

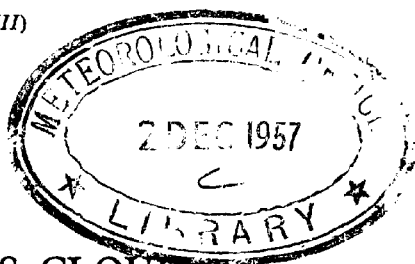
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FORECASTING CIRRUS CLOUD
OVER THE BRITISH ISLES

By D. G. JAMES, Ph.D.



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Summary.—Some synoptic features are presented which are known to be associated with 4 oktas or more cirrus cloud over the British Isles. A combination of thirteen of these features is suggested for use in forecasting the occurrence of cirrus cloud up to 9 hr. ahead, the features being evaluated from the current synoptic charts. For forecasts of up to 24–36 hr. ahead, a combination of six of the features is suggested, the evaluations in this case being made from forecast charts.

Introduction.—A direct approach to the forecasting of cirrus cloud from physical principles would require accurate measurement or assessment of humidities and vertical motion in the upper troposphere. As neither of these is at present practicable it is necessary to fall back on associations between the presence of cirrus cloud and features of the synoptic charts and upper air observations. These features will normally be connected with humidity and vertical motion aloft but it cannot be expected that the associations will be unique.

Statistical studies^{1*} give some clue as to which of the associations referred to above are likely to be useful and a forecasting trial has demonstrated a possible method of using these for forecasting in the area of the British Isles.

General.—Aircraft observations over the British Isles indicate that there is cirrus cloud for about half the time over any given area. In an analysis of cirrus observations¹ there were roughly twice as many reports of cirrus as of no cirrus, this probably being due to the reluctance of observers to report instances of no cirrus. Allowance is made for this over-emphasis of cirrus in the remarks on the statistics presented, but the reader will need to recall the fact in direct study of the diagrams and tables.

PART I

Features associated with cirrus cloud.—*Features of the surface chart.*—

(i) *Fronts.*—It is well known that fronts are often accompanied by cirrus cloud. The author¹ finds that 80 per cent. of his cirrus reports occurred within 600 miles either side of a surface front; but so also did 60 per cent. of the no cirrus reports. However, the frequency of cirrus against no cirrus increases as the surface front is approached, this increase being especially marked in the area just ahead of warm fronts and occlusions. The figures are in Table I.

These figures make it evident that there is a high probability of the presence of cirrus in the area near, and especially just ahead of, surface warm fronts and occlusions.

* The index numbers refer to the bibliography on p. 10.

TABLE I—FREQUENCY OF CIRRUS OBSERVATIONS WITH RESPECT TO SURFACE FRONTS

	Type of front	Distance from front in miles						No front within 600 miles
		Ahead			Behind			
		0-200	200-400	400-600	0-200	200-400	400-600	
		<i>number of occasions</i>						
Cirrus	Warm occluded	45	24	8	16	7	2	38
	Cold ..	18	12	4	10	3	1	
No cirrus	Warm occluded	2	12	9	1	6	5	33
	Cold ..	6	3	0	6	2	0	

(ii) *Cumulonimbus clouds*.—Surface reports of heavy showers or thunderstorms indicate the probability of anvil cirrus in the neighbourhood and are useful guides to its possible presence later in regions downstream. The moisture injection at high levels produced by these storms may be considerable, and although the original anvil cirrus may disperse, only a relatively small amount of upward motion may be required to produce cirrus cloud again.

Features of upper air soundings.—

(i) *Dew-points in the upper troposphere*.—It has been found¹ that the mean value of the depression of dew-point below air temperature at 500, 450 and 400 mb. was 10° C. for about 160 cases of cirrus and 15° C. for about 80 cases of no cirrus. These means are far enough apart to be useful in forecasting; dew-point depressions of less than 10° C. at any or all of these levels have more chance of being accompanied by cirrus than by no cirrus.

