year
Tiree	56°30'N 06°53'W	24	18.6	15.1	12.3	16.2	15.6
Spadeadam	55°02'N 02°38'W	292	10.5	10.5	8.7	9.2	9.7
Rannoch Moor	56°41'N 04°35'W	307	10.0	10.6	9.8	10.1	10.1
Moor House	54°41'N 02°23'W	595	15.2	12.2	11.4	13.6	13.0
Gt Dun Fell	54°41'N 02°27'W	857	21.5	19.8	16.8	20.5	19.7

The record at Tiree is typical of the exposed west coast of Scotland, and the offshore islands. The mainland stations exhibit a similar annual variation of wind speed as the record at Tiree, with higher values generally in winter. Wind speeds are seen to increase with height until at about 700 m the speed over land is about that at sea level near the western coast. There is some evidence that the rate of increase with height of mean wind speed varies slightly with geographical location, being highest in the North West and lowest in the South East (Booth & Danby, 1977). Complex topography has a big effect on local wind structure (Gloyne, 1967) and differential heating rates between valley slopes and bottoms will often cause local air circulations to be formed (Defant, 1949).

TEMPERATURE

The standard lapse rate of daily mean temperature with height adopted by the Meteorological Office is 6°C for 1000 m. Measurements *in situ* by Smith (1950) show an annual variation in monthly mean lapse rates on the Western slopes of the Welsh mountains. Values range from 4.8°C/1000 m in March to 7.2°C/1000 m in October. The value for a year was 6.4°C/1000 m which is comparable to the value of Manley (1943) in the Northern Pennines of 6.9°C/1000 m. The high incidence of polar maritime air masses over Britain causes the relatively big lapse rates that are found in upland regions through most of the year. Warm sea surface temperatures in the North Atlantic raise the temperature of the lower layers of the atmosphere relative to the air higher up.

Another feature of a maritime climate is the relatively small annual variation in monthly averaged daily mean air temperature. This parameter ranges from about 9°C in the extreme south west of England and the Scottish Western Isles up to more than 13°C in the south east of England away from the Channel coast. Local maxima of more than 12°C occur in the Scottish Highlands and Southern Uplands. As an index of 'continentality' it highlights the favourable position of most upland areas in the west of Britain. The same parameter for some continental locations has the following values: Paris 15.9°C, Berlin 19.9°C, Minsk 25.6°C and Winnipeg 37.9°C, all lying between 45°N and 55°N latitude.

The 'flatness' of the curve of variation in mean temperature through the year has two very important consequences for upland climates in Britain. Firstly, the length of time between the upward and downward parts of the curve crossing any 'base' value will shorten rapidly with height, since the curve does not appear to 'sharpen' appreciably with altitude and temperature lapse rates are high. Secondly, the area between the annual mean temperature curve and the 'base' value will also decrease rapidly with height. The area referred to is approximated by calculation of 'Accumulated Day Degrees' and is an estimation of the energy available for growth purposes.

Agronomists have largely accepted the concept of 'growing season' defined as the length of time for which average daily mean temperature is above a certain threshold value, 6°C for example for grass growth. Since the length of the 'growing season' is a function of annual mean temperature and the amplitude of the annual variation of mean temperature, the geographical variation of the parameter is appreciable. At mean sea level, average yearly values of daily mean temperature are generally higher to the west and vary, for example, from 11°C in Cornwall to abour 8°C in Caithness. In similar fashion the length of the 'growing season' above 6°C varies from about 365 days in Devon to 240 days in North Scotland, again for places at or near mean sea level. Gloyne (1958) has calculated that the greater annual range in monthly average daily mean temperature in the Southern Uplands of Scotland results in less variation in the length of the 'growing season' with height than observed in West Wales or on Dartmoor. The more maritime climate of South Devon gives a lapse rate of 'growing season' length of about 9 days for each 100 ft (30.5 m) increase in altitude, while in the Southern Uplands the rate is about 4 days/100 ft (30.5 m). Conrad (1944) gives a value for Switzerland which corresponds to about 2 days/100 ft (30.5 m), a striking example of how in more continental climates there is a much more gradual decrease in the length of 'growing season' with height. The variation of this parameter from year to year is discussed by Gloyne (1973) using data from Eskdalemuir Observatory.

The variation in accumulated 'day degrees' with altitude is less well investigated. Shellard (1959) evaluates 'day degrees' above and below several base values for many places in Britain using the technique of Thom (1954). Maps of 'day degree' values above a base of 43°F (6.1°C), based on rather old temperature averages are found in Gregory (1954). Values decrease northwards and with height, reflecting changes in mean temperature. Parry (1976) has shown how the variation in accumulated 'day degrees' with secular changes in climate can affect marginal agriculture.

