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CLOUD IN RELATION TO ACTIVE WARM FRONTS NEAR BIRCHAM NEWTON, 1942-46

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CLOUD IN RELATION TO ACTIVE WARM FRONTS NEAR BIRCHAM NEWTON, 1942–46

By J. S. Sawyer, M.A. and F. E. Dinsdale, B.Sc.

Summary.—The cloud structures of 76 active warm fronts are examined in relation to a number of parameters available to the operational forecaster. The only significant correlation (about 0·4) is between the extent of frontal cloud and the component of wind relative to the surface front taken normal to the front at its upper boundary. An examination of the vertical distribution of cloud in relation to the frontal zone reveals a tendency for the slope of the edge of the cloud to be steeper than the slope of the front.

Introduction.—In an investigation of the cloud structure of warm and quasi-stationary fronts near Bircham Newton during the three months January to March 1942, Matthewman[1]* found that the cloud structure was not closely related with any of the synoptic parameters which he selected to represent the activity of the front. As his sample, however, included a number of feeble and inactive fronts, it was thought possible some more definite relationships might have emerged if attention had been confined to active warm fronts. This has not proved to be so, and the present paper reports the results of an analysis of the cloud structure of a series of active warm fronts with rain belts at least 50 miles wide.

As a measure of the extent of cloud at the front Matthewman adopted a classification based essentially on the proportion of the vertical column between the ground and 400 mb. occupied by cloud, the class number increasing with the proportion of cloud from class 1, no cloud, to class 6, continuous cloud. The cloud class number naturally tended to increase towards the front, and it was thought that any relationship between the class number and the other synoptic parameters might have been obscured thereby. To avoid this difficulty a classification was attempted on various other bases, but the essential results of the investigation were unaffected.

Data and technique.—During the period 1942–46 aircraft ascents were made at least twice daily at Bircham Newton or Langham. These ascents ceased in May 1946, and it was not therefore possible to extend the period of investigation into the post-war years. The British *Daily weather reports* for this period were examined, and 76 cases were found where the surface warm front was reasonably well determined and where the aircraft temperature sounding showed clearly both upper and lower boundaries of the frontal zone at or below the 400-mb. level. The ascents were seldom synchronous with the surface chart, but did not usually differ by more than one hour. In each case a vertical cross-section was drawn along the normal from Bircham Newton to the surface front utilizing any other sounding, whether British or foreign, near this normal and not made at a time differing by more than 2 or 3 hr. from the time of the chart. On each cross-section were plotted the positions of the upper and lower boundaries of the frontal zone at each ascent together with the reported cloud.

In analysing the soundings to select the frontal zone only broad thermal considerations were employed. No attention was paid to humidities. In some cases a small adjustment was made to the position of the surface front or that of an ascent in order to correct for a time discrepancy where this gave a distorted picture.

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

Measurements of surface winds and speeds of fronts were made on the *Daily weather reports*. The upper winds were taken from Downham Market, interpolating in time and space where necessary. The Downham Market wind soundings, however, seldom differed by more than one hour from the Bircham Newton ascents.

It was found that in 7 out of the 76 cases the warm air could not be satisfactorily identified at the surface, and the surface front marked on the charts could not therefore be taken as the lowest point on the upper boundary of the front. In tests involving the distance of Bircham Newton from the surface front these 7 cases were omitted for the sake of uniformity.

Cloud classification.—Matthewman classified the vertical distribution of cloud reported by the Bircham Newton aircraft into 6 groups as follows :—

Class 1 .. No cloud.

Class 2 .. Cloud, apart from cirrus, cirrostratus or cirrocumulus, only below or near the base of the frontal zone(s).

Class 3 .. One or more thinnish layers of cloud above or near the top of the frontal zone(s). Here thinnish implies not more than 150 mb. deep.

Class 4 .. Thick cloud extending above the frontal zone(s), but with one or more lanes of clear air, at least 150 mb. deep, between the ground and 400 mb. Here thick implies more than 150 mb. deep.