(ii) *Winds*.—An analysis^{1,2} of a number of reports of the presence or absence of cirrus cloud in relation to the reported wind direction at upper levels showed that there was a marked preference for cirrus to be present with wind directions between SW. and NW. The actual figures are in Table II.

TABLE II—DISTRIBUTION OF WIND DIRECTIONS AT VARIOUS PRESSURE LEVELS FOR REPORTS OF CIRRUS AND NO CIRRUS

Pressure		Wind directions								Total
		N.–NE.	NE.–E.	E.–SE.	SE.–S.	S.–SW.	SW.–W.	W.–NW.	NW.–N.	
mb. 500		<i>number of occasions</i>								
	Cirrus ..	17	11	6	5	19	30	40	19	147
	No cirrus	11	5	7	2	8	8	13	12	66
400	Cirrus ..	15	13	3	4	22	31	36	22	146
	No cirrus	8	4	7	5	11	6	12	13	66
300	Cirrus ..	17	13	2	7	14	35	29	26	143
	No cirrus	7	6	4	4	11	11	10	14	67
200	Cirrus ..	13	17	0	5	11	39	34	29	148
	No cirrus	9	4	2	3	9	8	16	12	63

Statistical tests, bearing in mind the relative frequencies of winds from the different directions, show that this preference is greatest at the 400-mb. level. Conversely, although the number of cases is small, there is a marked tendency for cirrus to be absent with upper winds between east and south.

(iii) *Warm air advection aloft.*—Murgatroyd and Goldsmith² suggest that warm air advection at cirrus levels is frequently observed when cirrus cloud is reported. A test of this¹ gives the results set out in Table III.

TABLE III—ASSOCIATION OF CIRRUS WITH ADVECTION OF WARM OR COLD AIR

Pressure		Warm Advection	Cold Advection	Neither	Totals
mb.		<i>number of occasions</i>			
500–400	Cirrus ..	52	41	42	135
	No cirrus	20	23	22	65
400–300	Cirrus ..	53	31	48	132
	No cirrus	20	26	21	67
300–200	Cirrus ..	50	42	42	134
	No cirrus	16	30	18	64
500–300	Cirrus ..	70	37	35	142
	No cirrus	23	30	14	67

In compiling this table, a veer of wind with height of more than 5° and winds of more than 5 kt. at both levels were necessary for the case to be included under warm advection; correspondingly for cold advection.

It can be seen that the suggested association is supported, though not particularly strongly. Statistical tests show the association between warm air advection and the presence of cirrus to be closest in the 500–300-mb. layer.

(iv) *Lapse rate in the upper troposphere.*—An investigation¹ of the possibility of an association between mean lapse rate of temperature in the upper troposphere and the occurrence of cirrus shows that there is little variation in the mean lapse rate at cirrus levels between cases of cirrus present and cirrus absent. However, the presence of a layer in the upper troposphere with lapse rate greater than the wet adiabatic is found to be closely associated with cirrus cloud in that region.

Features of the 1000–500-mb. thickness pattern.—

(i) *Thermal ridges.*—The association of cirrus clouds with surface warm fronts suggests that the high cloud may be closely linked with thermal ridges in the 1000–500-mb. thickness pattern. Fig. 1 shows the distribution of the ratios of a sample of observations of cirrus and no cirrus, with respect to an idealized wave length in the thickness pattern.

In compiling this figure it was observed that several thermal ridges, exhibiting no well marked surface-frontal characteristics, were accompanied by extensive cirrus cloud sheets. The figure clearly shows the ratio of observations to be considerably greater in the thermal ridge than in the trough.

(ii) *Curvature of thickness lines.*—In compiling Fig. 1 it was found that only about half of the observations could be assigned with any confidence to a particular region of the wave-form. Consequently the observations were classified with respect to cyclonic or anticyclonic curvature of the thickness lines. The distribution obtained is in Table IV.