Finally in this section mention should be made of the combined effect of low temperature and high wind speed on biological organisms. The term 'wind chill' is now often applied to various empirical estimates of heat loss from exposed skin areas, ignoring radiation effects. Howe (1962) has investigated the distribution of a parameter first formulated by Siple & Passel (1945). A short review of other papers on this topic and the associated one of plant resistance is given by Gloyne (1967). Upland areas in Britain are the most likely to experience combinations of wind and temperature that pose survival problems to animals and plants alike.

PRECIPITATION

A well known feature of upland climate is the increase of precipitation with height. The rate of increase is not uniform in Britain, being greater on the steeper western slopes than in the east. Several authors have suggested numerical values for different locations. Gloyne (1968) evaluated estimates of 280 mm/100 m for the western slopes of the Scottish mountains and 85 mm/100 m for the gentler eastern slopes. The value for western slopes in Wales is put at 166 mm/100 m by Rodda (1962). In the same paper Gloyne (1968) suggests a ratio of 4 to 1 between the average number of rainfall hours in the North West Highlands and in Eastern Lowland Scotland. This implies a variation of rainfall intensity with altitude since the ratio between average annual rainfall amounts is about 7 to 1.

Average annual amounts for high altitude areas range from around 5000 mm in North West England (Lake District) and North West Scotland, down to about 1000 mm in the Eastern Scottish upland areas and Eastern Wales. In terms of average rainfall hours the extreme north west of Scotland exceeds everywhere else in Britain with 2000 hours (Gloyne, 1968), an average of 5½ hours a day! In order to put these figures into perspective the drier areas of lowland England receive about 600 mm a year in about 500 hours. The high rainfall amounts in western upland areas are mainly a result of forced lifting of moist air from the Atlantic. A secondary effect common to all uplands is that on clear days radiation receipts are relatively higher, implying greater surface heating and the onset of convective cloud formation.

The general high rainfall and low evaporation ensure an adequate supply of ground moisture on those occasions when conditions are suitable for convective activity.

The occurrence of snow increases with altitude as a result of the lowering of temperature levels and the general increase in precipitation. Jackson (1976) analyses data on falling snow observations. The average number of days (per year) with falling snow ranges from 10 in south and west coastal regions of England up to more than 75 in North East Scotland. The North-East is a preferred area for snow since north or north-easterly airstreams are the most associated with favourable snow forming conditions. Jackson also notes estimates for the rate of increase in the number of annual snow falling days with height. Following the pattern established by rainfall, the greatest rate of increase with altitude is associated with the areas of greatest snow occurrence. South West England has a value of 5.1 days/100 m compared to that of 11.4 days/100 m in the Scottish mountains. The west-east variation in snow falling days in Scotland is well established by Dunsire (1971).

As would be expected the number of days with lying snow also increases with altitude. Manley (1971) gives estimates of days per 100 m as between 10 for

Wales and 16 or more for North Scotland. In the same paper Manley states average values of 100 days of snow cover per year at 2000 ft (609.6 m) in the Eastern Highlands of Scotland, at 2500 ft (762 m) in the North Pennines and at 3000 ft (914.4 m) in Snowdonia.

HUMIDITY AND EVAPORATION

The forced lifting of moist Atlantic airflows over western uplands causes high level humidity values throughout the year. The daily minimum level of relative humidity usually occurs in mid afternoon when air temperatures are at their maximum. Values of relative humidity taken from Meteorological Office (1976b) show that the annual mean value at Great Dun Fell (847 m) at 1500 GMT is 91%, at Watnall (119 m) 74% and at Tiree (9 m) 81%. This variation between representative stations for high level, inland and coastal areas is marked. The annual variation at 1500 GMT of monthly mean values is very small at Tiree (June 80%, January 82%) reflecting the small annual range in monthly mean temperature already remarked upon. For a similar reason the range at Watnall (June 63%, January 85%) is higher and that for Great Dun Fell is still appreciable (June 82%, January 97%). The high values of relative humidity are naturally associated with cloud cover and therefore with decreased radiation receipts. The net result is that evapotranspiration, the combined effect of water transfer by plants and direct evaporation processes, is greatly reduced over upland areas, often causing water-logged soils unsuitable for cultivation and a disease risk for animals.

CONCLUSION AND SUMMARY

The principal features of British upland climate when compared with the climate of lowland areas are:

(i) A reduction in radiation and bright sunshine due to higher cloud amounts;

(ii) An increase in wind speed with height, reaching and eventually exceeding speeds over the open sea;

(iii) Large lapse rates of temperature with height, causing rapid reductions in the length of 'growing season' and the energy available for growth;

(iv) A general increase of rain and snow with height, gradients varying from west to east of the country;

(v) High humidity and low evapotranspiration.