Class 5 .. Continuous or almost continuous cloud extending from near the ground to near or above 400 mb., but with one or more layers or lanes of clear air not more than 150 mb. deep.

Class 6 .. Continuous cloud extending from near the ground to near or above 400 mb.

The 76 cases were first classified according to this system and relationships determined between the class numbers (referred to hereafter as the C class number) and the various parameters suggested in the original paper. Tables I to III show that the C class number is very much dependent upon the distance of the ascent from the surface front. This of course is no more than synoptic experience indicates, but as one of the objects of the paper was to determine what simple measurements a forecaster might make in order to estimate the general cloudiness of a warm front, an attempt was made to obtain a classification which was not dependent on the distance from the surface front. For this purpose attention was confined to cloud in or above the frontal zone. Nevertheless the association of class number with distance from the surface front was very little reduced. One such classification (the class number being later distinguished as the X class number) is given below :—

Class 1 .. No cloud in or above the frontal zone except cirrus above 400 mb.

Class 2 .. Cloud occupying less than 25 per cent. of the space between the lower limit of the frontal zone and 400 mb.

Class 3 .. Cloud occupying 25 to 75 per cent. of the space between the lower limit and 400 mb.

Class 4 .. Cloud occupying more than 75 per cent. but not all the space between the lower limit and 400 mb.

Class 5 . Cloud continuous from the lower boundary to 400 mb.

The correlation coefficients between distance from the surface front and the C and X class numbers are both about − 0·6.

Finally, the regression equation of the X class number upon distance from the front was calculated :— $X = 4{\cdot}0 - 0{\cdot}005\,d$ (where d is distance in miles) ; 69 cases were included. The departures of the X class numbers from the values calculated from the regression equation were obtained to form a new classification Y, and correlation coefficients between Y and the various parameters determined.

In none of the 76 cases was there a cloudless ascent at Bircham Newton, and hence class C1 has been omitted from the following tables.

Results.—*Relation of cloud at Bircham Newton to the cloud at simultaneous soundings.*—There were in all 41 other aircraft ascents, mainly foreign, which were used in the cross-sections. These were also given a C class number and are compared with the Bircham Newton ascents in Table I. The figures confirm that in individual cases the C class number increases towards the front.

TABLE I—RELATION OF THE CLOUD AT BIRCHAM NEWTON TO THE CLOUD AT SIMULTANEOUS SOUNDINGS

	C class number less than that for Bircham Newton	C class number equal to that for Bircham Newton	C class number greater than that for Bircham Newton
	number of cases		
Sounding towards warm front ..	0	0	3
Sounding away from warm front	27	11	0

Relation of cloud at Bircham Newton to the distance from Bircham Newton of the mid point of the frontal zone at the ground.—The distances ranged from 20 to 450 miles, and the mean distance decreased steadily with increasing class number, ranging from 305 miles in C class 2 to 66 miles in C class 6. There was considerable scatter about the mean in each class. Table II shows the C class number tabulated according to three ranges of distance from the surface front (69 cases). It shows the tendency for the class number to increase towards the front.

TABLE II—NUMBER OF CASES OF SPECIFIED CLOUD STRUCTURES WITHIN STATED RANGES OF THE DISTANCE FROM THE FRONT

Distance of Bircham Newton from surface front	C class number 2	3	4	5	6	All
miles	*number of cases*					
< 100	0	4	6	9	4	23
100–300	4	12	13	3	1	33
> 300	9	3	1	0	0	13

Relation of cloud at Bircham Newton to the pressure at the upper (warm) boundary and the lower (cold) boundary of the frontal zone.—As might have been expected from the previous paragraph the means of both the pressure at the upper boundary and the pressure at the lower boundary increased steadily with increasing C class number (see Table III). The number of cases considered was 76. Again there was considerable scatter about the mean in each class.