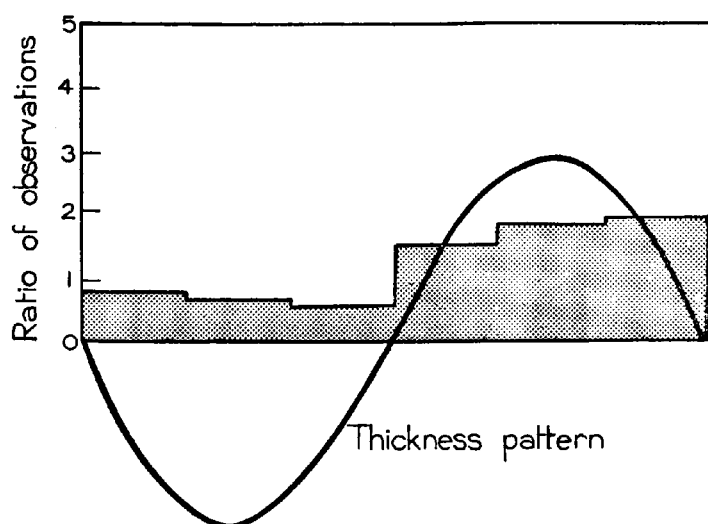


FIG. 1—RATIOS OF THE NUMBER OF OBSERVATIONS OF CIRRUS TO NO CIRRUS IN RELATION TO AN ASSUMED WAVE-FORM IN THE TOTAL THICKNESS PATTERN.

TABLE IV.—ASSOCIATION OF CIRRUS WITH CURVATURE IN THE 1000–500-MB. THICKNESS PATTERN

	Cyclonic	Anticyclonic	Neither	Totals
	<i>number of occasions</i>			
Cirrus	59	54	49	162
No cirrus	31	15	35	81

These figures show that cyclonic curvature of the thickness lines is almost as likely to be accompanied by no cirrus as by cirrus; but that anti-cyclonic curvature is much more likely to be accompanied by cirrus than no cirrus.

(iii) *Thermal Winds.*—An examination of the possibility of an association between thermal wind speed in the 1000–500-mb. layer and occasions of cirrus and no cirrus has given the means in Table V.

TABLE V.—ASSOCIATION OF CIRRUS WITH THERMAL WIND SPEED

	Cirrus	No cirrus
Mean thermal wind (kt.)	21	16
Number of reports	174	79

The difference between these means is small but nevertheless statistically highly significant; there is a useful association between thermal winds greater than, say, 20 knots, and the occurrence of cirrus cloud.

(iv) *Deep cold pools and intense thickness troughs.*—Abnormally low temperatures in the upper troposphere frequently lead to local or widespread instability which may be expected or observed (surface reports, sferics). It may therefore be expected that deep cold pools and intense thickness troughs will be associated with the presence of cirrus for the reasons outlined above.

Features of the 300-mb. contour pattern.—

(i) *300-mb. ridges.*—French and Johannessen³ have shown that, under certain assumptions, upward motion can be expected in the upper troposphere if there is advection of cyclonic vorticity at 300 mb. Ascent would therefore be expected forward of a trough and to the rear of a ridge in the 300-mb. contour pattern. A test of this¹ gives the distribution of ratios of observations of cirrus to no cirrus with respect to an idealized wave-form in the 300-mb. pattern as shown in Fig. 2. It will be noted that the high values of the ratio occur ahead of the trough line but that the highest values are found close to the ridge line. This might be expected because the over-all ascent of the air is likely to be greatest by the time it has reached the ridge.