REFERENCES

Barry, R G & Chorley, R J (1968) *Atmosphere, weather and climate.* London: Methuen.

Booth, C & Danby, N P (1977) *A guide to exposure levels in Scotland and the North of England.* Forestry Commission, Draft Research Information Note.

Collingbourne, R H (1976) Radiation and Sunshine. In: *The Climate of the British Isles.* Eds. Chandler, T J & Gregory, S. London: Longman.

Conrad, V (1944) *Methods in climatology.* Cambridge, Massachusetts: Harvard University Press.

Defant, F (1949) Zur Theorie der Hangwinde, nebst Bemerkungen zur Theorie der Berg und Talwinde. *Archiv fur Meteorologie Geophysik und Bioklimatologie,* **1**, 421-50.

Dunsire, A (1971) *Frequencies of snow depths and days with snow lying at stations in Scotland for periods ending winter 1970/71.* Bracknell: Meteorological Office (Climatological Memo No 70).

Geiger, R (1965) *The climate near the ground.* Translated from the 4th German edn of 1961 by Scripta Technica. Cambridge, Massachusetts: Harvard University Press.

Glover, J & McCulloch J S G (1958) The empirical relation between solar radiation and hours of bright sunshine in the high altitude tropics. *Quarterly Journal of the Royal Meteorological Society,* **84**, 56-60.

Gloyne, R W (1958) *On the growing season.* Bracknell: Meteorological Office (Agricultural Memo No 18).

Gloyne, R W (1967) Wind as a factor in hill climates. In: *Weather and agriculture.* Ed. Taylor, J A. Oxford: Pergamon.

Gloyne, R W (1968) Some climatic influences affecting hill land productivity. In: *Hill Land Productivity.* British Grassland Society, Symposium No 4, Aberdeen 1968. Ed. Hunt, I V.

Gloyne, R W (1973) Notes and some speculations on the effects of climate on the development of horticulture in Scotland. *Scientific Horticulture,* **23**, 22-40.

Gregory, S (1954) Accumulated temperature maps of the British Isles. *Transactions of the Institute of British Geographers,* **20**, 59-73.

Howe, G M (1962) Windchill, absolute humidity and the cold spell of Christmas, 1961. *Weather,* **17**, 349-58.

Jackson, M C (1977) The occurrence of falling snow over the United Kingdom. *Meteorological Magazine,* **106**, 26-38.

Jones, M E (1976). Topographic climates: soils, slopes and vegetation. In: *The Climate of the British Isles.* Eds. Chandler, T J & Gregory, S. London: Longman.

Lauscher, F (1951) Uber die Verteilung der Windgeschwindigkeit auf der Erde.

Archive fur Meteorologie Geophysik und Bioklimatologie, 2, 427-440.
MAFF (1976) *The agricultural climate of England and Wales.* Technical Bulletin No 35. London: HMSO.
Manley, G (1943) Further climatological averages for the northern Pennines, with a note on topographical effects. *Quarterly Journal of the Royal Meteorological Society,* 69, 251-61.
Manley, G (1952) *Climate and the British scene.* London: Collins.
Manley, G (1971) The mountain snows of Britain. *Weather,* 26, 192-200.
Meteorological Office (1974) *Averages of bright sunshine over the United Kingdom, 1941-1970.* Bracknell: Meteorological Office (Climatological Memo No 72).
Meteorological Office (1976a) *Averages of bright sunshine for the United Kingdom, 1941-1970.* London: HMSO.
Meteorological Office (1976b) *Averages and frequency distributions of humidity for Great Britain and Northern Ireland, 1961-70.* Bracknell: Meteorological Office (Climatological Memo No 103).
Parry, M L (1976) The significance of the variability of summer warmth in upland Britain. *Weather,* 31, 212-217.
Rodda, J C (1962) An objective method for the assessment of areal rainfall amounts. *Weather,* 17, 54-59.
Shellard, H C (1959) *Averages of accumulated temperature and standard deviation of monthly mean temperature over Britain 1921-50.* London: Meteorological Office (Professional Notes No 125).
Siple, P A & Passell, C F (1945) Measurement of dry atmospheric cooling in sub-freezing temperatures. *Proceedings of the American Philosophical Society,* 89, 177.
Smith, L P (1950) Variations of mean air temperature and hours of sunshine on the weather slope of a hill. *Meteorological Magazine,* 79, 231-3.
Taylor, J A (1976) Upland climates. In: *The Climate of the British Isles.* Eds. Chandler, T J & Gregory, S. London: Longman.
Thom, H C S (1954) Normal degree days below any base. *Monthly Weather Review,* 82, 111-115.