TABLE III—RELATION OF CLOUD AT BIRCHAM NEWTON TO THE PRESSURE AT THE FRONTAL BOUNDARIES

	C class number				
	2	3	4	5	6
	millibars				
Mean pressure at the upper (warm) boundary..	525	601	665	685	760
Mean pressure at the lower (cold) boundary ..	747	826	869	890	940

Relation of cloud at Bircham Newton to the slope of the warm boundary of the frontal zone.—As it seems probable that there is usually some variation in the slope of the frontal zone at both warm and cold boundaries, it is necessary to specify exactly what was taken as the slope for the purpose of comparison between classes. It was defined simply as the ratio of the height of the warm boundary at Bircham Newton to the distance of Bircham Newton from the surface front. The number of cases considered was 76. In the seven cases where the warm air did not reach the ground, the slope was measured to that point vertically above the surface front which the warm boundary was considered to have reached.

It will be seen from Table IV that there was some increase of slope with increasing C class number, but that the scatter about the mean in all cases was large. In order to determine if any relation existed between the cloudiness and the slope of the front when the effect of distance from the front was eliminated, the Y class number was correlated with frontal slope; the resulting correlation coefficient was negligible.

TABLE IV—RELATION OF CLOUD AT BIRCHAM NEWTON TO THE SLOPE OF THE WARM BOUNDARY OF THE FRONTAL ZONE

	C class number				
	2	3	4	5	6
Mean slope of the warm boundary	0·010	0·012	0·013	0·017	0·014

The overall mean slope was 0·013—slightly greater than the conventional value of 1 in 100 often quoted as typical for warm fronts.

Relation of cloud at Bircham Newton to the pressure thickness of the frontal zone.—The average of all 76 cases was 210 mb., and Table V shows that there was some decrease of the mean pressure thickness with increasing class number. This is probably due to the tendency for the frontal zone to become somewhat deeper or more diffuse away from the surface front. There was again a wide scatter in each class, e.g. from 50 mb. to 350 mb. in C class 5. The correlation with the Y class number was zero.

TABLE V—RELATION OF CLOUD AT BIRCHAM NEWTON TO THE PRESSURE THICKNESS OF THE FRONTAL ZONE

	C class number				
	2	3	4	5	6
	millibars				
Mean pressure thickness of the frontal zone ..	222	224	205	202	180

Vertical distribution of cloud reported at Bircham Newton in relation to the frontal zone.—In order to get a picture of how the reported cloud was distributed in relation to the frontal zone, the percentage frequency of occurrence of cloud at specified levels was calculated for three ranges of distance from the front. Table VI shows these results together with the overall percentage frequency. The figures convey the general impression of frontal cloud mainly in the warm air at distances greater than 200 miles but extending downwards through the frontal zone as the surface front is approached. Taking all cases together there is a chance of about 1 in 2 of finding cloud at any point between the lower boundary and a height of 16,000 ft. above the upper boundary, the ceiling of course being the 400-mb. level. The two 100-per-cent. figures in column 3 are due to a solitary case where the upper boundary was 16,000 ft. below 400 mb. in that particular range.

TABLE VI—PERCENTAGE FREQUENCY OF OCCURRENCE OF CLOUD AT SPECIFIED LEVELS IN RELATION TO THE HEIGHT OF THE FRONTAL ZONE

		Distance from front			
		< 100 miles	100–200 miles	> 200 miles	All cases
	Number of cases	23	22	24	69
		per cent.			
Above upper boundary of frontal zone	16,000 ft.	67	67	100	78
	14,000 ft.	50	67	100	80
	12,000 ft.	58	60	75	67
	10,000 ft.	62	55	71	65
	8,000 ft.	61	54	44	59
	6,000 ft.	74	47	47	62
	4,000 ft.	69	67	42	63
	2,000 ft.	83	53	50	62
Frontal zone	Upper boundary	87	50	33	58
	¾ of depth of frontal zone above lower boundary	91	64	29	58
	Mid point	91	46	13	50
	¼ of depth of frontal zone above lower boundary	87	50	13	47
	Lower boundary	78	50	21	47
Below lower boundary of frontal zone	2,000 ft.	40	24	17	30
	4,000 ft.	0	12	0	7
	6,000 ft.	0	0	8	3

Relation of cloud at Bircham Newton to the temperature difference across the frontal zone measured on the saturated adiabatic scale.—The difference of saturated potential temperature from the cold to the warm air vertically across the frontal zone is a measure of the thermal strength of the zone. Table VII indicates that there is no correlation between this and the C class number.