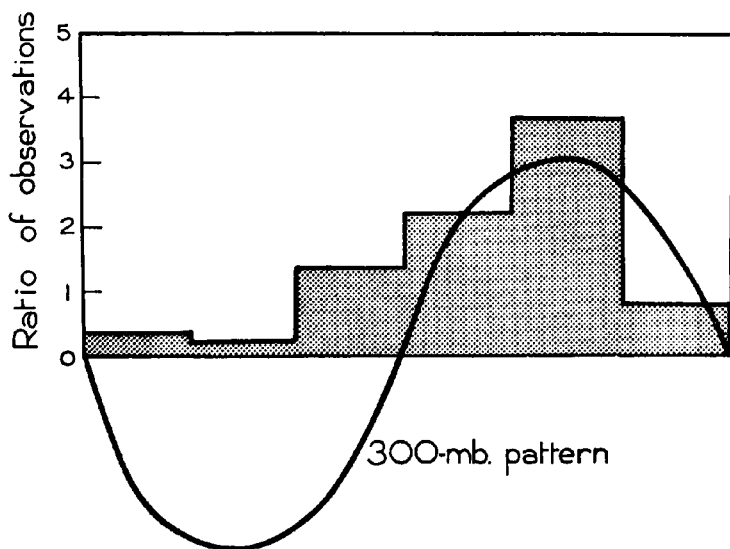


FIG. 2.—RATIOS OF THE NUMBER OF OBSERVATIONS OF CIRRUS TO NO CIRRUS IN RELATION TO AN ASSUMED WAVE-FORM IN THE 300-MB. CONTOUR PATTERN.

(ii) *Jet streams.*—Murray's analysis of flights through jet streams⁴ suggests that there is a marked difference between the distribution of high and medium cloud on either side of a jet axis. This hypothesis is confirmed by analysis of a large number of cirrus reports from aircraft, the results of which are presented in Fig. 3.

This figure shows that the greatest ratio of cirrus to no cirrus observations occurs up to 300 miles from the jet axis on the high pressure side.

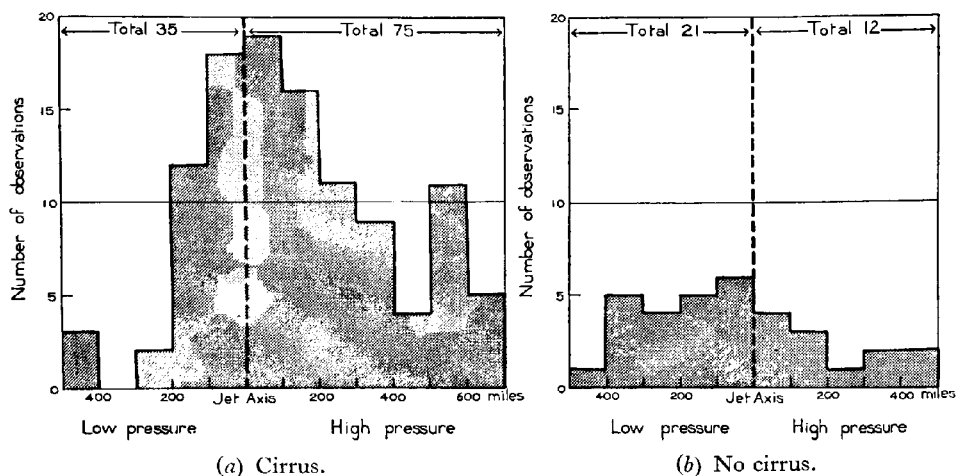


FIG. 3—RELATION BETWEEN FREQUENCY OF REPORTS AND DISTANCES FROM JET-STREAM AXIS AT 300-MB.

The effect of topography.—It has been demonstrated⁵ that cirrus cloud can be formed by ascent produced by relatively minor hills. However, the majority of occasions of orographic cirrus must require the air at cirrus levels to be nearly saturated initially, or possibly even super-saturated with respect to ice for extensive cloud, so that over-all ascent, however caused, would then lead to cloud formation. No method of allowing for orographic effects can be given, but it will be shown below that a reasonable success in forecasting cirrus is attained without such allowance.

Diurnal variation.—Reports from surface observing stations suggest that there is a diurnal variation of cirrus cloud, with maxima of observations at dawn and dusk and a minimum near midday. This apparent minimum is most marked during the summer months, there being little variation in frequency of observations during a day in winter. Ludlam⁵ has already given a reason to expect a diurnal variation of orographic cirrus in this fashion, though how far this is responsible for the apparent variation is doubtful, owing to uncertainty as to the proportion of cirrus caused by orographic features; some authorities² claim such formations are relatively rare. However, means of a large number of aircraft reports at various times of the day throughout the year do not confirm the existence of a minimum around midday. It is possible therefore that the diurnal minimum in the frequency of surface observations in the summer months is produced mainly by observers' inability to observe tenuous high cloud when the sun has a high altitude.

Summary.—The above paragraphs suggest that the following synoptic features or regions near such features are associated to a greater or lesser degree with the presence of cirrus cloud.

Surface charts.—

- (i) The region near and just ahead of surface warm fronts and occlusions.
- (ii) Reports of cumulonimbus clouds.

Upper air soundings.—

- (i) Lapse rates at cirrus levels greater than the moist adiabatic.
- (ii) Dew-point less than 10° C. below temperature at 500, 450 or 400 mb.
- (iii) 400-mb. wind between SW. and NW.
- (iv) A veer of wind between 500 mb. and 300 mb. of 5° or more.

(Since the international code provides for reporting wind direction to the nearest 10° , wind veer of 20° is the minimum which can be regarded as a definite indication of warm air advection.)

Upper air charts.—

- (i) A ridge in the 1000–500-mb. thickness pattern.
- (ii) 1000–500-mb. thermal wind greater than 20 kt.
- (iii) Anticyclonic curvature of the 1000–500-mb. thickness lines.
- (iv) Deep cold pools or intense troughs in the 1000–500-mb. thickness pattern.
- (v) The area in, or just to the rear of, a 300-mb. ridge.
- (vi) The region on the anticyclonic side of a 300-mb. jet stream, and within 300 miles of the jet axis.

PART II

A suggested method of forecasting cirrus cloud.—*Forecasting the occurrence of 4 oktas or more cirrus cloud.*—There are many ways in which the associations set out above may be applied to the problem of forecasting the occurrence of 4 oktas or more cirrus cloud in the area of the British Isles. Whilst none of the associations is unique some of them are stronger than others and might therefore be expected to carry more weight in a forecasting procedure. On the other hand, some overlap others, e.g. warm fronts and thermal ridges. A reasonable technique might result by giving many of the associations an equal weight. The following paragraphs describe simple methods of using the associations which gave reasonable success in a forecasting trial carried out in the Forecasting Research Division at Dunstable.

(i) *6–9 hr. ahead.*—It was assumed that deductions from current charts and upper air soundings would be valid for a period 6–9 hr. ahead and so these were used to supply positive or negative answers to as many of the following questions as possible, using the nearest upstream sounding from the forecast area where necessary.

(a) Is the depression of dew-point below air temperature at 500 mb. less than or equal to 10° C.?

(b) Is the depression of dew-point below air temperature at 450 mb. less than or equal to 10° C.?

(c) Is the depression of dew-point below air temperature at 400 mb. less than or equal to 10° C.?

(d) Is the lapse rate in the 500–300-mb. layer greater than the wet adiabatic?

(e) Is the 400-mb. wind between SW. and NW.?

(f) Is there a veer of wind between 500 and 300 mb. of 20° or more?

(g) Is the 1000–500-mb. thermal wind greater than 20 kt.?

(h) Is the forecast area in a ridge in the 1000–500-mb. thickness pattern?

(i) Is there anticyclonic curvature of the 1000–500-mb. thickness lines?

(j) Is there a deep cold pool or intense thickness trough in the 1000–500-mb. thickness pattern?

(k) Is the forecast area in, or just to the rear of, a ridge in the 300-mb. contour pattern?

(l) Is the forecast area on the anticyclonic side of a 300-mb. jet stream and within 300 miles of the jet axis?

(m) Is the forecast area up to 300 miles ahead of a surface warm front or occlusion?