TABLE VII—RELATION OF FRONTAL CLOUD TO THE TEMPERATURE DIFFERENCE ACROSS THE FRONTAL ZONE

	C class number				
	2	3	4	5	6
	degrees Fahrenheit				
Mean saturated adiabatic difference across the frontal zone	10·8	10·3	10·7	9·8	11·2

The correlation between the Y class number and the change of saturated adiabatic potential temperature across the zone was negligible, namely 0·05.

Relation of cloud at Bircham Newton to the geostrophic wind shear in the horizontal across the surface front.—The range of values in each class was from 10 kt. or less to 60 kt. or more, so that although Table VIII shows an increase in the means from C class 2 to C class 5 there can be but small significance in the result. The correlation of wind shear with Y class number was likewise small, namely 0·17.

TABLE VIII—RELATION OF FRONTAL CLOUD TO THE GEOSTROPHIC WIND SHEAR ACROSS THE FRONT

		C class number					
		2	3	4	5	6	All
Number of cases		13	21	24	13	5	76
		knots					
Geostrophic wind shear in the horizontal across the surface front	Mean ..	28	31	32	34	28	31
	Standard deviation	16	14	17	22	15	..

Relation of cloud at Bircham Newton to the rate of increase of geostrophic wind shear in the horizontal across the surface front.—The same method of measuring this parameter was adopted as was used by Matthewman[1], namely the change of wind shear along the normal through Bircham Newton used in the cross-section. The difficulty of measuring this shear on the subsequent chart owing to rapid occlusion was avoided by taking only the change during the preceding 6 hr. It was felt too that this might have a greater bearing upon cloud development than the mean rate of change over a 12-hr. period. No relationship was revealed. However it is noteworthy that the mean rates are all positive (see Table IX).

TABLE IX—RELATION BETWEEN FRONTAL CLOUD AND THE RATE OF CHANGE OF GEOSTROPHIC WIND SHEAR

		C class number					
		2	3	4	5	6	All
Number of cases		13	21	24	13	5	76
		knots					
Rate of increase of geostrophic wind shear in the horizontal across the surface front	Mean ..	1·2	0·7	0·8	0·9	0·6	0·9
	Standard deviation	2·2	1·7	1·9	3·5	3·3	..

The correlation of rate of increase of wind shear with Y class number was 0·19; it is doubtful whether this is significant.

Relation of cloud at Bircham Newton to the wind shear in the vertical across the frontal zone parallel to the surface front.—This shear was taken as the difference between the components parallel to the surface front of the winds at the upper and lower boundaries of the frontal zone. Table X shows no correlation whatever between this shear and the C class number. Likewise the correlation with the Y class number was zero.

TABLE X—RELATION BETWEEN FRONTAL CLOUD AND VERTICAL WIND SHEAR PARALLEL TO FRONT

		C class number					
		2	3	4	5	6	All
Number of cases		13	21	24	13	5	76
				knots			
Wind shear in the vertical across the frontal zone parallel to the surface front	Mean ..	28	25	20	25	23	24
	Standard deviation	22	18	17	17	11	..

Relation of cloud at Bircham Newton to the wind shear in the vertical across the frontal zone normal to the front.—The wind shear across the zone normal to the surface front gives somewhat more interesting figures. From Table XI it is seen that there is some increase in the means with increasing C class number, but the correlation is only 0·16. This correlation is improved to 0·28 if the Y class number is substituted.

TABLE XI—RELATION BETWEEN FRONTAL CLOUD AND VERTICAL WIND SHEAR NORMAL TO THE FRONT

		C class number					
		2	3	4	5	6	All
Number of cases		13	21	24	13	5	76
				knots			
Wind shear in the vertical across the frontal zone normal to the surface front	Mean ..	8	11	13	9	19	11
	Standard deviation	8	9	9	11	13	..