In the test it was found that on average between ten or eleven of the above questions could be answered on each occasion. A forecast of cirrus was made if an affirmative answer could be given to five or more of the above questions; otherwise the forecast indicated no cirrus. In this way 24 out of a possible 27 cases of cirrus and 43 out of 51 cases of no cirrus were correctly forecast. It was found that no individual indicator or group of indicators gave successes comparable with those obtained by answering as many of the above questions as the observations and charts would allow.

(ii) 24–36 hr. ahead.—Cirrus forecasts for more than 6 hr. ahead are liable to considerable error, since the information used in the assessments has itself to be subjectively forecast. Nevertheless, a test carried out at Dunstable, in which cirrus forecasts for 24–36 hr. ahead were made, achieved considerable success. In fact 22 out of a possible 29 cases of cirrus, and 35 out of 43 cases of no cirrus were correctly forecast, the occasions being spread over a year. The observations from this year had not been used in the previous analysis.

The method followed was to answer as many as possible of the following six questions:

(a) Is the air likely to be moist?

Using the 500-mb. prontour and latest available actual chart, the air at this level was traced back, from the area at the time for which the forecast was required, to the region of an available radio-sonde ascent. Examination of the depression of dew-point below temperature at the levels 500, 450 and 400 mb. (sometimes values at higher levels than 400 mb. were also available) answered the question "is the dew-point depression less than or equal to 10° C., at or above 500 mb.?"

(b) Will the area at the time for which the forecast is required, be up to 300 miles ahead of a surface warm front or occlusion? The surface prebaratic was used here.

(c) Is the area forecast to be on the anticyclonic side of a 300-mb. jet stream and within 300 miles of the jet axis?

(d) Will the area be in, or just to the rear of, a 300-mb. ridge?

(e) Will the area be in a thermal ridge as suggested by the 1000–500-mb. prethickness chart?

(f) Will the 300-mb. wind over the area be veered from that at 500 mb. by 20° or more?

A forecast of cirrus cloud was made if two or more affirmative answers were made to the above questions.

Forecasting the bases and tops of cirrus cloud.—There is good evidence² that in general the tops of cirrus clouds are determined by the tropopause: more than 50 per cent. of all cirrus tops reported by aircraft are within 5,000 ft. of the tropopause. These reports also indicate that if the tropopause is low, say below 35,000 ft., most cirrus tops are within 2,000 ft. of the tropopause, but this distance increases as the tropopause height increases. In fact when the tropopause is at about 45,000 ft. the cirrus tops are generally some 5,000 ft. below. Reports show that the average cloud thickness also increases with the height of the tropopause, being about 4,000 ft. when the tropopause is low and 8,000 ft. when the tropopause is at about 45,000 ft. Thus to obtain an estimate of the base and top of any cirrus cloud expected, a forecaster could determine the height of the tropopause and relate the base and top of the cirrus cloud to this value.

Other work on this subject⁶ suggests that the top of cirrus cloud is closely associated with the height of the horizontal wind maximum, and that the cloud base

is usually at a discontinuity of wind shear below this maximum. Thus several sharp changes in wind shear would be accompanied by several layers of cirrus cloud provided that the other parameters are favourable. In this case a forecaster must estimate the wind profile to be expected from 500 mb. up to the tropopause.

No test of comparison between these methods has been made, and no recommendation can be made concerning the accuracy of either method.

ADDENDUM—CIRRUS CLOUD IN THE STRATOSPHERE

Sufficient reports have been received of cirrus cloud well in the stratosphere to be certain that cloud can occur at these heights. However, the number of reports is not sufficient to admit of a statistical analysis of the synoptic parameters. It is nevertheless remarkable that for all cases of dense cirrus cloud observed in the stratosphere over the British Isles from 1952–54, there was advection of anticyclonic vorticity at 300 mb., which, assuming little or no vertical motion at the tropopause, implied a mean downward motion in the layer from 300 mb. to the tropopause. Obviously no forecasting rule can be formulated for the few cases which have been observed and a considerably larger number of reports must be obtained before an analysis of any kind can be contemplated.

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