Relation of cloud at Bircham Newton to the difference in speeds between the surface front and the component of wind normal to the surface front at the upper boundary.—Matthewman achieved his highest correlations with this parameter, and Table XII suggests there is a positive relationship also with the C class number in the present series of fronts.

TABLE XII—RELATION BETWEEN FRONTAL CLOUD AND THE DIFFERENCE IN SPEEDS BETWEEN THE WARM AIR AND THE SURFACE FRONT

		C class number					
		2	3	4	5	6	All
Number of cases		13	21	24	13	5	76
				knots			
Difference between speed of surface front and normal component of wind at the upper boundary	Mean ..	3	6	8	7	21	7
	Standard deviation	15	12	10	12	4	..

The correlation between the C class number and this parameter is only 0·23, but if one case is omitted (where the frontal analysis is in some doubt but the wind speeds are very high) this correlation can be improved to 0·41. Using only occasions of appreciable shear through the frontal zone, i.e. where the shear is greater than or equal to 12 kt., the correlation is again slightly improved to 0·45.

The matter was tested further as it seemed to be the most fruitful sphere of investigation. Still restricting the cases to shear greater than or equal to 12 kt., correlation with the X class number was found to be 0·49. The general correlation with the Y class number (omitting the one case mentioned earlier) was 0·37 (68 cases); so that it is clear that the relationship does not arise primarily from an association of both variables with distance from the front.

Relation between cloud at Bircham Newton and the difference in speeds between the surface front and the component of wind normal to the surface front at the lower boundary.—Nothing very significant is revealed by Table XIII. The correlation between the Y class number and this parameter was also very small, namely 0·14.

TABLE XIII—RELATION BETWEEN FRONTAL CLOUD AND THE DIFFERENCE IN SPEEDS BETWEEN THE COLD AIR AND SURFACE FRONT

		C class number					
		2	3	4	5	6	All
Number of cases		13	21	24	13	5	76
					knots		
Difference between the speed of surface front and normal component of wind at lower boundary	Mean ..	−4	−5	−4	−2	+2	−4
	Standard deviation	15	8	6	15	10	..

Relation between the cloud at Bircham Newton and the ageostrophic motion of the surface front.—This parameter is simply the speed of the front (taken as before over a 12-hr. period) subtracted from the geostrophic component of wind normal to the surface front measured on the line of cross-section through Bircham Newton. There is some increase in the means from C class 2 to C class 6 but obviously little correlation. With the Y class number the correlation was only 0·12.

TABLE XIV—RELATION BETWEEN FRONTAL CLOUD AND THE AGEOSTROPHIC MOTION OF THE SURFACE FRONT

		C class number					
		2	3	4	5	6	All
Number of cases		13	21	24	13	5	76
					knots		
Ageostrophic motion of the surface front	Mean ..	13	13	11	16	16	13
	Standard deviation	8	8	6	14	10	..

It may be of some passing interest to note that the average value of the ratio, speed of front to geostrophic wind normal to front, for the 76 cases is 0·67.

Conclusions.—The results are generally in close agreement with those of Matthewman, and this in spite of the fact that the careful selection of active warm fronts of the present paper represents a very different sample from the heterogeneous collection of January–March 1942. The fact that the Matthewman cloud classification is closely linked with the distance of the ascent from the surface front in the case of an active warm front has been borne in mind throughout, but the Y classification which does not have this dependence gives essentially the same results.

The present study confirms the existence of a small but significant correlation (about + 0·4) between the extent of cloud and the component of wind relative to the surface front taken normal to the front at its upper boundary. However, it would appear that there are no simple and reliable measurements that a forecaster can make in order to estimate the cloud structure of a warm front.

One result additional to those of Matthewman's investigation is the tendency demonstrated by Table VI for the slope of the edge of the frontal cloud to be steeper than the slope of the front, so that at distances greater than 200 miles from the surface front the cloud lies mainly in the warm air, whereas within 100 miles of the front the cloud usually extends down through most of the transitional zone.

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